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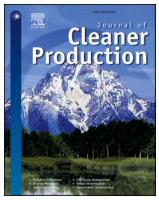

Design thinking for sustainable development: A bibliometric analysis and case study research

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ABSTRACT

This paper describes the role of Design Thinking (DT) in the context of sustainable development (SD), based on a perceived research need to identify the features which may characterise its deployment, and identify ways via which it may be optimised, especially in the implementation of the United Nations Sustainable Development Goals (UN SDGs). The main goal of this study is to examine the connection between DT and SD and showcase examples of what has been done to deploy it, using real-case situations. From a methodological perspective, the paper deploys a set of two methods: bibliometric analysis and case studies. Among other findings, the paper shows that DT can be used to help implement the UN SDGs by providing an approach that emphasizes human-centered design. This includes identifying problems, creating user-friendly solutions, and testing them in order to ensure that they are effective. Also, by using DT, companies, organisations, and governments can create low-cost, high-impact, and sustainable solutions to help achieve SDGs such as SDG8, SDG9, SDG12, and SDG13, among others. Overall, DT provides a framework for combining creative and analytical reasoning, specific mindsets, and diverse hands-on tools and techniques to improve critical thinking abilities towards sustainability challenges. The novelty of the paper relies on the fact that the combined use of the two methods allowed the identification of some useful features of DT, which may facilitate its deployment in sustainability contexts. This may assist future studies since it provides a theoretical basis for the field.

1. Introduction

The importance of design thinking for sustainable development has witnessed a growing interest among scholars. Innovation approaches in particular serve to render complex problems more tangible, facilitating a deeper comprehension and aiding in the resolution process (Brenner

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et al., 2016). Among these approaches, "Design Thinking (DT)" stands out as one of the most recurrent and impactful in companies to gauge the needs of users at the beginning of an innovation process. The term originated in 1957 at Stanford University (Auernhammer and Roth, 2021), became popularized in the 1970s and 1980s but gained significant prominence in the 1990s with the establishment of IDEO, a prominent design and innovation company (Cai et al., 2023; Tomlinson, 2018).

Precursors and exponents of DT placed it at the intersection between humanities and sciences as a form of modeling for the "artificial" domain (Cross, 2023) that is not simply synonymous with creativity but represents a set of practices addressed at various organizational levels (Dorst, 2011).

DT refers to a cooperative and creative problem-solving process - one where emphasis is placed on identifying the problem to solve rather than the solving of a problem on its own - that assists with understanding people and possibilities and thus developing effective solutions that are both innovative and practical (Foster, 2021; Shapira et al., 2017). Its scope at times can even go beyond traditional problem-solving, spacing into the confines of wicked challenges (Bender-Salazar, 2023), such as that of sustainable development (Pryshlakivsky and Searcy, 2013; Murphy, 2012).

In doing so, products and services can be produced that are tailored to the needs of the target group. This creates better consumer experiences and generates more profit. Furthermore, DT allows for the creation of services and products that are both sustainable and socially responsible (Shapira et al., 2017).

Therefore, DT is an approach that follows a systematic method to address design challenges, emphasizing the use of clearly defined steps in the process. In this case, the definition of design refers to the improvement of ergonomic, functional, and visual aspects of a given product or service in order to meet the needs of the final consumer, improving their consumption experience, satisfaction, comfort, and safety. In other words, it is an approach that aims to provide products and services based on customer needs (Foster, 2021).

Conducting research into DT is imperative for acquiring a comprehensive understanding of its foundational principles, methodologies, and multifaceted impact across diverse domains (Liedtka, 2015). This empirical inquiry is of paramount importance owing to DT's emergence as a potent problem-solving and innovation paradigm, wielding extensive influence in realms such as business, education, healthcare, and beyond (Micheli et al., 2019; Shafiee et al., 2020). The scrutiny of DT research offers an avenue for elucidating its role in stimulating creativity, its facilitation of user-centric design, and its efficacy in fostering interdisciplinary collaboration.

In particular, the importance of DT methods in overcoming issues in the development of sustainable initiatives is surging, given its high potential for transformative value in the field. Despite this, however, the combined implementation of DT and sustainability has been thus far bounded as it presents a fundamental challenge, i.e., a shortage of scientific literature and analysis on DT in sustainability research Maher et al. (2018).

Thus far, there have been discussions in the extant literature of various topical and sectoral aspects at the intersection of design thinking and sustainability. Some studies provide an overview of research on DT. For instance, Bhandari (2022) conducted a bibliometric review of research on DT and identified 16 major thematic clusters focused on various issues such as various schools of DT, design frameworks, digital learning, interdisciplinary learning, innovation, sustainable business models, entrepreneurship, policy development, socio-cultural perspectives, design processes, creativity, service industry, leadership, professional and technical communication, and outcome-based learning. In another bibliometric review, Fatima and Singh (2023) focused on the use of DT in business, management, and accounting. They found that "service design, service innovation, customer experience, innovation management, project management, and 21st-century skills" are emerging areas in this field. Nevertheless, none of them comprehensively addresses the multifaceted role of DT in sustainable development under an overarching lens. Table 1 presents five recent studies on the combination of the two topics, along with the indication of the respective literature gap.

There is a research gap on how DT research can contribute substantially to the formulation of empirically grounded best practices, thereby fortifying decision-making processes, product development procedures, and the overall efficacy of problem-solving strategies across a spectrum of domains. Based on the need to address this research gap, and for studies on the connections between DT and sustainable development, this paper departs from the following research questions (RQs):

RQ 1: What are the connections between DT and sustainable development?
RQ2: Which examples are there to illustrate such relations?
RQ 3: How may DT help to implement the United Nations Sustainable Development Goals (UN SDGs)?

The novelty of the paper relies on the fact that the combined use of the two methods allowed the identification of some useful features of DT, which may facilitate its deployment in sustainability contexts, thereby offering insights for more effective and sustainable problem-solving practices. By employing a dual-method approach, the study not only illuminates the intricacies of DT but also emphasizes its potential application in the specific context of sustainability. The integration of bibliometric analysis and case study examination adds depth to our understanding, revealing not only the theoretical underpinnings of DT but also its practical effectiveness in addressing sustainability challenges. The findings extend the body of knowledge for future advances and innovations in the integration of DT principles into sustainable development practices.

Against this background, this paper is structured in five sections. Section 2 provides an outline of how DT relates to sustainable development. Section 3 presents the methods used in an international study that was undertaken to better understand these connections, using

Table 1
Recent studies on the varied topics at the intersection of DT and sustainability literature.

Reference	Summary	Gap
Tiewtoy et al. (2024)	Design thinking for the deployment of sustainable solutions in the context of small-scale agricultural communities.	Comprehensive, non-sectoral discussion of the multifaceted role of DT in sustainable development/ sustainability.
Tantiyaswasdikul (2023)	Literature review on the contribution of DT as an innovation driver in sustainably built environments.	Comprehensive, non-topical discussion of the multifaceted role of DT in sustainable development/ sustainability.
Kurek et al. (2023)	Bibliometric analysis of DT as a strategy in support of the innovation process in sustainable business models.	Comprehensive, non-topical discussion of the multifaceted role of DT in sustainable development/ sustainability.
Bothner and Grundmeier (2023)	Similarity of various didactic principles of Education for Sustainable Development (ESD) to the interdisciplinary method of DT, and DT's potential for implementing (ESD) in the textile and fashion sector.	Comprehensive, non-sectoral/non-sectoral discussion of the multifaceted role of DT in sustainable development/ sustainability.
Avsec (2023)	DT as a mechanism for technology-enhanced sustainable knowledge transfer improvement.	Comprehensive, non-topical discussion of the multifaceted role of DT in sustainable development/ sustainability.

bibliometric analysis and a set of 22 case studies, whose results are presented and discussed in Section 4. Section 5 concludes the paper by drawing from some of its key findings and provides some suggestions on how DT can help implement the UN SDGs.

2. Literature review

This section provides an overall view of some of the features of DT in a sustainable development context. It reviews the trends of the applications of DT in the literature to show how DT may be used to foster sustainable development. As seen in the previous section, DT refers to a creative problem-solving process that assists with understanding people and possibilities and thus developing effective solutions that are both innovative and practical (Foster, 2021; Shapira et al., 2017). In doing so, products and services can be produced that are tailored to the needs of the target group. This creates better consumer experiences and generates more profit. Furthermore, DT allows for the creation of services and products that are both sustainable and socially responsible (Shapira et al., 2017).

Sustainable development is based on the principles of equity, efficiency, and sustainability that provide a balance among social, environmental, and economic aspects (Enriquez-Puga et al., 2009; Moldovan et al., 2022). By combining both DT and sustainable development, new innovative solutions to complex problems can be created. These solutions will account for all aspects of sustainability and ensure that ethics are maintained. More specifically, the combination ensures that consumer needs are met without compromising the integrity of the natural environment (Shapira et al., 2017).

As with all processes, DT has its advantages and disadvantages. Considering DT characteristics and to better understand its strengths, weaknesses, opportunities, and threats, a Strengths, Weaknesses, Opportunities, Threats (SWOT) analysis was developed, based on the review of the literature (Table 2).

As strengths, DT encourages the generation of creative ideas and the development of innovative solutions to complex problems; shares an inclusive approach; can be applied to a wide variety of industries and contexts, and it's a versatile problem-solving tool, promoting teamwork and collaboration (Barsalou, 2017; Brenner et al., 2016). However, DT exhibits notable weaknesses, including demanding significant time investment, lacking a well-defined structure, and necessitating a substantial shift in organizational culture, often met with resistance (Beacham and Shambaugh, 2011). DT also presents various opportunities, beyond its applicability to diverse topics and contexts. The ongoing trend of digital transformation offers a promising environment for further development of "DT capabilities" (Dragicevic et al., 2023).

Digitalisation enhances the capability of DT to provide a unique framework for reevaluating processes and user experiences, including digital participation (Liedtka, 2015; Tomlinson, 2018; Simon, 2023). The framework, if applied in an urban context can promote inclusiveness and good governance by addressing the challenges of public participation (Simon, 2023). Nevertheless, DT faces certain threats. It may not be suitable for addressing uncertainty, ambiguity, and future challenges (Schwarz et al., 2023). Misconceptions and a lack of understanding can hinder its effective adoption (Wrigley et al., 2020). Additionally, some organisations may have cultural or structural barriers that impede the implementation of DT principles (Wrigley et al., 2020; Weiland and Knizhnik, 2022). Lastly, DT-based solutions risk becoming ineffective if they fail to adapt to evolving market and technological trends (Beacham and Shambaugh, 2011; Dorst, 2011; Schwarz et al., 2023). To improve the adaptation of DT to changing trends, Schwarz et al. (2023) suggested the integration of Strategic Foresight (SF) with DT. SF will provide DT with the framework for addressing emerging and future needs (Gordon et al., 2019; Schwarz et al., 2023).

Table 2
A SWOT Analysis of DT based on the review of the literature.

Strengths	Weaknesses	Opportunities	Threats
- Encourages creativity and innovation - Inclusive approach - Flexibility and adaptability - Promotes teamwork and collaboration	- Can be a time-consuming process - Only works when the context is well-defined and the goal is clear. - Resistance to change	- Caters for many topics - Allows discussions in many contexts - Can be a useful tool to rethink processes and user experiences	- It may not be the right approach for ambiguous problems - Misunderstanding can lead to its misapplication or rejection - Cultural and organisational limitations - Market trends change

Table 3
The most weighted keywords.

	Keyword	Total link strength	Occurrences
1	sustainability	203	900
2	DT	222	766
3	sustainable development	129	471
4	product design	73	375
5	students	46	275
6	innovation	42	189
7	engineering education	31	180
8	ecodesign	28	166
9	curricula	26	163
10	planning	34	158
11	education	28	139
12	teaching	25	132
13	sustainable design	21	102
14	design process	17	89
15	design education	17	85

In summary, DT offers a user-centric, creative, and collaborative approach to problem-solving, rendering it a potent instrument for fostering innovation. Nevertheless, it comes with notable challenges, including resource requirements and organizational resistance to change. By capitalizing on its strengths and opportunities while addressing its weaknesses and threats, organisations can harness the full potential of DT to drive innovation and achieve success.

To improve services and products in an agile and well-planned way, some authors consider DT to incorporate a total of 5 steps. The first refers to Empathy, in the sense of listening to and giving voice to all consumers of the final design and understanding their real needs. The second refers to the definition process, which is understood as the use of the information captured in the first step for the definition of clear and formal parameters; that is, it aims to identify the real problem that pervades a certain product or service. The third step concerns Ideation, which consists of the elaboration of a solution that satisfies the Definitions obtained. The fourth step deals with the Prototype to create a minimum viable product or service, given the information collected in the previous steps. Finally, the fifth step refers to the Test stage, in which the product or service is tested to understand if what was created is in accordance with the consumers' needs (Tomlinson, 2018; Magistretti et al., 2022; Cross, 2023).

This approach, therefore, helps companies to seek innovative and efficient solutions to their internal and external problems, encouraging the understanding of ambiguous problems or problems of difficult definition, as well as creativity and empathy in the process of creating products and services. In this regard, in order to maintain focus on the user/consumer, DT can be applied in different areas, effectively contributing to the development of strategies in the preparation of projects, in the management of stakeholders, in problem-solving, and in the approach with the customer (Barsalou, 2017; Brenner et al., 2016; Tomlinson, 2018).

Beyond these steps, some principles, characteristics, and attributes can be highlighted in relation to DT. According to Micheli et al. (2019) and Cai et al. (2023), DT has a number of attributes characterizing specific DT practices respectively, such as creativity and innovation; the

embracing of diversity; user-centeredness and involvement; problem-solving characteristics; iteration and experimentation processes.

Furthermore, DT also involves the establishment of interdisciplinary collaborations, the development of visualization skills, the adoption of integrative approaches; the creation of new knowledge and insights, among others.

Although it is not specifically designed to reduce biases, the practice of DT can help mitigate cognitive biases, since it enables the creation of empathy with users, and promotes team diversity, experimentation, and continuous learning (Liedtka, 2015). By creating opportunities for multidisciplinary teams, this approach presents great cost-benefit, allowing for greater involvement and engagement of teams in the process. In addition, it also contributes to greater interaction with the final consumers, providing the dialogue between the company and the main beneficiaries of its services and products (Magistretti et al., 2022). It is, therefore, an approach capable of transforming the process of marketing goods and products, the elaboration of strategies, and the organisation and allocation of the companies' resources (Tomlinson, 2018).

The notion of DT research, however, has not been free from critique (Lee, 2021). Some of the criticism relates to the fact that a trade-off between traditional and novel views is highlighted (Lee, 2021). Also, there is a risk that DT focuses more on abstract issues, which risks falling into excessive vagueness (Lee, 2021). Nonetheless, the use of DT does bring some benefits, through attention to multifaceted innovation and a user-centered perspective, involving various groups, for problem-solving (Beacham and Shambaugh, 2011). In particular, the maturing of research on DT means that an extension of conventional design is being seen (Dorst, 2011).

Traditionally, DT has been applied to different professional fields, even though it lies mainly in the design sphere (e.g. architecture, interior, fashion, graphic, and product configuration projects) (Beacham and Shambaugh, 2011; Shafiee et al., 2020). Nevertheless, according to the novel human-centric approach, the delegation of DT should be replaced by direct engagement in interdisciplinary, participatory, and system-based decision-making. This would ensure greater support for contemporary societal and workplace needs (Beacham and Shambaugh, 2011).

In terms of sectors, there has been a recent uptake of DT as an efficient problem-solving mechanism, especially in medicine, IT, and education (Dorst, 2011). With regards to the latter, in response to the growing industry demand for more punctual problem-framing techniques, business schools and universities started to deliver DT lessons as part of their business programmes and courses, either through enhanced internal capacities or through collaborative alliances with other institutions (Shafiee et al., 2020). The range of uses of DT in the educational sector can also divert from direct teaching. For instance, universities can implement it to build a better online learning experience by adopting a student-centric outlook, building on students' real experience and needs to identify improvement gaps, and simultaneously redesign the curriculum (Broadbent and Lodge, 2020; Clark et al., 2020). Another example is represented by the integration of the DT methodology to innovate the development of instructional media in schools by pinpointing learning issues faced by students (Luthfi and Wardani, 2019).

Due to its merits, DT has gained traction in the business industry in recent years. This is attributed to the creative and strategic problem-solving capabilities in complex issues. This is specifically beneficial to sustainable development problems, which are often multifaceted and require critical thinking to develop holistic approaches (Mansoori and Lackeus, 2020; Shapira et al., 2017).

DT is based on six main components that are useful for sustainable development (Shapira et al., 2017). Firstly, human-centeredness is essential. People are placed in the centre of all projects to ensure needs are met effectively. Secondly, DT is research-based to understand the drivers and barriers of processes. Thirdly, it is context-based to help understand the bigger picture. Furthermore, it involves collaborations that span various disciplines, which has been highlighted as imperative to sustainable development. Additionally, it is a nonlinear concept that allows for the development of multiple solutions and further integrates optimism that ensures that everyone in the process believes that change is possible (Shapira et al., 2017).

Therefore, DT can assist in finding the cause of sustainability problems and addressing them by visualising outcomes. DT has been shown to aid in the development of the circular economy. Designers are able to create products that incorporate reuse and recycling to ensure that eco-friendly alternatives are developed (Andrews, 2015).

The combination of the six components highlighted by Shapira et al. (2017) is very important in addressing sustainability problems. However, while the components suggested by Shapira et al. (2107) are appropriate for handling sustainability issues, they do not suffice to cover all aspects of DT relevant to sustainable development. For instance, Santa-Maria et al. (2022) observed that circularity is not embedded in the components proposed by Shapira et al. (2017). Moreover, Borthwick et al. (2022) argued for the inclusion of environmental and ethical values in the components to make them life-centered rather than human-centered. The relevant aspects of DT, including the six components, are exemplified by this study through the review of the literature and case studies. In the education domain, researchers have identified that embedding education for sustainable development in design curricula will assist in nurturing more environmentally conscious designers. This will make DT more popular in sustainable development. In doing so, students produce items that have increased longevity, efficiency, and reduced environmental impact. This involves assessing life cycles and designing products that can be repaired and remanufactured to increase usefulness (Andrews, 2015).

DT is already receiving increased attention in various educational sectors, especially from an international perspective, and is one of the 17 future skills according to Ehlers (2020). Panke (2019) identifies seven application areas for DT in education based on a comprehensive literature review: (1) curriculum development, (2) course content development, (3) a teaching-learning approach, (4) a learning goal, (5) student support, (6) process improvement and/or continuous professional development for teachers, and (7) organisational development. For example, in the context of curriculum development, DT can be applied to integrate sustainability topics into existing curricula or to develop new sustainability-focused educational programmes together with stakeholders. As a teaching and learning approach, DT enriches the typical principles of project-based learning with novel perspectives in the area of education for sustainable development. This encourages problem solvers with an empathetic foundation who can use their acquired skills to create innovative solutions. In the area of training and support for teachers, programmes need to be developed to include DT for sustainable development. Individual training for teachers and the availability of teaching and learning resources are also helpful (Müller and Schmidberger, 2022).

Müller and Schmidberger (2022) highlighted the importance of organisational development to the other fields of application of DT in education elaborated by Panke. Only a holistic approach (Whole Institution Approach) has the potential to contribute to the integration of sustainable development in all areas of activity in educational institutions. In this way, the institution itself acts as a role model for learners (UNESCO, 2017). DT can be applied to shape the process of anchoring sustainable development in the strategy and mission statement of the organisation in a participatory way (Müller and Schmidberger, 2022).

The integration of DT with a circular economy is one of the emerging approaches for making production and consumption more sustainable through need analysis, interdisciplinary and collaborative processes, creation and delivery of value, and prototyping and testing (Kurek et al., 2023). It fits well with smart city development and the circular economy, which are related to SDG 11 and 12 respectively (United Nations,

2015). For instance, applying DT and the circular economy in manufacturing systems can lead to better financial and environmental performance, thereby fostering sustainability practices (Liu et al., 2023). Similarly, Leal Filho et al. (2021) identified "smart design" concepts as one of the emerging requirements for successful e-mobility implementation in a circular economy context.

In other instances, DT has been incorporated into the development of smart cities. It is useful for focusing on the six components of smart cities, which include people, environment, government, economy, lifestyle, and mobility. This will lead to the development of innovative urban ecosystems and communities that are sustainably conscious. This type of transformation is beneficial to developing new technologies and systems that prioritise people and the environment simultaneously (Tsoriyo et al., 2022; Ali et al., 2023). Recently, the integration of DT into urban development involves the frameworks of geodesign and digital twin (Lieske and Hamerlinck, 2023; Kliskey et al., 2023). Geodesign involves the use of geospatial technologies in DT by visualising different development scenarios (Riaz et al., 2023). On the other hand, digital twin involves the creation of digital models or counterparts of physical or real-world objects such as cities (Riaz et al., 2023). The two frameworks are increasingly applied in the design, planning, and development of smart sustainable cities (Kliskey et al., 2023; Riaz et al., 2023). Most especially, geodesign and digital twins enable collaborative and multidisciplinary design processes and thereby facilitate stakeholder engagement and public participation (Kliskey et al., 2023). They have been applied in 3D city modelling, construction, brownfield redevelopment, automated parking systems, land use planning, and climate change resilience management (Ali et al., 2023; Hammond et al., 2023; Riaz et al., 2023; Srirangam et al., 2023).

The relationship between DT and SD is crucial in creating innovative solutions for complex problems. DT and SD are interconnected concepts that can collaborate to address challenges effectively. This synergy is evident in various ways:

a) Life-centered approach: DT and SD share a focus on understanding human needs, environmental values, and ethics (Gould et al., 2019).
b) Systems thinking: Both DT and SD involve understanding how different elements interact within a whole. DT considers how products or services fit into users' lives, while SD focuses on the interactions between economic, social, and environmental factors (Buhl et al., 2019).
c) Innovation and creativity: DT and SD aim to seek innovative and creative solutions to tackle complex issues like climate change, poverty, and inequality (Milovanovic et al., 2021).
d) Iterative processes: Both concepts follow iterative processes of prototyping, testing, and refining solutions, allowing for continuous improvement (Maher et al., 2022).
e) Collaboration: Both concepts bring together individuals from diverse disciplines to understand problems and develop solutions collaboratively (Fisk et al., 2024).
f) Long-term focus: DT and SD share a common goal of designing for the future needs of users, highlighting the importance of a long-term perspective in creating sustainable solutions (Schumacher and Mayer, 2018).

Ultimately, both processes are inherently future-oriented, raising awareness of the fact that economic, social, and environmental factors interact and impact each other.

3. Methods

The overarching aim of this study was to provide insights into how DT can be deployed to support sustainable development as a whole, particularly in the implementation of the United Nations Sustainable Development Goals. In order to achieve these goals, a dual approach to the study was undertaken, consisting of a review of the literature on DT using bibliometric analysis and a set of 22 case studies that illustrate the various contexts within which DT is being applied as a method. The approaches used are now described in turn.

3.1. Bibliometric analysis

The input data for bibliometric analysis was retrieved from Scopus. Among various academic databases, Scopus was chosen due to its comprehensive inclusion of high-caliber scholarly studies pertaining to the subject matter under investigation. The Web of Science is another widely recognized database. However, it has a more selective approach toward indexing academic literature. As we aim to understand the overall landscape of the field and determine key thematic areas, we selected Scopus for its broader coverage of the relevant literature. To set the boundary for the literature search, we restricted ourselves to papers focused on both DT and sustainability/sustainable development. We employed an expansive search strategy that encompassed various terms related to DT and sustainable development: (("DT" OR "designerly thinking" OR "designerly ways of knowing, thinking and acting" OR "thinking like a designer" OR "thinking by designer*" OR "design thinker*") AND ("sustainable development" OR "sustainability" OR "SDG*")). This search string was informed by earlier research on DT (Bhandari, 2022; Fatima and Singh, 2023). This approach was implemented iteratively. In simpler terms, we initiated the process with a preliminary search term and then adjusted it based on the examination of Scopus's retrieved outcomes. That was repeated until adding relevant terms did not result in additional items. The literature search on Feb 25, 2023, returned 468 documents. No limits were established to the year of publication. After excluding documents not written in English, 462 documents remained and were used for bibliometric analysis.

VOSviewer was used for bibliometric analysis. Other bibliometric software tools such as SciMAT and CiteSpace have been used in the literature (Sharifi, 2021). VOSviewer was used due to its user-friendly interface and its utility for providing sub-clusters related to the research topic. Among different bibliometric analysis methods, we used the co-occurrence analysis, as we wanted to identify key terms and thematic research areas. For this purpose, complete bibliographic details of the selected papers were added to the software. In addition, we developed and added a thesaurus file to the software to ensure that synonyms are not counted separately (e.g., 'design thinking' and 'DT'). The resulting outcome of the term co-occurrence analysis is an interconnected network of nodes and connections, in which the size of each node corresponds to its frequency of co-occurrence and the width of each connection corresponds to the intensity of the relationship between nodes. Terms that are significantly connected establish thematic clusters and are visually presented in distinct colors. These will be further discussed in Section 4.1.

3.2. Case studies

A case study approach is a method often deployed in studies in various fields, where specific contexts are identified by concrete examples. In the field of sustainable development research, a case study approach is often used, alone or in combination with other research methods (Leal Filho et al., 2022a; 2022b). The term "case studies" is used here by purpose, since we have identified and herewith present concrete examples where DT for sustainable development is demonstrated in various contexts.

Based on the proven soundness of case studies as a research method, in the second part of the research, a new search in the literature was performed to identify case studies to illustrate the uses of DT in the context of sustainability and to complement the bibliometric analysis. The criteria used in the selection of the case studies are: relevance to the research questions, representativeness, availability of data, theoretical significance, and comparative potential.

To perform the search, in order to obtain a sample of papers

specifically about DT and sustainability and to consider another database, the terms "design thinking" AND ("sustainability" OR "sustainable development" OR "SDG" OR "sustainable development goal") were used in different databases, such as Scopus, Web of Science, and Google Scholar. The "case study" term and its synonyms were not part of the search terms or phrases as we were not looking for studies that employed case study as an approach or method but captured references to real life or practical scenarios within a bounded physical system, irrespective of it being alluded to as a "case study" or not.

An illustrative set of publications was then selected based on their relevance to the topic the diversification of the methods used, and the study region. A list of 195 papers was then created. The cases and associate studies were identified and retained in the study based on the expert judgment of the reviewers. After that, 22 papers were selected for thematic analysis (Braun and Clarke, 2012) to identify the issues tackled, the associated SDGs, the nature and number of participants, the countries involved, and whether the DT operationalized was tailor-made, conventional, or part of a hybrid approach. These details enabled us to inductively generate insights into how DT can be employed in different contexts and SDGs. Therefore, the themes extracted from the studies have been presented in Table 5, Table 6, and Table 7. Additionally, thematic analysis of the whole three tables (i.e. Tables 5–7) was conducted (Braun and Clarke, 2012) and synthesised in Table 8.

4. Results and discussion

This section presents and discusses the results obtained and cross-checks them with the literature.

4.1. Results from the bibliometric analysis

The co-occurrence analysis shows how sustainability and DT are linked to each other (Fig. 1). Four key thematic areas can be distinguished from the bibliometric analysis.

Table 3 lists the top 15 most weighted keywords across all clusters. The total link strength refers to the influence or reach of each theme in the search. The higher it is, the higher the impact of the topic in the respective field.

Nodes refer to major terms used in the literature and node size is proportional to the frequency of co-occurrence of a term with other terms. Key values obtained from the term co-occurrence analysis include occurrence, links, and total link strength.

> "Occurrence implies multiple appearances in other articles, while the value of links represents the number of links associated with a particular keyword compared to others, and the total link strength refers to the accumulation of values for a particular keyword's link strength". (Arvianto et al., 2021, p. 6).

As it is seen from the analysis, there is are noticeable trend towards a frequent co-occurrence between the terms Sustainability and Design thinking. This may be explained if one bears in mind that DT is being used as one of the many approaches to handle "wicked problems in social and ecological systems" (Bender-Salazar, 2023, p.1) thus addressing the social and environmental aspects of sustainability.

Besides, lately, DT theories and practices have gained prominence and have been employed more often in management academic discourses and the business sector (Bender-Salazar, 2023). This way, design thinking "moves beyond the traditional creative sphere and enters the realm of addressing wicked problems across a wide spectrum of sustainability topics" (Bender-Salazar, 2023, p.4).

The thematic areas are summarised for each cluster, and the keywords in each cluster are listed (as shown in Table 4). Each category is named, with the iconic keywords in each category.

The identified thematic areas are clearly interconnected and closely related to DT itself. As a transformative learner, a design thinker can see beyond others, draw from a variety of viewpoints, and create novel solutions that outperform current options (Taimur and Onuki, 2022). Moreover, "design thinking actively sources dynamic capabilities for digital transformation" (Oliveira et al., 2024, p.2). Finally, organisations can practically use DT to execute circular innovation and, more generally, accelerate the shift to a more sustainable society (Bocken et al., 2023).

The *red cluster* is dominant and is focused on issues such as DT, innovation, social sustainability, environmental impact, etc. Sustainability is a dominant thematic area of the cluster. This reflects the extensive volume of papers that deal with the core issues of sustainability. Sustainability issues are complex and transcend disciplinary and geographic boundaries (Brandt et al., 2013). Sustainability has often been perceived as the ability to keep environmental systems stable and resilient. However, its social and institutional dimensions have also increasingly received attention (Lee et al., 2020). Despite this, standard methodologies are unable to address the complex and dynamic concerns associated with sustainability. Previous research demonstrates that DT benefits individuals and organisations in the development of problem-solving approaches, innovative ideas, or dealing with uncertainty capabilities, thereby offering innovative solutions for promoting sustainability (Beckman, 2020). DT is not an inelastic process but rather a framework that integrates creative and analytical modes of reasoning and various functional tools and techniques to address societal problems. Many of the present challenges that limit progress towards the SDGs can be overcome if design approaches are integrated into sustainability science (Maher et al., 2018).

As earlier stated, a circular economy is a crucial component of sustainable development. It can be operationalized by the transformation of culture through the use of DT and social innovation, whether imposed from the top or initiated at the bottom (Deniz, 2021). Santa-Maria et al. (2022) suggest that DT provides a viable method for creating conceptual solutions to sustainability challenges that are rooted in the circular economy. However, to achieve this objective, it is crucial to incorporate sustainability considerations into every stage of the problem-solving process and ensure they play a guiding role during the initial phase of defining the problem (p.5-6).

The *green cluster* has also received significant attention in the literature. It is mainly focused on education for sustainable development. Conventional learning methods can provide students with a broad understanding of sustainability but tend to lack a holistic point of view. According to Earle and Leyva-de la Hiz (2021), there is a need to reposition education so that it actively addresses complex environmental and social concerns by utilizing more imaginative, inclusive, and iterative methodologies. Such a paradigm shift will offer an opportunity for critical introspection and significant restructuring of educational systems. Studies emphasize design thinking as a distinct methodology that aids in problem-solving through the utilization of empathy, reevaluating perspectives, creating prototypes, conducting experiments and tests, and iteratively redesigning solutions (Beckman and Barry,

Table 4
Keywords in each cluster.

Cluster colour	Thematic areas	Keywords
Red	Sustainability	DT, innovation, planning, climate change, social sustainability, circular economy, environmental impact
Green	Learning and education	Education, teaching, curricula, engineering education, higher education, learning, problem-solving
Blue	Digital transformation	The design process, Internet of Things, information management, design making, human-computer interaction, human-centered design
Yellow	Sustainable design	Product design, ecodesign, sustainable design, design education

Table 5
Case studies on DT for sustainable development in teaching.

Case study	Issues tackled	Literature	SDGs	Number of participants/ organisations	Countries involved	Tailor-made DT approach or conventional DT	DT central or combined with other approaches	Journal
The DT-based Ignite STEM curriculum framework	The Ignite STEM curriculum framework for embedding education for sustainable development into the curriculum using DT is developed. To scale up this process a train-the-trainer scheme is developed reaching over 1500 students from 16 schools. Preliminary findings suggest successful areas of the scheme.	Dotson et al. (2020)	SDG 4	over 83 trainers (4 interviewed) over 1500 students from 16 schools trained (102 surveyed)	Guatemala and USA	Tailor-made	Central	Frontiers in Education
DT for architecture teaching to support sustainable development	The study focuses on undergraduate students' application of DT in their architecture studies. Findings suggest that self-directed learning is crucial to the development of DT.	Avsec and Jagiełło-Kowalczyk (2021)	SDG 4	117 students from one university	Poland	Conventional	Central	Sustainability
Fostering innovation competencies in tourism higher education via design-based and value-based learning	The method developed combines a learning method based on design and value. A case study is presented with Master students of tourism.	Phi and Clausen (2021)	SDG 4	60 students of the Masters of Tourism	Denmark	Conventional	Combined with value-based education	Journal of Hospitality, Leisure, Sport & Tourism Education
A disruptive model for delivering higher education programs within the context of entrepreneurship education	Creation of a solution using DT and Lean Startup principles for higher education entrepreneurship disciplines to innovate considering sustainability targets.	de Waal and Maritz (2022)	SDGs 4, 9, and 12	Seven teams (do not specify the number of people in each team)	Australia	Conventional	Combined with the principles of Lean Startup	Education + Training
Sustainable Design and Prototyping Using Digital Fabrication Tools for Education	Development of a model using sustainable prototyping and DT to evaluate processes of prototyping for educational purposes.	Soomro et al. (2021)	SDGs 4, 9, and 12	87 students	NA	Tailor-made	Central	Sustainability
An experimental approach to knowledge co-creation, discourse design, and collaborative writing within biocultural diversity with a manifesto 'sprint'	New methodological and co-creation approaches are needed in Digital Humanities (DH) for cross-disciplinary collaboration oriented to sustainability in an attempt to set effective and engaging ways of rapid knowledge generation for public awareness and policy-making.	Senabre Hidalgo et al. (2022)	SDG 4, 15	18 participants	Diverse nationalities were represented	Tailor-made	Centra	Cogent Arts & Humanities
MetMAP graphical tool for the integration of sustainable development in initiatives	The study described the DT MetMAP graphical tool and applied it to gain insights into sustainable development activity in one Ecovillage in Australia.	Maher et al. (2022)	SDGs 4, 11 and 17	Applied to one ecovillage	Australia	Tailor-made	Central	Sustainability Science

2007; Dorst, 2011; Dunne and Martin, 2006; Elsbach and Stigliani, 2018; Glen et al., 2014; Martin, 2009; Starkey and Tempest, 2009; Wastell, 2014). According to recent publications, there is expected to be an increase in demand for those with strong problem-solving abilities and creative thinking in the near future. DT can be a useful approach to expand the students' abilities to think critically about complex problems, including those of sustainability (Manna et al., 2022). According to Boyle et al. (2022), DT is an innovative teaching strategy that encourages cross-cutting skills including analytical reasoning, creative thinking, and teamwork among engineering students. It is a proven

Table 6
Case studies on DT for sustainable development in businesses and industry.

Case study	Issues tackled	Literature	SDGs	Number of participants/ organisations	Countries involved	Tailor-made DT approach or conventional DT	DT central or combined with other approaches	Journal
The "Circular Sprint"	The "Circular Sprint" process framework for the development of business models aligned with sustainable development was developed by three main means. Firstly a literature review was conducted. Secondly, expert feedback was collected and integrated into the framework. Finally, a series of co-creation workshops were undertaken.	Santa-Maria et al. (2022)	SDGS 9, 12, and 17	Sixteen experts and 107 participants through six workshops	A range of countries	Tailor-made	Central	Journal of Cleaner Production
Design-implementation gap of sustainable business models by prototyping	Many promising business model ideas fail to reach the market, which is needed to achieve impact. In addition to providing a normative theory in terms of a sustainable business model innovation process, a tool is suggested that organisations can use to translate sustainable business model ideas defined "on paper" into small-scale pilots as a first implementation step.	Baldassarre et al. (2020),	SDG 8, 9	15 academics 9 startups 14 employees	Netherlands	Conventional	Central	Journal of Cleaner Production
DT to sustainable service to slow fashion brands	DT methodology was applied to the creation and development of an innovative clothing rental service based on second-hand	Bernardes et al. (2018)	SDGs 12 and 17	430 participants	Portugal	Conventional	Central	Industria Textila
DT in the circular economy (CE) that exists in the Australian fashion sector to create a sustainable pathway	By employing design-thinking strategies, Australian SMEs with a foundation of product stewardship and circular purpose can create new systems of viable closed-loop business models and design processes.	Piller (2022)	SDG 8, 12	N/A	Australia	Conventional	Central	Strategic Direction
DT for social innovation	Tourism social entrepreneurs have developed an intuitive ability to apply DT to social innovation	Mahato et al. (2021)	SDGs 11,12 and, 17	10 participants	Vietnam	Tailor-made	Central	Journal of Hospitality and Tourism Management
DT to improve sustainability aspects of new textile products	A literature review combined with field research in four textile companies resulted in the development of a process framework to achieve more sustainable practices aligned with a circular economy.	Teixeira et al. (2023)	SDGs 9 and 12	Four textile companies	Brazil	Tailor-made	Central	Journal of Cleaner Production
DT in Corporate Social Responsibility (CSR) Strategy and Its Influence on Innovation	Explores the role of DT in CSR strategy and its influence on innovation through an empirical study of a French trail-running product manufacturer	Szostak and Boughzala (2020)	SDGs 9,12, and 17	Six participants from one company	France	Tailor-made	Central	Journal of Innovation Economics & Management
An evaluation of the Circular Economy for the Data Centre Industry (CEDaCI)	By employing DT, the CEDaCI project is creating a positive impact and initiating change across the sector, and innovative outputs will ensure that	Andrews et al. (2021)	SDG 8,9	32 participants for the survey 9 professionals for semi-structured interviews	Online participants came from a range of countries	Conventional	Central	Sustainability

(*continued on next page*)

Table 6 (*continued*)

Case study	Issues tackled	Literature	SDGs	Number of participants/ organisations	Countries involved	Tailor-made DT approach or conventional DT	DT central or combined with other approaches	Journal
	sectoral transformation continues.							
An evaluation of a three-phase mapped process for Playful Design Jams (PDJ)	PDJ can improve creativity, critical thinking, communication, and collaborative engagement of persons. This study also contributed to the theory and practice of advanced thinking skills and creativity development through facilitation.	Tang et al. (2020)	SDG 9, 12, 17	121 (pre and post-Jam questionnaire respondents and interviewees)	N/A	Tailor-made	Central	Thinking Skills and Creativity
Designing thinking in sustainability-oriented innovation	By combining the literature on sustainability-oriented innovations and the DT literature key challenges regarding sustainable development were addressed. The results were presented in a framework and further discussed in relation to relevant literature.	Buhl et al. (2019)	SDGs 9, 12, and 17	NA	NA	Conventional	Central	Journal of Cleaner Production

Table 7
Case studies on DT for sustainable development in communities.

Case study	Issues tackled	Literature	SDGs	Number of participants/ organisations	Countries involved	Tailor-made DT approach or conventional DT	DT central or combined with other approaches	Journal
Participatory Learning and Co-Design for Sustainable Rural Living, Supporting the Revival of Indigenous Values and Community Resiliency in Sabrang Village, Indonesia	A multi-stakeholder participatory co-design approach is proposed based on the learning philosophy of Niteni to address sustainable development issues in Indonesia's rural areas.	Utami et al. (2022)	SDGS 4, 11, 12, 15 and 17	58 participants	Indonesia	Tailor-made	Central	Land
Participatory knowledge integration to promote safe pesticide use in Uganda	Development of knowledge, through DT in a workshop, for safe pesticide management, identifying the main challenges to be addressed.	Wiedemann et al. (2022)	SDGs 4, 12, 15, and 17	33 participants	Uganda	Conventional	Central	Environmental Science and Policy
Integrating DT and Living Labs approaches	A coastal management model was built through the application of the Living Labs concept and DT techniques	Anton et al. (2022)	All SDGs	15 participants	Romania	Tailor-made	Central	Inventions
DT to enhance the engagement of individuals in fighting food waste.	The CEASE (Communities, Engagement, Actions, Shareability, Ecosystems) DT model is proposed for maintaining food consumer behaviour and achieving zero waste.	Massari et al. (2022)	SDGs 2, 12, 15, and 17	2 organisations	United States	Tailor-made	Central	Socio-Economic Planning Sciences
DT potential in jamming sustainability sessions	A sustainability jamming session was evaluated for its DT components. A range of characteristics that have the potential to support and hinder DT in these settings are presented and discussed in relation to relevant literature.	Kagan et al. (2020)	SDGs 9, 11, and 17	1 sustainability jam event	Germany	Conventional	Central	Journal of Cleaner Production

Table 8
Summary of characteristics of DT for sustainable development.

DT can be applied in a range of contexts
DT can be applied in a range of disciplinary areas
DT can be central or combined with other approaches
DT can be tailor-made or conventional
DT applied in organisations and with individuals ranging from small to a large number (e.g. 10–430 participants)
DT can be used to develop skills, knowledge, and pedagogical approaches in formal, informal, and non-formal contexts
DT can be applied within techno-centric and eco-centric paradigms including indigenous thinking
DT can support the integration of stakeholder perspectives
DT can be used across a range of SDGs

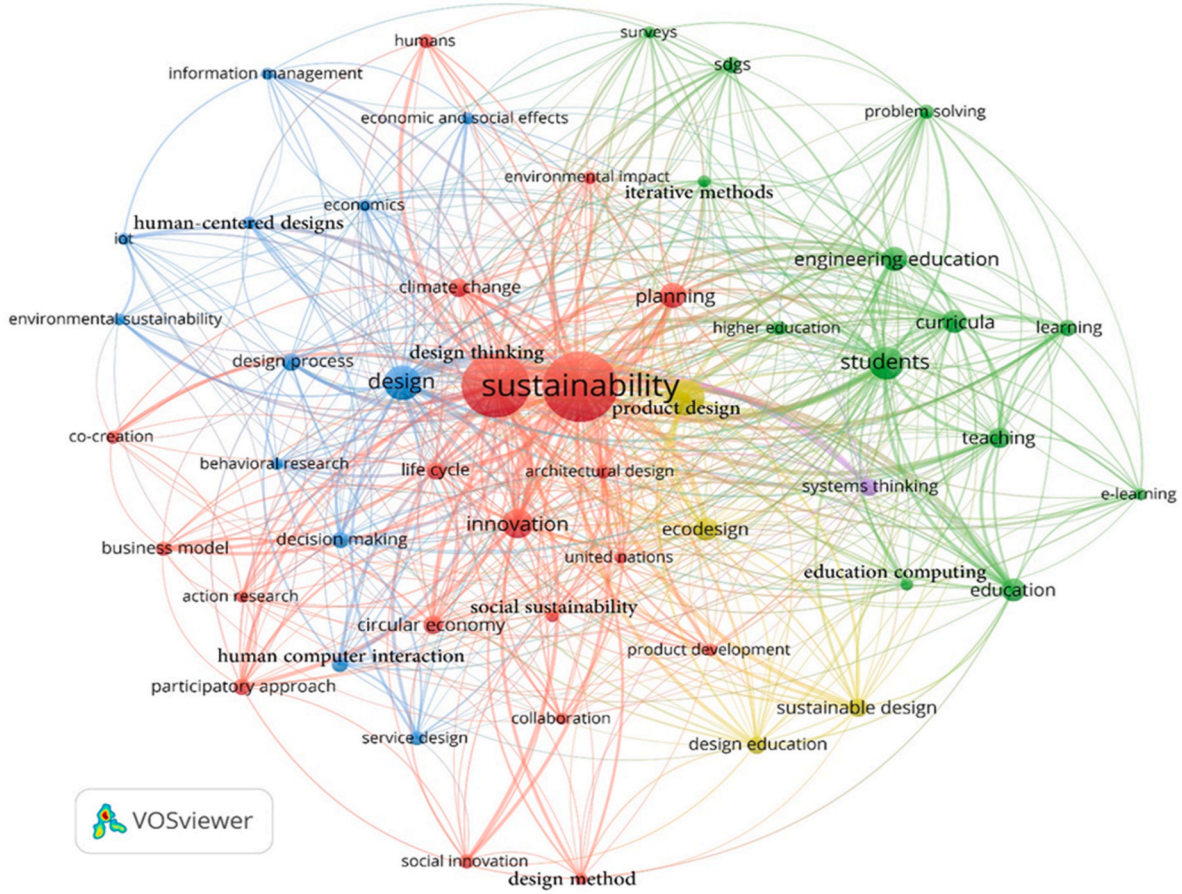

Fig. 1. Results of the term co-occurrence analysis.

educational approach for engineering domains and other academic subjects.

The *blue cluster* features terms such as the Internet of Things (IoT), information management, human-centered design, human-computer interaction, etc. The impact of digital technologies on company operations and procedures is significant, resulting in transformations to how firms generate, distribute, and retain value (Ancillai et al., 2023). To generate value in the era of the Internet of Things, companies must engage in a continuous pursuit of innovation. (Kulakli and Arikan, 2023). In fact, the IoT is an important enabling factor for responsible digital transformation and innovation. Furthermore, the Internet of Things has great potential for creating social value because it is converging many technologies from the Fourth Industrial Revolution including artificial intelligence, cloud computing, and blockchain (World Economic Forum, 2018). Besides the IoT's use of DT could spur innovation and provide a useful foundation for co-creation activities.

The principles of DT have resulted in the recognition and integration of pertinent user needs and behaviors when striving for product sustainability. When applied within the realm of social innovation, DT focuses on addressing the requirements of both end-users and the supporting infrastructure surrounding a given product or service (Curralo et al., 2022). DT involves the observation of complex real-life scenarios through a perspective that emphasizes empathy and places humans at the center (Overmyer and Carlson, 2019). Imagining future scenarios, which also highlight the role of DT in realizing possibilities and defining it as a mindset, is an essential part of creating a human-centered approach to problem-solving (Docherty, 2017). The influence of DT extends beyond "technological and non-technological innovations", as well as the economy; it also encompasses society on a broader scale (Freimane, 2021). The European Commission Staff (2013) recognized the necessity to assess the societal and economic impacts of design, as well as its contribution to value generation in conjunction with other intangible resources. However, there is an acknowledged drawback to the DT's human-centered strategy: users frequently struggle to comprehend and articulate their unmet wants and demands for new goods and services. (Radnejad et al., 2021). Some academics (Norman

and Verganti, 2014) contend that the traditional approach to DT, which is constrained by a human-centered perspective, is only appropriate for achieving incremental rather than radical changes. They propose for using DT, the strategy should be switched from being human-centered to being design-driven in order to create a radical breakthrough. By developing a comprehensive grasp of users' social, economic, political, and cultural situations, designers and innovators can spot unmet demands that fundamentally alter the design of a good or service (Radnejad et al., 2021).

The *yellow cluster* is clearly focused on eco-design and sustainable design. In the early 1980s, scholars raised the issue of the environmental and social responsibilities of designers. Papanek (1971) challenged designers "to face their social and moral responsibilities instead of only their commercial interests" (p.6).

According to Ulrich and Eppinger (2015), the potential ecological repercussions of a product encompass various aspects such as the usage of energy, depletion of natural resources, discharge of liquids, emission of gases, and generation of solid waste. These impacts can be broadly categorized into two main areas: energy and materials. Both categories pose significant environmental challenges that require effective solutions. At the initial phases of product development, strategic choices pertaining to material utilization, enhancing energy efficiency, and mitigating waste production play a key role in minimizing or eradicating detrimental environmental effects. However, after establishing the design concept for the product improvements about its ecological performance often necessitates lengthy iterations to achieve satisfactory outcomes. Micklethwaite (2022) suggests for designers to align their practices with sustainability objectives and shift from limited perspectives to a comprehensive comprehension of sustainability, there is a need for an increase in sustainability literacy.

Overall, the use of DT in the context of sustainable design is entirely justified. Empathy plays a vital role in making this methodology valuable within this specific circumstance. This approach, characterized by its exploratory nature, follows an iterative and nonlinear process that often uncovers unforeseen revelations and creative resolutions. Hence, it imitates the approach and mindset of designers. Also, design is considered to be the core of the driving force of system innovation and change (Liedtka, 2015) and complementary to technological innovation and social innovation (Ceschin and Gaziulusoy, 2016). "If designers follow the concept of sustainability at the beginning of the design and development stage, it will definitely lead the design results in a more environmentally friendly and low-carbon direction" (Yang et al., 2022, p. 3).

4.2. Results from the case studies

The literature has pointed out many ways in which DT can be applied to sustainable development. In this section we report on the results from the 22 case studies where DT for sustainable development is demonstrated in the context of teaching (Table 5), businesses and industry (Table 6), and communities (Table 7). Tables 5–7 provide an overview of the experiences from these case studies and list some specific features associated with them and their respective contexts.

The range of case studies in which DT has been applied or developed suggests the flexibility of DT for sustainable development. The analysis also shows its flexibility regarding contexts and ways in which it can be applied. This is demonstrated firstly, because it has been applied in a range of countries and a range of continents such as Europe, the Americas, Africa, and Asia. Further research is needed to gain insights into the differences in use depending on the country and continent. Secondly, DT for sustainable development is of interest to a range of disciplinary areas, demonstrated by the wide range of journals in which the case studies have been published. Thirdly, DT for sustainable development is used in its conventional form but can also be tailor-made. Further research is required to understand in which cases it is optimal to create a tailor-made approach and in which cases it is better to opt for a conventional approach. Fourthly, DT can be applied to organisations as well as individuals ranging from small (e.g. 10 participants) to large numbers (e.g. 430 participants). Further research into the constraints and impact related to the number of individuals and organisations could be undertaken. Finally, most case studies use DT as a central approach. However, it is demonstrated through some of the case studies that it can also be combined with other approaches such as value-based education (Phi and Clausen, 2021) or the principles of Lean Startup (de Waal and Maritz, 2022). Further research could be undertaken, to understand to what extent DT can be combined with other approaches and the pros and cons of doing so.

The illustrative case studies suggest that there are substantial links between sustainable development and DT. Firstly, an important focus is the use of DT to foster skills, knowledge, and pedagogical approaches for sustainable development in formal, informal, and non-formal contexts (Dotson et al., 2020; Avsec and Jagiełło-Kowalczyk, 2021; Senabre Hidalgo et al., 2022; Phi and Clausen, 2021; Utami et al., 2022; de Waal and Maritz, 2022; Soomro et al., 2021; Wiedemann et al., 2022; Anton et al., 2022). Education for sustainable development is key to integrating environmental, social, and economic aspects (Earle and Leyva-de la Hiz, 2021). Therefore, DT is an important tool to embed education for sustainable development in a range of contexts.

Secondly, the illustrative case studies suggest that DT can foster social innovation within and beyond technocentric approaches (Utami et al., 2022; Anton et al., 2022). This is important because there has been a prioritisation of technocentric approaches to develop innovation for sustainable development, and other worldviews need to be integrated appropriately (Carayannis and Campbell, 2010).

Thirdly, the case studies illustrate how DT can be used to contribute to sustainable development in a wide range of disciplinary areas. These include management studies (Santa-Maria et al., 2022); fashion (Piller, 2022; Bernardes et al., 2018); environmental management (Wiedemann et al., 2022); tourism (Phi and Clausen, 2021; Mahato et al., 2021), food waste (Massari et al., 2022), strategy and policy development (e.g. Szostak and Boughzala, 2020). This shows the multidisciplinary use of DT in the context of sustainable development. This is important because sustainable development needs to be embedded across all sectors, and knowledge from across all sectors is required for sustainable development (United Nations, 2015).

Fourthly, the case studies suggest that DT helps to incorporate a range of stakeholder views, including those of indigenous communities (Utami et al., 2022), government agencies (Utami et al., 2022; Wiedemann et al., 2022), businesses (Santa-Maria et al., 2022), and non-governmental organisations (Wiedemann et al., 2022). The development of interconnections between stakeholders is crucial to advance sustainable development policy integration processes at different levels (i.e. organisational, regional, national, and international; Vargas et al., 2019). Therefore, DT can support the development of stakeholder interconnections for sustainable development.

Overall, the case studies also illustrate how DT can be applied towards achieving different sustainable development goals (SDGs) and specific targets. Pieces of evidence captured in the various outputs reviewed align with SDGs 2, 4, 8, 9, 11, 12, 15, and 17, corresponding to Zero Hunger, Quality Education, Decent Work, and Economic Growth, Industry Innovation and Infrastructure, Sustainable Cities and Communities, Responsible Consumption and Production, Life on Land, and Partnerships for the Goals, respectively. Taking the case of SDG 4 on Quality Education, and its target 4.7, DT can be pivotal in fostering the integration of STEM curriculum for sustainable development (Dotson et al., 2020), self-directed teaching in different disciplines such as architecture (Avsec and Jagiello-Kowalczyk, 2021), and it can be employed to support a learning method intended to boost innovative skills in learners (Phi and Clausen, 2021), which can become a catalyst for economic prosperity. Another interesting aspect of the cases analysed that are related to education for sustainable development is the connection of two or more SDGs. In Soomro et al. (2021) for example, the authors use sustainable prototyping and DT for teaching, connecting

the SDGs 4, 9, and 12 in the same research.

Whilst DT can spur innovation, which is central to achieving Industry Innovation and Infrastructure (SDG 9) (Buhl et al., 2019; Santa-Maria et al., 2022; Teixeira et al., 2023; Andrews et al., 2021), the case studies further posited the same applies to the realisation of Decent Work and Economic Growth (SDG 8), Sustainable Cities and Communities (SDG 11), and Responsible Consumption and Production (SDG 12). It takes a synergistic effort to achieve the SDGs, and this can be evidenced through partnership. And although partnership for the SDGs is encapsulated in SDG 17, other SDGs such as Zero Hunger (SDG 2), and Life on Land (SDG 15) provide a platform to exemplify it (Massari et al., 2022; Wiedemann et al., 2022; Anton et al., 2022). Given this realisation, deliberate attempts must be made to ensure that DT becomes a focal point for innovation in reaching the goals. Additionally, further research is needed to understand to what extent DT can be used to address each and all SDGs and what the limits for its use are in relation to each SDG. The experiences from the paper, combined with lessons learned from the literature, allow the identification of a set of trends related to DT and SD, some of which are summarised in Table 8.

Overall, Table 8 illustrates how DT may provide a contribution to a better understanding of sustainable development. This aligns with other analyses on the links between DT and sustainable development (e.g. Maher et al., 2018; Deniz, 2021; Santa-Maria et al., 2021). However, although there is a range of tools, approaches, and outcomes giving an indication of the impacts of DT on sustainable development, there does not seem to be a systematic approach to evaluate the impact of DT at the large scale (i.e. country and international level) across sectors. Therefore, future research on DT for sustainable development could focus on the evaluation of the impacts of the use of DT for sustainable development at the international level across sectors.

5. Conclusions

The purpose of this study was to explore the role of DT in sustainable development. Using a bibliometric analysis and a set of 22 case studies, the paper discusses the role of DT in a sustainable development context, also outlining its potential and limitations.

The bibliometric analysis showed that DT could be valuable in enhancing problem-solving skills, innovation, and adaptability for individuals and organisations. This is because of its distinctive approach to problem definition, human-centredness, holistic thinking, and willingness to consider alternatives. When combined with sustainability science, design-based methods can provide solutions to the current limitations that hinder progress towards SDGs and offer significant opportunities to achieve them effectively in a complex real-world setting. Additionally, DT principles can assist in developing circular economy-based solutions to sustainability issues. To achieve this, sustainability considerations must be included in the problem-solving process, and problem-framing approaches must adhere to the same principles. Furthermore, DT principles have led to the recognition and inclusion of relevant user needs and behaviours in sustainable product development. Overall, DT provides a framework for combining creative and analytical reasoning, specific mindsets, and diverse hands-on tools and techniques to improve critical thinking abilities towards sustainability challenges.

Furthermore, the literature has identified various applications of DT in sustainable development. This paper provided 22 case studies of its effectiveness. Firstly, DT is used to promote skills, knowledge, and pedagogical approaches for sustainable development in various contexts, emphasizing the integration of environmental, social, and economic aspects through education. Secondly, DT facilitates social innovation, moving beyond technocentric approaches and integrating diverse perspectives for sustainable development. Thirdly, DT is applied across disciplinary areas such as management, fashion, environmental management, tourism, food waste, and strategy and policy development, reflecting its multidisciplinary nature. Lastly, DT enables the inclusion of stakeholder views, ranging from indigenous communities to government agencies, businesses, and non-governmental organisations, fostering stakeholder interconnections for sustainable development. Overall, DT has the potential to significantly contribute to sustainable development. However, there is a lack of systematic evaluation of its impact at a large scale, necessitating future research to assess the effectiveness of DT for sustainable development internationally across sectors.

In sum, when considering the application of DT to specifically implement the UN Sustainable Development Goals, the experiences gathered in the study show that:

a) DT can be used to help implement the UN SDGs by providing an approach that emphasizes human-centered design. This includes identifying problems, creating user-friendly solutions, and testing them in order to ensure that they are effective.
b) By using DT, companies, organisations, and governments can create low-cost, high-impact, and sustainable solutions to help achieve SDGs such as SDG8, SDG9, SDG12, and SDG13.
c) DT can be used to develop products or services that reduce - or eliminate - the use of resources, such as water or energy, while still being affordable and accessible to those who need them (e.g. SDG1, SDG2, SDG3, SDG6, SDG7).
d) DT can be used to create low-cost and effective solutions to challenges related to healthcare, education, access to energy, clear water, and other needs, helping to achieve goals such as SDG3, SDG4, SDG7, SDG8, and SDG9.
e) DT also encourages collaboration and cooperation between different stakeholders, nationally and internationally, which can help ensure that the solutions created are effective and sustainable (SDG17).

The implications of this paper to theory are as follows. Firstly, it shows that there is a sound basis in the literature for the further development of DT, especially in a sustainable development context. Secondly, a theoretical implication of the paper is DT may encourage a reflection on the importance of creative problem-solving and encourages thinking outside the box. Moreover, it is seen that DT's iterative and adaptive nature allows for continuous improvement and refinement of solutions as new information becomes available or as circumstances change.

The paper also has implications for practice. The first one is that it illustrates how much can be achieved by introducing DT in sustainability efforts as a whole, and in implementing the SDGs in particular, also including areas such as Education for Sustainable Development (ESD). Also, the paper shows that DT may greatly assist in the process of raising awareness about sustainable development, providing a sound basis for a greater understanding of many complex problems in the real world. Through empathy, reframing, prototyping, experimentation, testing, and redesign, as previously mentioned, students (and future professionals) may be able to develop sustainable products that are aligned with the circular economy, hence enhancing social innovation, among many other aspects. A further implication of the paper to practice is that it has demonstrated that DT is a problem-solving and innovation approach that can be effectively applied to address the challenges of sustainable development. Also, the paper has shown that DT may encourage a human-centered and iterative process that takes into account the needs and perspectives of various stakeholders while aiming to create sustainable solutions.

One of the main lessons from the paper is that, in implementing DT in a sustainability context, it is important to identify the key stakeholders involved in the issue and engage with them to gain a comprehensive understanding of the problem. In addition, the implementation process needs to be preceded by a clear definition of the problem or sustainability challenge to be addressed. Finally, it is useful to generate a wide range of creative ideas and potential solutions to the defined problem, encouraging brainstorming and open-mindedness.

In terms of future research, some areas which may be subject of

further research are:

a) Theory of DT: there is a perceived need for more studies that may analyse how to better explore the interface between DT and sustainable development.
b) Practice-related DT: much can be gained by undertaking studies that may encourage the adoption of DT approaches in collaboration with various groups, to scale up sustainable solutions and address similar challenges.
c) The impacts of DT: Future research may also be performed, to evaluate the environmental implications of DT, considering factors like resource usage, waste generation, and carbon footprint.
d) Barriers to implementing DT: In order to cater to its further development, an analysis of the main difficulties experienced by educators in the use of DT focused on sustainable development in HEIs is needed.
e) Further development of DT: To enhance its effectiveness, the elaboration of new models to assess the maturity of the use of DT in sustainability initiatives may be useful, be it among universities or companies.

The study has some limitations. The first one is the fact that the bibliometric analysis focused on the subject matter of DT from a sustainability perspective and did not include other areas. A further limitation is related to the fact that the sample of 22 case studies was not large enough to allow definitive conclusions to be drawn. Also, the study did not provide an in-depth analysis of the implementation of DT, such as the diverse needs, concerns, and perspectives of the people and communities affected by sustainability challenges. Moreover, the paper did not consider incremental improvements and radical innovations which DT may catalyse, to address sustainability challenges.

Despite these limitations, the study provides a welcome contribution to the literature, since it has analysed and documented trends related to DT on sustainable development, providing evidence of its connections to sustainability. This, in turn, helps to foster a broader understanding of the international implications of this important topic.

Future studies may focus on how DT may encourage collaboration on sustainable development initiatives, hence taking advantage of its innovation potential. In conclusion, DT is applicable in a wide range of initiatives related to or leading to sustainable development - including the implementation of the UN SDGs - in which complex problems may be addressed by multidisciplinary approaches, taking into account issues such as circular economy, social injustices, or the impacts of climate change, among others, as illustrated in this paper.

CRediT authorship contribution statement

Walter Leal Filho: Writing – review & editing, Writing – original draft, Validation, Supervision, Project administration, Methodology, Conceptualization. **Iris Schmidberger:** Writing – review & editing, Writing – original draft, Validation, Methodology, Conceptualization. **Ayyoob Sharifi:** Writing – review & editing, Writing – original draft, Validation, Methodology, Conceptualization. **Valeria Ruiz Vargas:** Writing – review & editing, Writing – original draft, Project administration, Methodology, Investigation, Formal analysis. **Izabela S. Rampasso:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis. **Thais Dibbern:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis. **Olena Liakh:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis. **Yusuf A. Aina:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis. **Laís Viera Trevisan:** Writing – review & editing, Writing – original draft, Investigation, Formal analysis. **Marcellus Forh Mbah:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis. **Rosley Anholon:** Writing – original draft, Conceptualization. **Valerija Kozlova:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data used is available through academic databases

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