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Digital Transformation and Environmental Sustainability: A Review and Research Agenda

Abdul Karim Feroz [1], Hangjung Zo [1,*] and Ananth Chiravuri [2]

[1] School of Business and Technology Management, College of Business, Korea Advanced Institute of Science and Technology (KAIST), Daejeon 34141, Korea; akferoz@kaist.ac.kr
[2] College of Business and Economics, United Arab Emirates University, Al Ain 15551, United Arab Emirates; ananth.chiravuri@uaeu.ac.ae
* Correspondence: joezo@kaist.edu; Tel.: +82-42-350-6311

Abstract: Digital transformation refers to the unprecedented disruptions in society, industry, and organizations stimulated by advances in digital technologies such as artificial intelligence, big data analytics, cloud computing, and the Internet of Things (IoT). Presently, there is a lack of studies to map digital transformation in the environmental sustainability domain. This paper identifies the disruptions driven by digital transformation in the environmental sustainability domain through a systematic literature review. The results present a framework that outlines the transformations in four key areas: pollution control, waste management, sustainable production, and urban sustainability. The transformations in each key area are divided into further sub-categories. This study proposes an agenda for future research in terms of organizational capabilities, performance, and digital transformation strategy regarding environmental sustainability.

Keywords: digital transformation; environmental sustainability; artificial intelligence; big data analytics; Internet of Things; systematic literature review

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1. Introduction

Digital transformation is a process driven by digital technologies where disruptions are triggered in organizations, and its impacts are enormous on the organizational value creation, strategy, and structure mechanisms [1]. Digital transformation has stimulated new business models and has caused disruptions in the global markets and industry. The shock waves of digital transformation have crashed the traditional businesses, resulting from the entry of digitally savvy firms. We can observe some prominent instances of such in the global market. For example, the hotel industry was radically disrupted by Booking.com and Airbnb [2], revolutionary changes were brought to the music industry by Spotify [3], and the incumbent firms have been transformed, e.g., the digitalization of Starbucks [4]. These disruptions are enabled by digital technologies such as IoT, big data analytics, cloud computing, mobile technologies, and artificial intelligence [5].

Even though digital technologies are the primary enablers, other factors have also driven digital transformation. These include evolving consumer behaviors and expectations, digital competitions [6], and data availability. It has been noted that the impacts pertinent to digital transformation are vast and extend beyond consumer behavior or organizations into other domains such as healthcare [7] and social dynamics [8].

Furthermore, digital transformation is expected to exact a toll on the sustainability triangle, i.e., environmental sustainability [9,10]. The developments in digital technologies provide improvements to the environment and human health, and the whole food chain [11]. Hence, there is a need for more comprehensive studies to understand the impacts of digital transformation in various aspects that are currently ignored in the literature, such as the impact on corporate social responsibility [1], society [12], performance [2], and the environment. The protection of the environment against pollution and the degradation of resources remains a top challenge [13] and requires more digital transformation attention.

This research also indicates that the effects of digital transformation on environmental sustainability are uncertain [13], and hence this forms the motivation of our study. More importantly, our study's findings will help us to understand the impacts of digital transformation on environmental sustainability, which could help set policies and goals across nations, which is gravely missing today [14]. In this study, we map the digital transformation-related disruptions regarding environmental sustainability. This paper's main research question is "What disruptions are taking place in the environmental sustainability domain enabled by digital transformation?" Through a systematic literature review, this paper identifies and categorizes the impacts of digital transformations on environmental sustainability into four areas, namely, waste management, pollution control, sustainable production, and urban sustainability, which in turn are further divided into sub-categories (Figure 3). We propose three main environmental sustainability areas for further research, such as organizational capabilities, performance, and digital transformation strategy.

The remainder of this paper is organized as follows. The next section defines what digital transformation is and how it pertains to environmental sustainability. The research methods used for this study are presented in the following section. After that, we present the research's main findings and provide a theoretical framework for understanding the environmental sustainability disruptions caused by digital transformation. Subsequently, we discuss the significant implications of this research and propose an agenda for future research, and finally, the conclusion rounds out the paper.

2. Theoretical Background

2.1. Digital Transformation

The relentless intrusion of novel digital technologies into the market has been driving organizations to digitally transform their businesses. Digital transformation has gained strategic significance as a critical agenda for top management [15–19]. Various definitions describe the digital transformation in the literature [16–18,20–22]. The extant literature provides a good understanding of digital transformation and how it disrupts various aspects of our lives.

Digital transformation is referred to as "the use of new digital technologies to enable major business improvements in operations and markets such as enhancing customer experience, streamlining operations or creating new business models" [23]. This definition captures digital transformation as a process that considers the present and future of how digital technologies influence business models. Others defined digital transformation as a process of evolution where digital technologies and digital capabilities create value by stimulating business models, customer experiences, and operational processes [24]. Li et al. [25] specified digital transformation in terms of the impact of information technology (IT) on the organization and its alignment with business with small and medium-sized enterprises (SMEs). Legner et al. [26] defined it as a change mandated by IT to automation tasks. More recently, Vial [1] used semantic analysis to build a working definition of digital transformation from existing definitions in the literature and defined it as "a process that aims to improve an entity by triggering significant changes to its properties through combinations of information, computing, communication, and connectivity technologies" (p. 118).

From these various definitions, it is clear that digital transformation is not a single step undertaken for upgrading specific functions of organizations but is more of a process that brings fundamental changes in organizations and results in creating additional opportunities for improvement. Furthermore, digital transformation is not an organization-centric process but rather a phenomenon that triggers changes in the industry and society [1]. It is important to note how digital transformation differs from digitization and digitalization. Digitization is concerned with automated routines and tasks such as the conversion of analog into digital information. Digitalization is the addition of digital components to product or service offerings, and digital transformation is a more comprehensive introduction of new business models and digital platforms [2]. In this paper, we study digital transformation from the environmental sustainability perspective because, as indicated earlier, the effects of digital transformation on environmental sustainability are mixed [13].

2.2. Environmental Sustainability

The convergence of the circular economy and Industry 4.0, which aims to enhance resource use efficiency [27], has emphasized environmental sustainability. In the increasingly interconnected global world, stakeholders' relationships are redefined as the sustainability-based sharing economy [28]. Environmental sustainability is one of the essential principles of sustainability, which warrants that the quest for satisfying our needs should not compromise the quality of the environment, and the ecosystem should be sustained for the sake of future generations [29]. Incorporating environmental sustainability principles in operations can enhance organizations' value and make digitalization more valuable [30].

The constant increase of pollution and degradation of resources has rendered the protection of the environment an unprecedented ultimatum that needs the undivided attention of businesses and governments [31]. Consequently, there are increasing pressures from the market and stakeholders to adopt environmentally sustainable practices [32–34]. Hence, sustainable practices can be positioned such that they serve as a means of creating more value for customers and improving brand image. As organizations adopt digital transformation strategies, environmental sustainability practices also need to be considered for evolving business models and creating compelling impacts.

2.3. The Impact of Digital Transformation on Environmental Sustainability

Digital technologies such as artificial intelligence (AI), big data analytics, mobile technologies, IoT, and social platforms generate positive improvements for society and industry [1]. Digital technologies are also increasingly deployed in improving environmental sustainability. Companies are now introducing new products and platforms based on digital technologies used to ameliorate environmental sustainability. Goralski and Tan [35] highlighted AI-based technologies such as Smart Water Management Systems, PlantVillage, and Peter Ma's innovative use of AI for identifying waterborne diseases that have infested waters. Balogun et al. [36] conducted a study on implementing digitalization for improving environmental sustainability. Their study consisted of nine cases in various countries using big data and IoT to address environmental sustainability issues and improve the environment. It was also suggested that digital workplaces can contribute to environmental sustainability [37].

Companies are now relying on AI, IoT, and big data analytics for carrying out sustainable business practices that involve reduced carbon emission and minimizing other waste to the environment [38]. Big data analytics applications are increasingly changing how the impact on the environment is measured and mapped. Big data analytics can be used to design a method for enhancing food system traceability and the certification of goods in terms of their direct environmental performance (i.e., carbon footprint) or the practices used for their production processes [11]. Similarly, blockchain is considered a tool with enormous potential to achieve sustainability in business and industrial practices [39]. Blockchain offers capabilities to extend the product life cycle, maximize resource usage, and reduce carbon emissions, contributing to increasing sustainability [40].

The convergence of digitalization and environmental sustainability transcends organizational and industry levels and extends to the country level as well. For example, ElMassah and Mohieldin [41] conducted a study on how various countries worldwide are achieving sustainable development goals (SDGs) and how digital transformation helps them. Thus, this study maps these kinds of digital transformations taking place in the sector of environmental sustainability and identifies areas where further research is required in the future.

3. Research Method

As indicated earlier, this paper aims to present research trends and identify future research agendas regarding digital transformation in the environmental sustainability domain. This study employed a systematic literature review (SLR) method to achieve the research objective mentioned above. SLR has been an effective method for identifying research trends and defining future research opportunities [42,43]. This paper followed a step-by-step process for identifying research articles and analyzing them as per the SLR procedures. In this regard, we used the guidelines from the previous studies on doing a systematic literature review [44,45]. The whole process of the literature review is presented in Figure 1.

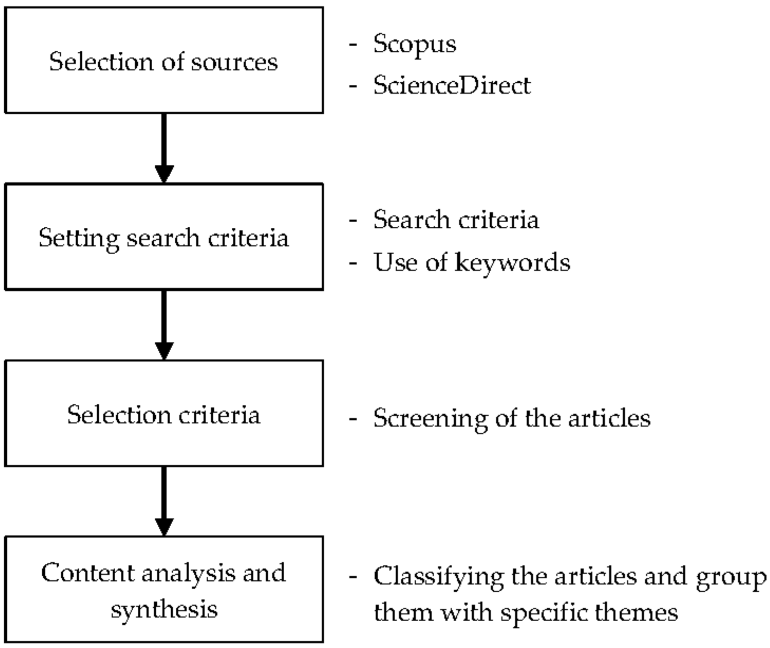

Figure 1. Overview of the literature search process.

3.1. Selection of Sources

Given this research's interdisciplinary nature covering digital transformation and environmental sustainability, we relied on multiple databases for maximum article coverage. An online search was conducted in Scopus, ScienceDirect, Web of Science, and JSTOR. Due to the availability of full articles, we mainly relied on Scopus and ScienceDirect to acquire the relevant articles. Scopus can provide sufficient coverage of social sciences and other cross-disciplinary fields [46], and ScienceDirect enables a general search in all fields and advanced search relevant to specific search fields [47].

3.2. Setting Search Criteria

We set specific search criteria to identify relevant articles. The literature search was conducted in two phases. In the first phase, we focused on identifying the current trends in environmental sustainability. Following this, in the second phase, we extended our search to digital technologies that enable transformations. We focused on digital technologies included in the SMACIT framework [48], which refers to social, mobile, analytics (big data), cloud and the Internet of Things, artificial intelligence, and how they enable disruptions in the environmental sustainability domain. These technologies are considered to cause digital transformations in organizations, industries, and society [1].

Using appropriate keywords is essential for identifying high-quality research articles. Keyword selection should be considered as an evolving step and should involve a continuous approach due to the limited lifespan of IT literature keywords [49]. To make our search as exhaustive as possible, we followed specific guidelines and strategies for keyword selection and literature search. Based on the guidelines for keyword selection from Levy and Ellis [49], we used the backward and forward approaches to ensure that we obtained a higher quality of literature search results.

The search started with the keywords that included digital transformation, sustainable digital transformation, environmental sustainability, sustainability, waste management, air pollution control, sustainable manufacturing, circular economy, sustainable cities, and urban sustainability in the first phase. These keywords yielded many results, given their multidisciplinary nature.

We used reference search techniques when we retained the relevant papers from using these keywords [49]. We looked at the papers' bibliography sections, which provided us more understanding of our research domain's literature trends. However, as mentioned before, our focus was only on how digital technologies such as AI, big data, IoT, social media, and cloud transformed the environmental sustainability spectrums. Therefore, we refined our keywords in the second phase.

The search focus was shifted to digital transformation related to technologies. We used keywords such as IoT, big data, cloud computing, social media, analytics, artificial intelligence, IoT and environmental sustainability, big data and environmental sustainability, artificial intelligence and environmental sustainability, IoT in waste management, IoT and sustainability, IoT in pollution control, artificial intelligence in waste management, artificial intelligence and sustainability, analytics in environmental sustainability, big data in waste management, big data in pollution control, big data in sustainability, social media in environmental sustainability, sustainable digital technologies, and so on.

3.3. Selection Criteria

The comprehensive search on the previous literature resulted in the retrieval of numerous articles, but we only focused on what was relevant to our research question based on the criteria defined in the previous section. The selection criteria for our sample were as follows: (a) the article had to be about environmental sustainability and had to include at least one of the aforementioned digital technologies, (b) the article had to have practical uses for reducing the impact on the environment, (c) the article had to be a published research work in an international journal, (d) conference papers were included if they were indexed in the Scopus database. Furthermore, we did not include any book chapters or research notes in our sample. By using these criteria, a total of 151 articles were selected from Scopus and ScienceDirect, which were reduced to 106 articles after further screening and evaluation (Figure 2).

We set specific criteria for the selection of articles for final review. We screened all the downloaded full-length articles in detail and isolated a sample for review. In the initial screening process, a table was developed that included details of the publication (e.g., the title of the paper, name of the author(s), year of publication, and name of the journal) and category (e.g., technology and environmental focus). We summarized each article separately in the table to fully understand its scope, focus, design, and findings for more detailed screening. All the articles were judged against the research relevance to select a final sample.

3.4. Content Analysis and Synthesis

After finalizing a sample of articles, a thorough content analysis was conducted. Just as in the literature search, we followed a systematic way to analyze the articles as well. A detailed table was constructed to categorize each article in terms of publication, scope, area, technology focus, and environmental impact. The selected articles covered the use of different digital technologies in reducing the impact on the environment by supporting different functions and processes in organizations. We analyzed them in detail and arrived at the main deductions arising out of them. We were able to group articles by different themes and developed a framework for a further research agenda. In the following section, we detail the key findings of this paper.

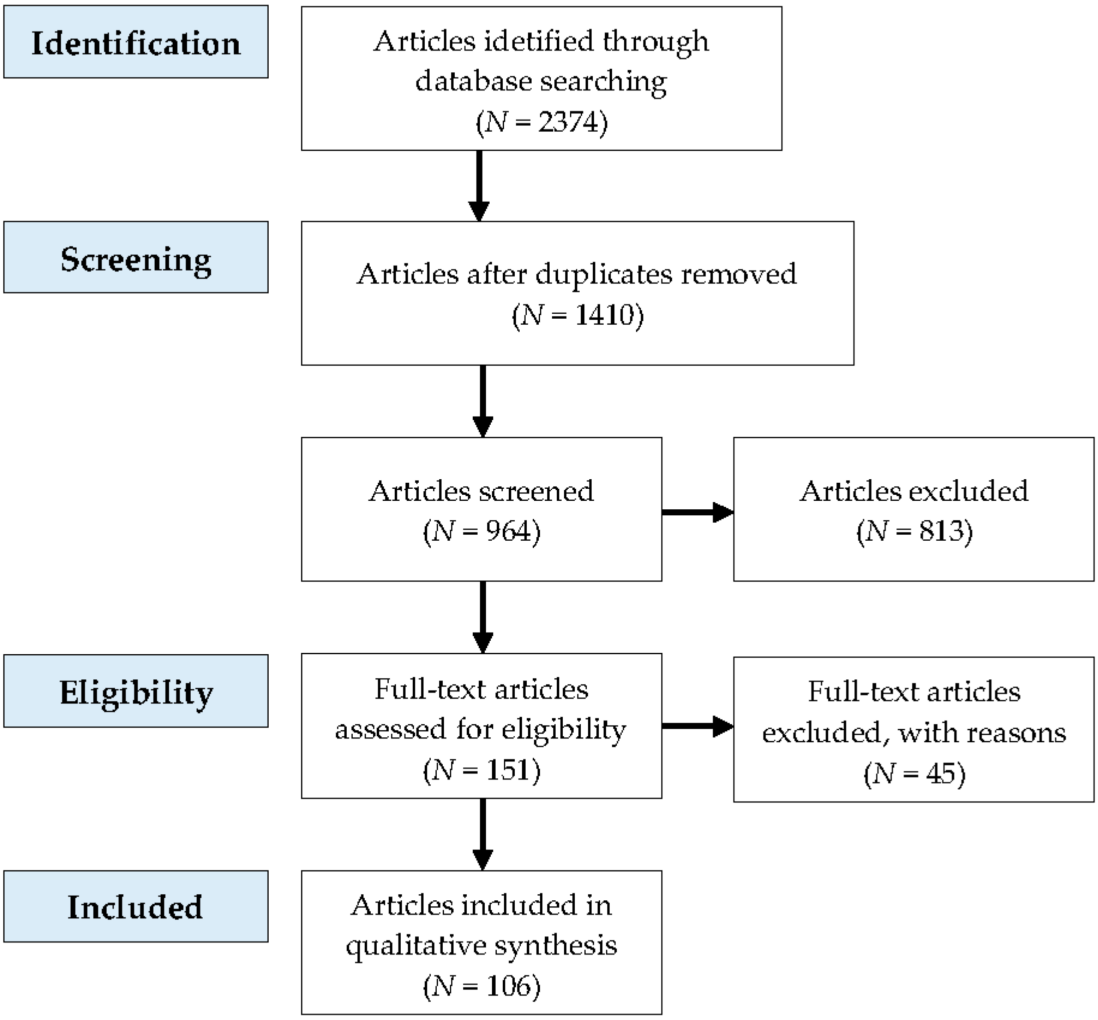

Figure 2. Steps taken for identifying the target articles according to the PRISMA standard [50].

4. Results

A thorough review of the selected articles revealed that digital technologies, including artificial intelligence, big data, IoT, social media analytics, cloud computing, and mobile technologies, cause transformations in the environmental sustainability domains (Tables 1–4). We observed that digital technologies enable transformations in different areas of environmental sustainability, such as pollution control [51–55], waste management [27,56–61], sustainable production [62–68], and urban sustainability [69–74]. All these studies show how digital technologies are transforming the different aspects of environmental sustainability.

Although the selected articles deal with different digital technologies, their core focus pertains to the specific environmental areas, so we themed them together. For example, studies on big data, IoT, AI, social media, and cloud technologies can be found in pollution control, waste management, sustainable production, or urban sustainability. Hence, we put them together into four themes, each of which has sub-categories outlined in the framework. The total number of reviewed articles in each category is outlined in Figure 3. It seems that pollution control is the area that had the highest number of studies regarding digital disruptions, followed by waste management. Studies related to the pollution category covered a wider variety of issues in modern society arising from carbon emission [75–77], climate change [78–80], and natural disasters [81,82]. The wide range of studies available in other environmental disciplines such as waste management [83–85] also contributed as a large chunk to the sample of this study.

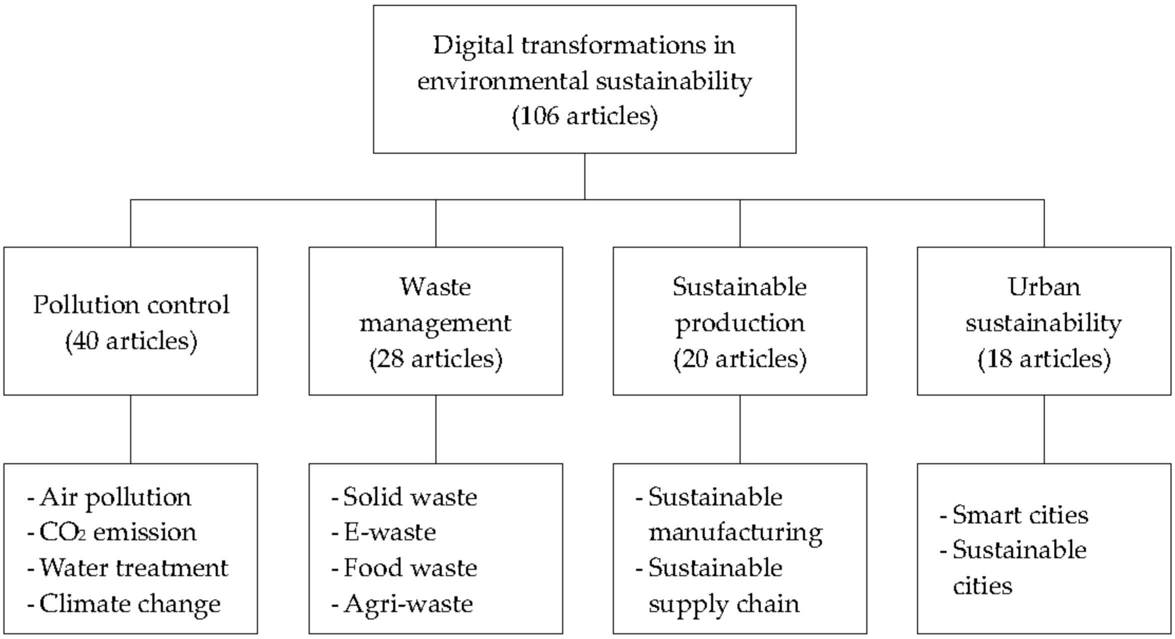

Figure 3. Identified digital transformations in environmental sustainability.

In terms of annual publications, we saw an increasing trend across all four categories over time. The trend is likely to continue as more publications are added to the literature in the upcoming years. The publication totals were 42, 28, and 17 in 2019, 2018, and 2020, respectively (Figure 4). Even though we searched the literature without setting any time limits, we could not retrieve articles before the 2010s to match our criteria, as described in the previous section. With the emergence of new digital technologies over time, more studies may appear in the literature with the search criteria.

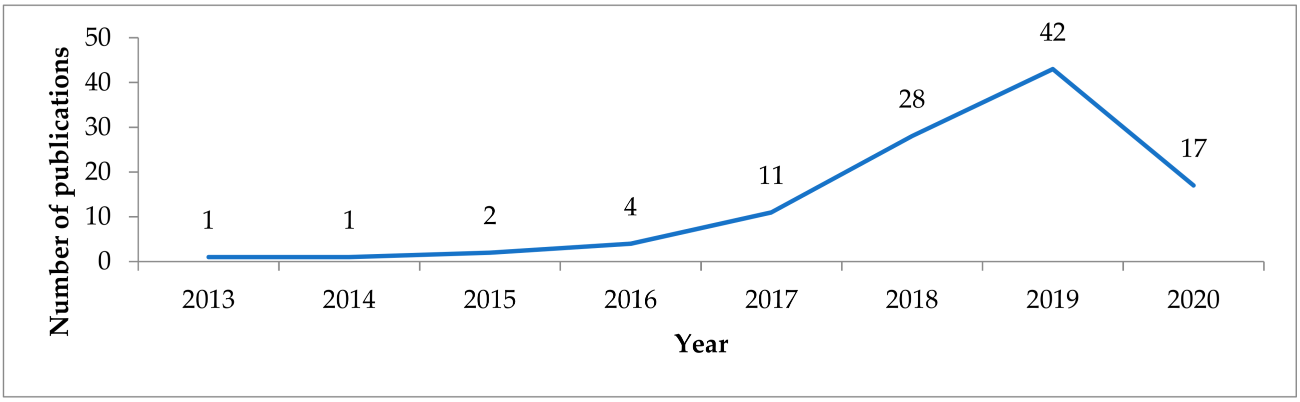

Figure 4. Number of publications by year.

4.1. Pollution Control

Pollution control warrants special attention as the environment and human health are under direct threat from pollutants emitted into surface water due to rapid urbanization [86]. Heavy industries (i.e., iron and steel, nonferrous metals, and metal products), energy industries (i.e., petroleum refineries and coal mining), and chemical industries have been identified as a major source of air and water pollution. Most countries have tried to regulate these pollution-intensive industries to improve their air and water quality for decades [87].

Digital technologies transform the ways pollution is measured, controlled, and managed. The literature shows that digital technologies enable significant disruptions in air pollution, carbon emission, wastewater treatment, disaster management, and climate change (Table 1). For example, the use of artificial intelligence for environmental pollution control proliferates. It is considered to be a very efficient way to tackle the complexities of uncertain, interactive, and dynamic environmental problems [88]. Similarly, big data can be useful in enabling the deployment of large scale next-generation green vehicles and supporting low-carbon transportation that will eventually assist in environmental sustainability by controlling CO_2 emissions [89]. An et al. [51] evaluated the efficiency of decision-making units in a big data environment and set the carbon dioxide emission permits for each decision-making unit with the minimum costs. The use of big data in such instances can highly reduce harm to the environment at a lower risk and cost.

Table 1. Digital transformations in pollution control.

Category	Main Findings	Related Studies
Air pollution	An unprecedented number of opportunities are afforded by digital technologies to study, control, manage, and predict air pollution in cities across the globe. Digital technologies are transforming the relevant processes and mechanisms in this regard.	Chen et al. [91], Honarvar and Sami [53], Idrees and Zheng [94], Kanabkaew et al. [54], Leng et al. [96], Ma et al. [92], Mihăiţă et al. [95], Shang et al. [97], Xie et al. [98], Zhang et al. [93]
CO_2 emission	As governments and business organizations worldwide move to adopt practices to reduce carbon dioxide emissions into the atmosphere, the digitalization of environmentally sustainable practices is gaining traction.	An et al. [51], Chuai and Feng [52], De Gennaro et al. [89], Demartini et al. [38], Hämäläinen and Inkinen [99], Herman et al. [100], Huang et al. [90], Lamba et al. [75], Liu [55], Miranda et al. [76], Singh et al. [77]
Water treatment	The treatment of wastewater through the application of digital technologies opens remarkable channels for efficient energy use and saves resources to minimize the impact on the environment.	Fijani et al. [101], Goralski and Tan [35], Hadipour et al. [102], Huang and Chen [103], Nag et al. [104], Soleymani and Moradi [105], Yu et al. [106], Zhao et al. [107]
Climate change/ Disaster management	Digital technology-driven methods can play a vital role in reducing the carbon footprint on the environment, regulating climate change, and managing natural disasters. Organizations are increasingly capitalizing on these opportunities.	Balogun et al. [36], Bui et al. [78], ElMassah and Mohieldin [41], Kaplan and Haenlein [108], Kashiwao et al. [79], Kavota et al. [81], Kim et al. [82], Roman Pais Seles et al. [80], Weersink et al. [11], Zhang et al. [109]

Furthermore, big data can play a crucial role in understanding the opportunities and challenges associated with climate change by measuring carbon emissions and employing techniques to reduce the footprint on the environment [80]. For example, Huang et al. [90] measured self-driving tour carbon emission flow and spatial relationship with scenic spots based on big data in China. In a similar study, Chuai and Feng [52] also used big data to measure carbon emissions' spatial distribution in China's Nanjing city, aimed at understanding and controlling air pollution. Other similar studies that involve big data were prevalent in the literature [75,91–93].

There were also studies on how IoT technology is being used to measure and control air pollution [94]. IoT sensors provide real-time monitoring information and demonstrate great potential as an effective tool to understand the $PM_{2.5}$ plume movement with temporal variation and geo-specific location, which can lead to better air quality [54]. Social media has been used to measure the impacts of air pollution and disaster management. Social media platforms are perceived to be useful with a relative advantage, are easy to use, and are therefore essential for disaster management [81]. Similarly, we came across studies using mobile technologies for pollution control. For example, Mihăiţă et al. [95] conducted a study focused on investigating real-time mobile air quality measurement through smart sensing units and data-driven modeling techniques that can be deployed to predict air quality accurately from the generated data sets.

4.2. Waste Management

Solid waste is becoming an environmental issue worldwide because of rapid urbanization and population growth [110]. Agriculture and food waste also have significant environmental and societal impacts on the cities and villages globally [111]. Therefore, digitalized systems in waste management are gaining popularity and driving innovations and business opportunities. For example, ZenRobotics's heavy picker uses AI technology to sort construction and demolition waste, industrial waste, metals, wood, hard plastics, and bags by color [27]. As indicated earlier, we divided the literature regarding solid waste, e-waste, food waste, and agri-waste for better understanding (Table 2).

Table 2. Digital transformations in waste management.

Category	Main Findings	Related Studies
Solid waste	The accumulation of municipal and industrial waste is imparting significant damage to the environment. Digital technologies are being used to develop new ways of coping with waste on remarkably large scales that were not imaginable a decade ago. Organizations can rely on sustainability-related opportunities to develop new business models in the age of Industry 4.0.	Adamović et al. [116], Bilal et al. [117], Fernández Núñez et al. [118], Ferrari et al. [56], Genuino et al. [119], Ghobakhloo [120], Jiang et al. [121], Lu et al. [122], Lu et al. [59], Lu et al. [123], Lu [114], Marques et al. [115], Qi et al. [124], Sharma et al. [112], Solano Meza et al. [125], Sujata et al. [85]
E-waste	There are increasing calls for effectively using digital technologies to manage the waste generated by electronic devices.	Garrido-Hidalgo et al. [126], Gu et al. [127], Kang et al. [128], Nowakowski et al. [113]
Food waste	Industrial and household food waste can be successfully disposed of using digital technologies such as IoT and big data.	Hong et al. [129], Logan et al. [84], Närvänen et al. [60], Wen et al. [130]
Agri-waste	Digital technologies are being employed to deal with the waste generated in agricultural processes for high-quality production.	Belaud et al. [83], Partel et al. [131]

Digital technologies are widely used in the environmental sustainability domain. AI has been used in global warming, waste management, wildlife care, geographic information systems, environmental risk assessment, energy concerns, land-use planning, and geoscience [112]. Similarly, in electronic waste or e-waste, AI techniques are used for collecting e-waste on demand from users [113]. Big data is also gaining popularity in waste management and recycling. Lu [114] used big data to identify illegal waste dumping cases from 2011 to 2017 in Hong Kong. The author used big data in the form of two million waste disposal records generated from around 5700 projects undertaken in Hong Kong during 2011 and 2012. In a similar study, Lu et al. [59] applied big data to compare and analyze public and private entities' construction waste management performance.

Other digital technologies such as IoT, cloud computing, and social media are also transforming the waste management arena [56,60,115]. For example, an IoT-based system was designed and used to treat food waste generated from the Asian Institute of Technology (AIT) campus community, and a significant amount of food waste reduction was observed [84]. Sujata et al. [85] conducted a study in which, using the theory of planned behavior, the authors established social media's role in stimulating recycling behavior.

4.3. Sustainable Production

A production system that relies on cleaner and sustainable mechanisms can reduce operating costs, improve profitability and worker safety, and reduce the environmental impact of the business [132,133]. Smart and sustainable manufacturing is increasingly gaining attention in the literature and deals with green, energy-saving, sustainable production, and renewable energy consumption [134]. Sustainable production can allow manufacturers to reduce resource use, degradation, and pollution while achieving development goals [135].

Sustainable smart manufacturing has been advanced by digital technologies such as IoT, cyber-physical systems, cloud computing, AI, big data analytics, and digital twin [136].

In the literature, we found that digital technologies such as AI, big data, and IoT are sustainably transforming the manufacturing sector in terms of green manufacturing [137], zero-waste manufacturing [138], efficient manufacturing [139] as well as sustainable supply chain. For example, Kaur and Singh [62] conducted a study and proposed an environmentally sustainable procurement and logistics model for a supply chain driven by big data for reducing carbon emissions. Zhang et al. [133] proposed a cleaner production method enhanced by systematic integration of product life cycle management and big data analytics to overcome issues in cleaner production mechanisms. Sustainable practices aid sustainable production in the supply chain, clean manufacturing, source reduction, and opting for green operations in any given industry's whole value creation process (Table 3).

Table 3. Digital transformations in sustainable production.

Category	Main Findings	Related Studies
Sustainable manufacturing	Digital technology-driven clean manufacturing processes without harm to the environment are being sought after the circular economy concept has emerged. Such processes can reduce not only the cost but also the negative impact on the ecosystem.	Kerdlap et al. [138], Kumar et al. [63], Liu et al. [136], Mao et al. [137], Mehmood et al. [140], Raut et al. [66], Ren et al. [134], Tao et al. [141], Wang et al. [142], Xiang et al. [143], Zhang et al. [144]
Sustainable supply chain	Digital technologies enable companies to eliminate waste across entire value chains to the fullest extent, enhance sustainable consumption, and eliminate harmful waste residue to the environment.	Bag et al. [145], Bressanelli et al. [146], Kaur and Singh [62], Liu et al. [136], Manavalan and Jayakrishna [64], Papadopoulos et al. [65], Wang et al. [142], Xu et al. [147], Zhang et al. [133]

4.4. Urban Sustainability

The fourth dimension of our framework, where digital technologies are transforming the environmental sustainability domain, is urban sustainability. Urban sustainability has been defined in various ways, but recent studies focus on the relationship between ecosystems and human well-being [148]. It also indicates a city life without excessive use of natural resources and abundant waste production. From the digital transformation perspective, we divided the available literature into smart cities and sustainable cities. Smart cities focus on improving citizens' lives, sustainability, and working efficiency with the latest digital technologies such as IoT [73]. Sustainable cities utilize digital technologies to control available resources in sustainable ways to improve social well-being [149].

Table 4. Digital transformations in urban sustainability.

Category	Main Findings	Related Studies
Smart cities	The technological developments of the modern world drive the transition of urban centers into smart cities by enhancing citizens' well-being, improving sustainability, expanding the scope of efficient energy use, and providing a conducive environment for healthy practices.	Al-Turjman and Malekloo [155], Allam and Dhunny [69], Chatterjee et al. [156], Esmaeilian et al. [157], Gohar et al. [71], Ju et al. [158], Khan [72], Lim et al. [159], Malik et al. [73], Osman [152], Pimpinella et al. [74], Sun and Zhang [151], Wu et al. [150]
Sustainable cities	Aided by digital technologies, smart cities further evolve into sustainable cities when they adopt zero-waste generation mechanisms, use of clean energy, and sustainable consumption practices.	Bibri [70], Honarvar and Sami [53], Kim [153], Martin et al. [160], Sodhro et al. [154]

Sustainable urban development has been facing severe environmental pollution, resource shortage, and traffic jams. A smart city is considered an effective approach to deal with such challenges [150]. Thus, many cities are increasingly adopting specialized digital technologies such as big data and IoT to address issues related to the environment and society [69]. Digital technologies such as IoT infrastructure, cloud computing, big data, mobile Internet, and artificial intelligence are at the core of smart cities to enhance the environment, resources, and connectivity [151]. These technologies provide unprecedented opportunities to combine sustainability principles in the context of smart cities and orchestrate strategies for fostering sustainable cities that aim to provide citizens with better services while reducing the footprint on the environment. For example, Osman [152] developed a new big data analytics framework for smart cities called the "Smart City Data Analytics Panel (SCDAP)" aimed at harnessing big data analytics applications for smart cities.

Air pollution control and green transportations are the dominant features of a smart and sustainable city. The real-time air pollution data play a vital role in urban sustainability [53]. Kim [153] proposed an alternative methodology based on big data for correlating reported and experienced fine dust levels to help prevent air pollution in the context of a smart city in Korea. Similarly, Honarvar and Sami [53] used big data to predict and monitor air pollution in a smart city context, which costs considerably lower than other expensive mechanisms. Gohar et al. [71] proposed the architecture for an ITS (intelligent transportation system) based on big data analytics in the context of a smart city. Other studies on how the use of IoT [70,72,154] and AI [69] transforms smart and sustainable cities are also available in the literature (Table 4).

5. Discussion

This study highlighted the domains within the environmental sustainability spectrum wherein digital technologies impact the ways and mechanisms by which waste, pollution, production, and urbanism are managed and controlled. This research discovered that digital technologies offer organizations unique opportunities to develop new business models that focus on the environment [35] or adopt digital technologies to incorporate environmentally sustainable practices into the current business models [38]. In either case, digital transformation improves environmental sustainability.

This study emphasized that the opportunities afforded by digital technologies for reducing the footprint on the environment are unique and would not have been possible a decade ago. For example, the application of big data in analyzing millions of garbage disposal records [59] is an unprecedented development that has a positive signal in the environmental sustainability arena. Such developments hold a huge potential for change for governments, companies, NGOs in business creation, policy implementation, and improving social life. They can equally benefit from digital transformations in environmental sustainability.

The digital transformation in this sector can create a common platform to combat the degradation of the environment through sustainability practices. For business organizations, the current trends in the digitalization of sustainability have opened many possibilities for realizing new business models and upgrading the current ones. It means that traditional businesses will compete on new frontiers and seek ways to build a competitive edge over their rivals. However, there is a need to understand further how the digital transformation trends of environmental sustainability can gain a competitive advantage. This study uncovered that literature had addressed the landscapes of digitalization regarding environmental sustainability, but there are no studies on understanding the capabilities required for sustainably transforming businesses and incorporating digital technologies.

Two important things should be noted here. First, some organizations want to embed principles into their business operations to reduce harm to the environment. For example, Nike adopted different approaches for minimizing the impact on the environment. On the other hand, there are businesses whose models are entirely focused on environmental sustainability. For example, Zenrobotics' entire business model is based on environmental sustainability and provides AI-based solutions to waste management [27]. The capabilities required for environmentally sustainable digital transformation for the former one will be completely different from the latter one. Hence, we suggest the following research agenda for future research in this area.

5.1. Research Agendum 1: Capabilities for Environmentally Sustainable Digital Transformation

In the environmental sustainability domain, some companies are already digitally savvy when they enter and would not need to bring fundamental changes to their business models. They already have the business model but would need to focus on the organizational aspects. With the help of the latest technologies, e.g., IoT, AI, big data, social media, cloud, and blockchain, they can further create more innovation opportunities regarding environmental sustainability. However, it is important to note that these technologies are not useful to independently reach sustainability objectives without the organizational capabilities to utilize them.

Capabilities should be dynamic and enable organizations to bring necessary changes through continuous assessment of external and internal environments. For example, dynamic capabilities describe the ability of an organization "to sense and shape opportunities and threats, to seize opportunities, and to maintain competitiveness through enhancing, combining, protecting, and, when necessary, reconfiguring the business enterprise's intangible and tangible assets" [161]. Since the capabilities needed for digital transformation have not received enough attention in the literature [162], future studies need to focus on digital transformation from the dynamic capabilities' perspective.

The literature gap also extends to incorporating environmental sustainability in the decision-making process at the strategic level. More studies are needed to make sense of digital transformation and how it relates to sustainability. To develop capabilities, we need to fully understand the phenomena thoroughly since scholars have not yet agreed on a single definition for digital transformation. Researchers need to define a clear distinction of how digital transformation differs from environmentally sustainable digital transformation. Then, attention should be given to the actual capabilities needed for the transformation in the latter case. Incorporating environmental sustainability principles in the digital transformation and strategic process is novel and requires more studies to understand the phenomenon adequately. In this regard, we suggest potential research questions for future studies as follows:

- How do we interpret the incorporation of environmental sustainability in digital transformation?
- What capabilities are needed for a digital transformation of organizations that want to incorporate environmental sustainability into their business models?
- What capabilities are needed for organizations that want to shift their entire business model to the environmental sustainability spectrum?
- How are the capabilities different for organizations whose business model is entirely based on environmental sustainability versus organizations that only want environmental sustainability as a corporate social responsibility principle without changing the business model?

5.2. Research Agendum 2: Organizational Performance and Digitalization of Environmental Sustainability Practices

In this research, we observed that digital technologies (IoT, AI, big data, social media, analytics, cloud, and mobile technologies) are pushing environmental sustainability practices toward digitalization in one way or another (Tables 1–4). So, the digital transformation of the sector seems to be inevitable, and that has implications for businesses, markets, and industries. New horizons are being unfolded for possibly creating new business models or streamlining the current ones. In the midst of all this, the issue of organizational performance comes into play. Business organizations that aim to incorporate environmental sustainability principles into their business models would want to understand whether such initiatives could lead to a better performance regardless of their social responsibility standings.

Creating value for customers and capturing that value would be significant for organizations when considering changes in the current business model to fit the environmental sustainability criteria. While the literature has shown that customer loyalty can be gained by incorporating sustainability and caring for the environment [30], the question of the firm's overall performance through the digitalization of environmental sustainability remains unanswered. Companies choose to digitally transform because they expect it to be beneficial in the digitalized world. The incorporation of sustainability practices should offer the same prospects to them. Otherwise, decision-makers will not accept it as a significant component in the process of digital transformation.

The second question is the impact of capabilities in this regard. Newly identified capabilities should help organizations renew business models through a sustained process that considers environmental sustainability principles. Hence, the development of specific capabilities for digital transformation that is environmentally sustainable and how it impacts the overall performance in terms of customer loyalty, financial reward, or increasing brand value need to be explored in further studies. In this regard, we propose the following questions for future research.

- What is the impact of the identified capabilities for environmentally sustainable digital transformation in enhancing organizations' performance?
- What specific resources are needed to enable the digitalization of environmental sustainability practices?
- Does the digitalization of environmental sustainability practices enable firms to develop a competitive advantage in the market?

5.3. Research Agendum 3: Digital Transformation Strategy and Environmental Sustainability

In this research, we discovered that digital transformation is a hot topic for discussion among top-level management, but there is no mention of how environmental sustainability practices can become a part of the strategic decision-making process. Following the emergence of new technologies, the digital transformation strategy calls for transforming products, processes, and organizational aspects [163]. The continued emergence of new technologies shapes how organizations carry out operations, create new business opportunities, and embark on industry-wide collaboration. The strategic responses from organizations to the disruption caused by digital technologies are reshaping business leaders' agenda.

In the past, technologies were viewed as auxiliary support systems for the organization's core functions, but these days new technologies are shifting this paradigm. Digital technologies are bringing radical transformation in the ways value is created and captured. This fact dictates a comprehensive understanding of the whole alignment of organizational strategy and digitalization. The top management should not see digital technologies as agents of improvement but as agents of transformation perpetually manifesting shock waves throughout the organization. In this sense, there is a need to incorporate environmental sustainability into the digital transformation strategy. The redefinition of business models owing to new digital technologies should be considered as a continuous process that encompasses all aspects of core business operations, including environmental sustainability. There has to be a focus on aligning sustainability practices into the core strategic renewal process as warranted by digital transformation. To find such an alignment, we propose the following research questions.

- How can we incorporate environmental sustainability into the digital business strategy?
- Which digital business strategies are needed for organizations that want to embark on environmentally sustainable digital transformation?
- What are the driving forces that are pushing organizations to carry out digital transformation sustainably?

6. Conclusions

6.1. Contributions to Theory

Digital technologies are transforming how environmental sustainability-related issues are measured and controlled. However, there is a lack of understanding in the academic literature on how organizations should adapt to these disruptions and the capabilities needed to ensure that environmental sustainability is incorporated in digital transformation. Hence, this study addresses the need for more comprehensive studies to understand digital transformation impacts in the environmental sustainability domain. Specifically, one of the objectives of this study is to focus on protecting the environment against pollution and the degradation of resources, which remains a top challenge [31].

We aim to contribute to the existing theory by developing a framework that shows how and where such digital transformations are taking place in environmental sustainability. Using the framework, we saw that major digital transformation disruptions occur in waste management, pollution control, sustainable production, and urban sustainability. As shown earlier, future academic research can investigate the questions that our study raised for capabilities, organizational performance, and digitalization and digital transformation study and extend our understanding of environmental sustainability. Our review will also help researchers in the environmental sustainability domain connect and work together on mutual interest issues.

6.2. Contributions to Practice

Findings from our study will help decision-makers in public and private enterprises identify and prioritize areas for investment. Our findings can help firms develop and evolve their environmental sustainability strategy, creating a "win-win" situation for all stakeholders. For example, we discovered that digital technologies offer organizations unique opportunities to develop new business models that focus on the environment [35] or adopt digital technologies to incorporate environmentally sustainable practices into the current business models [38]. These cases can be a starting point for board room discussions regarding their strategic plans and related execution. Managers can initially focus on incremental changes such as the digitalization of sub-processes and processes, creating a better business model.

6.3. Limitations and Future Research Directions

Our study identified many questions for further research requiring input from the industry. Some of these research questions may remain unanswered if firms fail to cooperate. We focused on digital transformation in the environmental sustainability domain only. This effort may have limited the scope and contributions of our study. Future studies could focus on the review and impact of digital transformation in other related sustainability fields such as economic and social domains and identify a common research agenda.

To conclude, we believe findings from our study should serve as a starting point for further research in the area of environmental sustainability. Future studies in this domain can focus on identifying digital transformation capabilities, the impact of digitalization on organizational performance, and transformation strategy adding value and enriching this field.

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