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The Impact of 4IR Digital Technologies and Circular Thinking on the United Nations Sustainable Development Goals

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Abstract: As we stand at the cusp of the fourth industrial revolution, digital technologies such as artificial intelligence, machine learning, the Internet of Things, Big Data, Blockchain, Robotics, 3D technologies, and many more have become the means and solutions to many of the world's problems. Most recently, these technologies have assisted in the global fight of the COVID-19 pandemic and other societal problems. Together with these innovative techniques, the concept of circular economy and its relevant tools such as life cycle costing, life cycle impact assessment, materials passports, and circularity measurements have been implemented in a number of sectors in different countries for the transition from a linear "take, make, and dispose" model towards a more circular model, which has shown positive results for the environment and economy. In this article, with the help of implementation, prototyping, and case studies, we explore how these technological advancements and innovative techniques are used in different sectors such as information and communications technology, the built environment, mining and manufacturing, education, healthcare, the public sectors, and others to provide an opportunity to understand and resolve the agreed upon framework in 2015 by 193 countries, that is, the 17 United Nations Sustainable Development Goals.

Keywords: digital technologies; Industry 4.0; circular economy; circular economy tools; new paradigms for the future

1. Introduction

The United Nations General Assembly (UN) in September 2015 adopted the 2030-Agenda for Sustainable Development that contains 17 Sustainable Development Goals (SDGs). Building on the principle of "leaving no one behind", the new agenda promotes a holistic approach to achieving sustainable growth for everyone. The SDGs are a blueprint for a better and more sustainable future for all and addresses the global challenges we face. The 17 Goals are all linked, and in order to leave no one behind, it is vital that they are achieved by 2030. They can be characterized into three systems, i.e., environmental, economic, and social. The SDGs advocate for action by all nations disadvantaged, wealthy and middle-income, to foster sustainability while protecting the earth. To better understand the 17 goals, we list and explain them in Figure 1 and Table 1 [1,2].

Figure 1. The list of 17 Sustainable Development Goals (SDGs) that are a common vision for society and a social contract between world leaders and citizens.

Table 1. The list of 17 SDGs explained.

Goal	Description
#1 No Poverty	Around 1 billion people still live in poverty, defined as earnings of less than US$ 1.25 a day. Objective 1 aims at a society where the poor are not vulnerable to climate change and have “fair access to economic capital.” (Economic)
#2 Zero Hunger	The end of hunger also involves ending starvation, protecting small farmers, and reforming agriculture itself so that agriculture and ecosystems can coexist. It also means protecting the genetic diversity of the crops we grow, while investing in research to make agriculture more competitive, especially in developing countries. In 2030, the goal is to ensure that no one is ever hungry. (Economic)
#3 Good Health and Well-being	This goal requires an ambitious plan to tackle a wide range of global health issues, from tuberculosis and AIDS to road accidents and alcoholism. This goal also calls for “universal health coverage” to be achieved; to minimize pollution-related illnesses and deaths; and to increase the global health workforce, especially in the developing countries. (Economic)
#4 Quality Education	The need to have access to university-level education, vocational training and entrepreneurship skills, and to pay particular attention to equity issues. This goal also includes the promotion of sustainable development education. (Social)
#5 Gender Equality	Equity and equality shall include protection from oppression and abuse. It also involves ensuring that women have an equal share of leadership positions and obligations, as well as land ownership and other tangible expressions of power in society. Note that the goals for this objective include a number of references to the need to be “acceptable” at a national level when explaining what they say. (Social)
#6 Clean Water and Sanitation	Extreme water shortage affects 40% of the world’s population, and nearly a billion people do not have access to the most basic technology: toilets or latrines. The goals for this objective include specifics of what we need to do to address this situation, including protecting the ecosystems that provide water. (Economic)
#7 Affordable and Clean Energy	About 1.3 billion people worldwide live without access to electricity. Modern energy is also related to access to water (Goal 6): you need energy to get water. In the wealthier countries that have energy, this goal encourages conversion to renewable sources, and calls for dramatic improvements in efficiency everywhere. (Economic)
#8 Decent Work and Economic Growth	At least 75 million young people around the world, aged 15–24, are unemployed, out of school, and looking to a grim future. This goal, while calling for economic growth to help close this gap, also calls for creativity and “decoupling” development from the destruction of habitats. (Economic)
#9 Industry, Innovation and Infrastructure	The planet is becoming more industrialized, but still not in ways that are durable and sustainable. The aim is to ensure that everyone can reap the benefits of what humanity can build and to promote a far more sustainable and environmentally friendly approach to industrial development. (Economic)
#10 Reduced Inequalities	The planet is astoundingly unequal: the richest 80 individuals have the same wealth as the bottom 3.5 billion. The goal requires a number of steps, including the regulation of financial markets, to raise the level of competition. Importantly, it also covers the topic of migration, which should be “natural, secure, routine and responsible”. (Social)
#11 Sustainable Cities and Communities	More than half of the population is living in cities, and by 2050 at least 66% will be living in towns—and much of the expansion of towns is taking place in Africa and Asia. Unless these cities are not sustainable, the planet would not be sustainable either. This target also includes topics such as travel, disaster preparedness, and even the protection of “the world’s cultural and natural heritage”. (Environment)
#12 Responsible Consumption and Production	The nations of the world (through the UN) have already decided on a “10-year plan” to make the way we manufacture and consume products more sustainable. This target applies to, but also includes, issues such as eliminating food waste, corporate sustainable strategies, public procurement, and making people aware of how their lifestyle decisions make a difference. (Environment)

Table 1. *Cont.*

Goal	Description
#13 Climate Action	In December 2015, the specifics of the global agreement on climate change were decided by another global negotiation mechanism (UNFCCC). The meeting created the Paris Agreement, which directs nations in their collective action to limit global warming to no more than 2 degrees C. (Preferably 1.5). (Environment)
#14 Life below Water	Global waters and life within them are over-fished, under-protected, and under-stressed by climate change and pollution. This goal outlines what we need to do to save them including study and learning, as we think very little of what lies under the surface of the water. The SDGs have brought new attention to the state of our oceans. (Environment)
#15 Life on Land	Life on our wonderful planet Earth is under tremendous stress. An ambitious target encompasses almost every aspect of the threat to living environments and biodiversity. We cannot afford to lose any more nature. (Environment)
#16 Peace, Justice and Strong Institutions	End violence and torture. Decrease weapons development and flow. Reduce corruption. Build policies and organizations that operate for everyone. This significant goal also requires a target that explicitly calls for policies to promote sustainable development, which will undoubtedly require the introduction of the SDGs themselves. (Social)
#17 Partnerships for the Goals	Ensuring that all countries have what they need i.e., funds, capabilities, technology, etc. to achieve the rest of the SDGs. The goals are a detailed list of these needs, including the need for collaborations. Every country and every sector have a part to play. (Social)

The SDGs are a powerful aspiration to improve our world, they lay out a path to where we collectively need to go, but how do we achieve them? To date, governments, corporations, civil societies, and the general population have taken their own steps to create a sustainable life for everyone. The G-20 countries and governments are among the top 20 countries globally that have taken steps and are leading the way towards achieving the goals. Companies and organizations such as Huawei, Nike, Hilton hotel group, and Lego, which are some of the world's leading brands, have all chosen to lead the way in suitability as well. In this paper, we concentrate on two newer trends that could possibly be used to achieve these goals.

1.1. 4IR-Digital Technologies

Since the beginning of the industrial revolution, we have seen a rise in technological advances. Factories were first powered by water and steam engines in the 19th century, production increased in the 20th century with the introduction of electricity, and finally, we witnessed automation in the 1970s. Today, we stand at the cusp of a new digital industrial technology known as Industry 4.0 (4IR). In this fourth technological wave in industry, cyber physical systems can interact with one another using artificial intelligence (AI), machine learning (ML), Big Data, and the Internet of Things (IoT), etc. Industry 4.0 will increase productivity and growth [3]. This timeline of each industrial revolution is depicted in Figure 2.

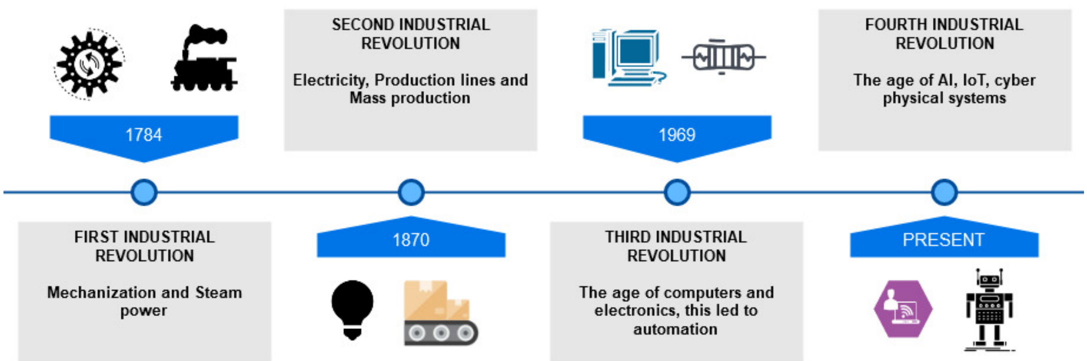

Figure 2. The industrial revolution timeline.

In the 1980's, Japan proposed the intelligent manufacturing system (IMS), thereafter the United States proposed the cyber physical system (CPS). Most recently, Germany proposed Industry 4.0, and China proposed China Manufacturing 2025 [4].

Technologies such as AI benefit from a number of technological advancements, which in turn opens a wealth of opportunities. The history of AI is filled with fantasies, possibilities, and promise. Imagination has been part of our DNA. Medical professionals—with cures and preventions in healthcare, agriculture—in monitoring systems, developing of smart cities, predictions in the finance sectors, transportation, and social interaction, to name a few, are sectors embracing the revolution [5]. A chart of the top 10 4IR digital technologies today is shown in Figure 3. Dileep George, artificial intelligence and neuroscience researcher has said [6]: "Imagine a robot capable of treating Ebola patients or cleaning up nuclear waste." Technologies used in solving real world problems are how we develop measures of success [7].

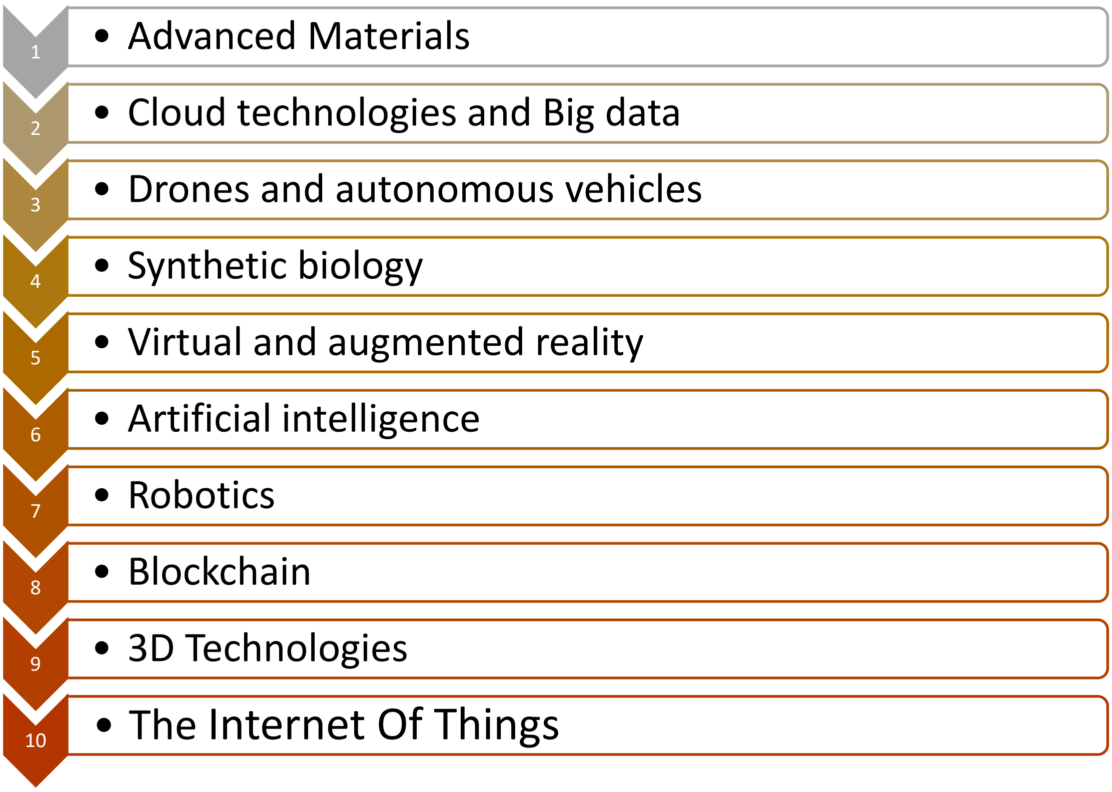

Figure 3. The top 10 4IR digital technologies today [8].

These days, this topic is always in the headlines for the wrong reasons, often depicted in dystopian terms as the technologies that will take away our work or even our lives. Yet, what if it could also become a powerful resource in the global campaign to meet the UN SDGs? These technologies are already being used in different areas to achieve other goals.

1.2. Circular Economy

The second solution discussed in this paper is the transition from a linear to a circular economy (CE). In recent years, the circular economy has gained growing popularity as a resource that provides solutions to some of the world's most challenging sustainable development problems. It achieved attention in the late 1970s, with much literature showing a link between sustainability and circular economy. Figure 4, which is adapted from the Ellen MacArthur foundation butterfly diagram, captures the essence of the circular economy using 4IR digital technologies. The foundation promotes and accelerates the idea of CE across different sectors and partnerships. An economy that is restorative and regenerative by design. It is based on three principles, accompanied by their symbol/icons used by the Allen McArthur foundation:

- Design out waste and pollution
- Keep products and materials in use
- Regenerate natural systems

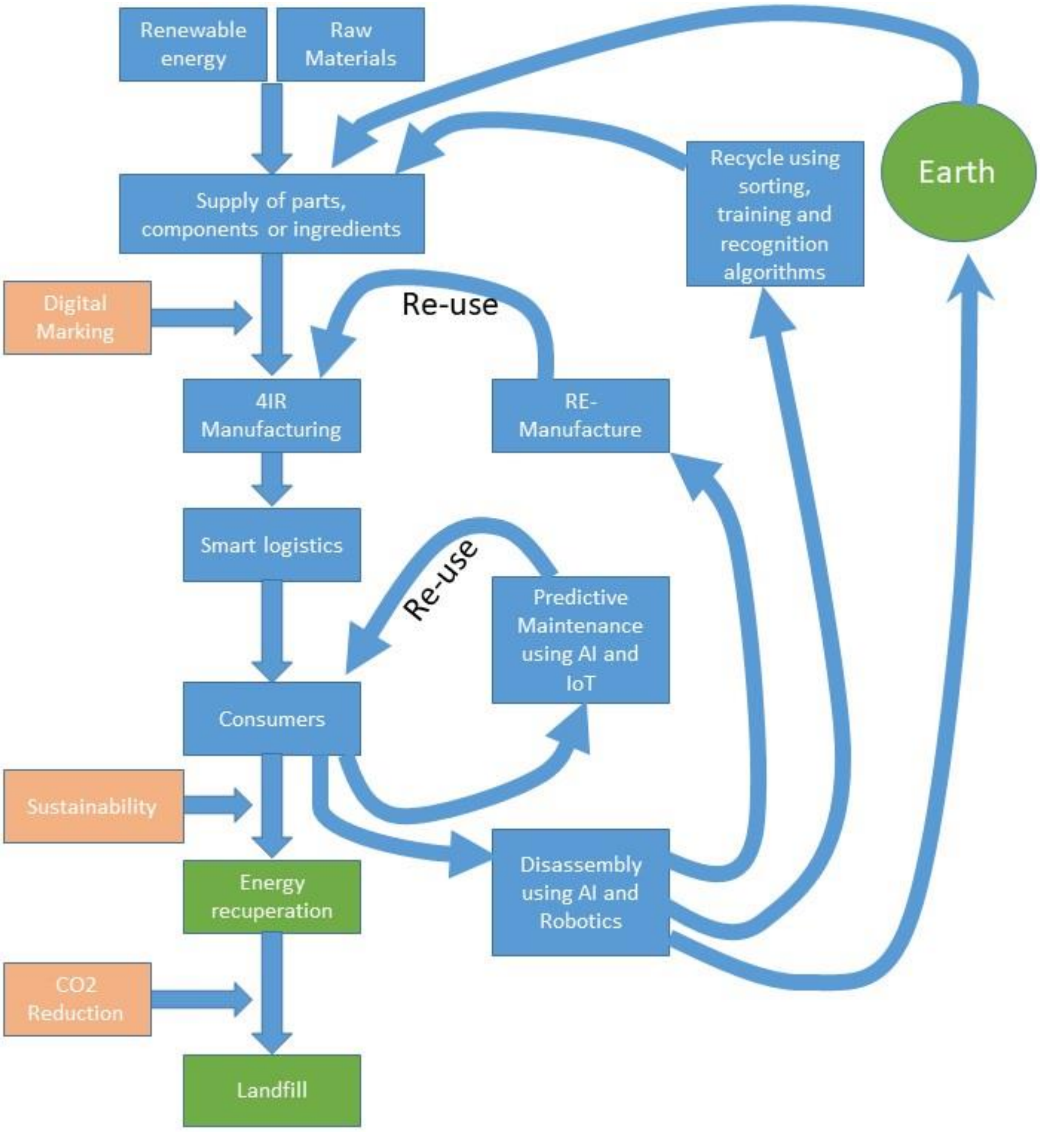

Figure 4. Adapted from the Ellen MacArthur foundation butterfly diagram, which captures the essence of a circular economy using 4IR digital technologies; it attempts to capture the flow of materials, components, and products, while adding an element of financial value and sustainability. This draws on many lines of thought, but is perhaps most recognizably inspired by the two material periods of cradle to cradle (cradle to cradle can be characterized as the design and processing of goods of all kinds in such a way that, at the end of their existence, they can be genuinely recycled, imitating the cycle of nature with anything either recycled or returned to earth, directly or indirectly via food, as a fully healthy, nontoxic, and biodegradable resource [9]).

Circular thinking has both environmental and economic benefits. Environmentally—it reduces greenhouse gasses, creates vital eco-systems, nature conservation. Economically—resources are saved, economic growth, increase in employment, increases in demand.

There are tools that can be used for the transition from a linear to a circular economy [10–13]. These tools are shown and explained in Table 2 below:

Table 2. Tools that can be used in the transition from a linear to a circular economy.

Tools	Description
Materials passports	Materials passports is a value tracking tool that can be used to bring back residual value to the market. Materials Passports makes information readily available at each stage i.e., from production, to purchase, to use and to maintenance. Passports contain a set of information about a particular material, product, or system. The information required is the properties of the material or product, such as physical or chemical, safety data sheets (MSDS, TDS), bill of materials (BOM), logistics, disassembly, and finally, recyclability. The process of generating one involves different companies and stakeholders. Some of the most common materials passports databases are: Madaster and Buildings as Material Banks (BAMB) [14].
Life cycle costing (LCC)	Derived from The International Organization for Standardization (ISO) 15686. LCC is an economic strategy that is the calculation of the overall cost of a commodity or resource, process or operation, discounted over its lifespan. LCC is used in various fields and for a variety of reasons to aid in decision-making. It can be defined by three types; conventional, environmental, and societal [15].
Life cycle assessment (LCA)	Derived from ISO 14040. LCA evaluates the cumulative environmental effect of the production process, use, disposal, and activities related to the construction and operation of a building or a commodity or material. However, economic or cultural considerations are not taken into account [15].
Life Cycle Impact Assessment (LCIA)	LCIA is a stage of analysis of the LCA during which the environmental effects of the product are calculated and evaluated. Effect evaluation consists of a variety of steps, including classification, definition, and weighting, among others. There is a range of LCIA methods available for the LCA analysis. Some provide for environmental evaluations, while others concentrate on environmental issues [15].
Circularity indices (CI)	Indices are intended to provide a value that shows how circular the system is. Some of the tools that can be used to carry out this are listed and explained below: *Material circularity indicator (MCI)* is a decision-making tool to determine how well a business or product performs in the transition from a linear to a circular economy. The product or materials MCI gives a value between 0 and 1 (or 0–100% of recirculated parts), a value that is higher than 1 implies higher circularity. The calculation for this indicator is quite complex, therefore, there are online digital calculators, such as circular economy toolkit (CET), circularity calculator, Ellen MacArthur's material circular indicator (MCI) tool, Flex 4.0 by Delft University, RELi 2.0 by USGBC to name a few [14]. *Circularity Index* is based on the circulation of materials but incorporates the energy ratio that is required. Other tools for CI include: *Circular Economy Indicator Prototype (CEIP) and Circular economic value (CEV)* [16].
Sustainability and reductions in carbon footprints	Carbon emissions and their effect on climate change are one of the key obstacles to achieving environmental sustainability. Carbon footprint, as a measure of environmental sustainability, has frequently been studied in order to quantify the environmental performance of a product or material, person, organization, city or country, using the Environmental LCA. Therefore, with the use of renewable and sustainable applications such as the ones discussed in this paper, we can reduce the impact on the environment which in turn has a positive impact on humanity.

In a report prepared for Microsoft Corporation (Microsoft) by PricewaterhouseCoopers LLP (PwC), it is said that by the year 2030, environmental applications using these kind of innovations and technologies discussed in this paper, could contribute up to approximately $5.2 tn to the global economy, a reduction in greenhouse gas emissions of about 2.4 Gt CO2e, and could also contribute to 38.2 million in job creation [17].

The paradigm of the circular economy is an alternative to the conventional, linear "take, make, and dispose" concept. "Designing out waste and emissions", "keeping goods and materials in operation", and "regenerating natural systems" are all CE concepts. CE has the potential to aid towards the achievement of the SDGs across all sectors [18].

2. Digital Technologies and Circular Economy Solutions towards Achieving the UN-SDGs

"2030Vision" is a collaboration that brings together businesses, NGOs, and governments with the technologies and resources required to achieve the SDGs. In December 2017, Sustainability wrote the first report of 2030Vision, which addressed the role of emerging technologies and innovations towards achieving the SDGs. However, in a recent publication by Mohammad Dastbaz, he questions whether the 2030Vision is a fake challenge or a time for action [19].

With 10 years remaining to achieve the goals outlined in the SDGs, we need to improve and speed up our efforts. We must tackle issues such as work transfer and social coercion, design and build technology securely and inclusively, and ensure equal access to its benefits. In this section, we look at the current trends, research in practice and impact in achieving the objectives using 4IR digital technologies and circular thinking [20].

In order to carry out the review on technological advancements together with circular applications to achieve the SDGs, we looked at numerous top quality and high impact publications. Together with this, we looked at actual prototyping, applications, and case studies that were conducted using the topics in this paper to achieve the goals. We classified our research and its impacts in three different sections: (Section 2.1) Digital technology solutions and (Section 2.2) Circular economy solutions. We further went on to look at how these two topics can work together in achieving the goals in (Section 2.3).

2.1. Digital Technology Solutions

According to a report by Global Market Insights, AI market size is anticipated to grow at a compound annual growth rate (CAGR) of more than 40% from the years 2019 to 2025 [21]. In another stat, Accenture and Frontier Economics estimate that by the year 2035, AI could increase labor and productivity by up to 40%, with an additional 3.8 trillion dollars' increase in gross value added (GVA) [22].

To date, the capabilities of these technologies are being used in a number of ways to achieve societal goals. One of the most recent examples is the fight against the COVID-19 pandemic. AI and machine learning are being used to save lives with their screening, tracking, and prediction algorithms. They are assisting in developing vaccines. IoT sensing devices are being used to monitor patients using wireless networks that are affected by the virus [23]. The McKinsey global institute, which was established in 1990 to develop a deeper understanding of the evolving global economy, has an evolving library of 4IR digital technology case studies, their benefits, and potential towards the UN-SDGs [24]. The possibilities and applications are endless in literature. We look at a few examples and their impacts in Table 3.

ICT Solution

The rapid development of the information and communication technology (ICT) sector and the growth of global inter-connectivity will play an increasingly important role in fostering economic and social change in many parts of the world, this in turn has a positive impact on the SDGs and the GDP. With the increase in social media platforms, more online visual communication tools due to the COVID-19 pandemic, the world seems much smaller, but at the same time there is an increase in construction and development of data centres globally. The ICT sector can bed be differentiated into a number of categories; communications and computing technologies, cyber-physical systems, data analysis and AI, data collection and IoT, data management and storage such as Big Data, software, and simulation technologies. Given the premise of the ICT sector, there is still inequality between developing and first world countries, rural and urban, men and women, when it comes to access to the internet. Therefore, we need to bridge the digital divide and harness ICT development and 4IR technologies towards achieving the UN SDGs [25].

Table 3. Examples of the impact on the UN SDGs when implementing digital technologies.

Goal/s	Application and Impact
All Goals	A novel information and communication technology (ICT) framework for SDGs, developed by Olivera Kostoska and Ljupco Kocarev. This is done using 4 steps in building and providing ICT structures in achieving SDGs [26]. • The output of SDGs should be influenced by three disciplines: governance science, sustainability science, and data science. • The implementation of SDGs should be activated by various actors at various spatial, temporal, and decision-making scales. • The governance of SDGs should be underscored by various governance theories that cause action across several levels and include actors from multiple sectors. • Implementation of SDG's should be affected by human behavior.
All Goals	The effect of ICT is of two-fold: on the one hand, there could be detrimental impacts on sustainability, such as electronic waste production. On the other hand, ICT is surely an enabler for more productive use of energy, education, and business processes, which is vital in achieving the SDGs. In more than 56 countries around the world, the International Federation for Information Processing (IFIP) is an umbrella body for information technology communities The IFIP Working Group on "ICT and Sustainable Development" was formed in 2005 to provide a forum for dialogue and study, for building a society where "no one is left behind". For any IT expert, as in other fields, compliance with the Code of Ethics that substantially contains "sustainability" should be self-evident [27].
#7 Affordable and Clean Energy #9 Industry, Innovation and Infrastructure #11 Sustainable Cities and Communities #12 Responsible Consumption and Production #13 Climate Action #16 Peace, Justice and Strong Institutions	The next generation sustainable data centers in the ICT sector are to use carbon free energy (CFE) and net zero results. Significant strides have been made in the last decade towards sustainable and efficient data centers. Data centers consume large amounts of the world's energy. Renewable sources and technologies such as fuel cells are being utilized. In the most recent research, 4IR technologies are being used in data centers for cooling purposes and energy conservation. AI and machine learning (ML) algorithms are being trained to detect cyber-attacks. Internet of Things (IoT) sensors are being used for early warning systems, thereby reducing downtime. These types of applications are being adopted across a number of industries.
#3 Good Health and Well-being #9 Industry, Innovation and Infrastructure	The Institute for Intelligent Systems (IIS) was established within University of Johannesburg in 2016. To achieve Industry 4.0 initiatives within the university among postgraduates, private, and public organizations [28]. Some of the projects and partnerships that are completed or in progress with the use of digital technologies under the IIS comply with the UN-SDGs. We look at a few here and see the impact on the goals. One standout project developed by a student allows persons with hearing impediments to be able to communicate with others via a mobile application. All that is required is a smart phone and a pair of headphones. Another project involved wireless IoT sensors in hospital rooms, which would monitor patient's health and behaviors, without nurses' hourly check-ins. They would simply be able to monitor patients from their desks in their wards. An AI and ML technique was used in order to assist in the control of shuttle vehicles in the coal mining industry. A graphical user interface (GUI) was designed in order to assist mining operators. The algorithms used in this optimization of these shuttle cars are Dijkstra's shortest path algorithm, K-shortest path algorithm, and discrete event simulation. Therefore, assisting for the shortest routes underground, the queuing of vehicles and safety of the drivers and miners [29].

Table 3. *Cont.*

Goal/s	Application and Impact
#1 No Poverty #2 Zero Hunger #4 Quality Education #5 Gender Equality #7 Affordable and Clean Energy #11 Sustainable Cities and Communities	In 2010, the Institute of Electrical and Electronics Engineers (IEEE) adopted its tagline: "advancing technology for humanity". A program developed by the IEEE called "Engineering Projects in Community Services" (EPICS—in—IEEE) organizes university and secondary school students to work on engineering-related projects for local humanitarian organizations or nongovernmental organizations (NGOs). To date, there have been many implementations of the program globally [30]. The University of Johannesburg's engineering students, together with an NGO and a local high school, came up with a "sun in a bottle" project for a nearby informal settlement. The project had provided solar lighting for the informal settlement. At the same time, technical and digital knowledge was taught to the high school learners and the people from the informal settlement by the engineering students. This took engineering and technology to a broader community, whilst at the same time solved a humanitarian issue and made the people there self-sustainable with the education they had required from the engineering student [31,32].
#1 No Poverty #2 Zero Hunger #3 Good Health and Well-being #5 Gender Equality #6 Clean Water and Sanitation #8 Decent Work and Economic Growth #10 Reduced Inequalities #12 Responsible Consumption and Production #13 Climate Action #14 Life below Water #15 Life on Land	Food and agriculture or now with the use of 4IR technologies, has come to be known as Smart agriculture. Technologies such as AI is being used to make predictions for harvesting of crops, weather patterns, combat pests, reducing waste and optimizing supply chains [20].
#3 Good Health and Well-being #4 Quality Education #5 Gender Equality #8 Decent Work and Economic Growth	The University of Johannesburg's Makerspace, a 3D printing and scanning area, which is also filled with robotics and other digital tools. The Space and equipment are expected to grow towards the development of Industry 4.0 implementation capacity, including addressing cyber-security challenges, business and economic models for open innovation, education, printable implants, and many other elements. Students and lecturers utilize the space and technologies for educational purposes; engineering and medical students are able to bring their ideas and concepts to life. Together with this, the public and less fortunate are encouraged to use the space under supervision so as to learn about newer technologies and make something of themselves out there in the world. Lately, the space has used 3D technologies to develop head shields using a global open source design; this was amidst the shortage of protective wear during the COVID-19 pandemic. Engineering teams at the university have used this technology to design and develop porTable 3D printed mechanical ventilators that have a customizable base plate to treat multiple patients during the pandemic [32–35].
#3 Good Health and Well-being	Researchers at the University of Sussex have used machine learning to reduce maternal mortality in Uttar Pradesh, India, based on the mother's perceptions and behavioral patterns. Further research is being done towards smart services in healthcare, where an array of digital technologies is being used. ICT equipment, IoT, radio-frequency identification (RFID), wireless networks, and cloud computing are all tools that are empowering medical institutions for a more efficient and effective public service [36].
#11 Sustainable Cities and Communities	Mega cities in Asia are using wireless technologies together with AI and social media to detect and warn about natural disasters.
#14 Life below Water	Billions of dollars are generated by theme parks and movies with the use of over 3000 dolphins, which are in captivity. A US engineering firm called Edge Innovations, are developing a robotic dolphin with the use of AI. With the hopes of this technology entertaining crowds and replacing real animals that are in captivity [36].

Table 3. *Cont.*

Goal/s	Application and Impact
#15 Life on Land	A nonprofit-organization (NPO), Resolve, has deployed cameras with image processing and neural networks to assist rangers in the African wildlife reserves in detecting poachers.
#16 Peace, Justice and Strong Institutions	Fraud and financial crimes are a major issue globally, many banks and financial organizations are using digital technologies to increase their security for their clients. One example is HSBC is using these technologies to monitor irregular transactions such as money laundering, fraud, and terrorist funding.

Whilst the impacts of 4IR digital technologies and the ICT sector on SDGs are of great assistance, some researchers believe they are of two folds [37]: On the one hand, they make more effective use of resources, education, and business operations, which are crucial to the success of the SDGs. On the other hand, there could be detrimental impacts on sustainability, such as the production of electronic waste. The latter is where innovations such as circular thinking come in. In 2016, Taiwan's government initiated several measures to implement a circular economy. There are 66 circular implementations in Taiwan, where over 360 partners are involved. Taiwan, the leading retailer and producer of electronic equipment, has built a circular economy (reduction in e-waste) with environmental protection for economic growth. Industry 4.0 can be an influential factor towards accelerating circular thinking [38].

2.2. Circular Economy Solutions

Over the course of time, the circular economy approach to sustainable development has gained traction among economists, politicians, and business people, and has also attracted the UN's attention. Unlike a linear approach, in the circular approach, resources for new goods derive from obsolete products. All is reused, remanufactured or, as a last resort, recycled back into a raw material or used as a source of energy as much as possible. Governments are encouraging and, in some situations, demanding the implementation of circular economy concepts that will lead to greater resource production and less pollution. Within the global stage, the UN SDGs contain a variety of relevant goals. The United Nations Industrial Development Organization (UNIDO) is the specialized agency of the United Nations that promotes industrial development for poverty reduction, inclusive globalization, and environmental sustainability. UNIDO projects already address various building blocks of circular economy [39]. The circular economy holds particular promise for achieving multiple SDGs, including #Goal 6 on energy, #Goal 8 on economic growth, #Goal 11 on sustainable cities, #Goal 12 on sustainable consumption and production, #Goal 13 on climate change, #Goal 14 on oceans, and #Goal 15 on life on land [40].

According to the European Environment Agency (EEA), concentrations of greenhouse gasses (GHG) rose to 435 ppm of carbon dioxide (CO_2) during 1995–2015, way above the acceptable level of ambient CO_2 concentration 350 ppm [41]. Together with this, energy generation and environmental impacts have increased significantly, which in turn has an impact on carbon footprints. With the global call for zero carbon emissions there needs to be solutions put in place; these include: low carbon materials, embodied carbon, and operational carbon. Therefore, environmental, social, and governance (ESG), which are the three main factors towards measuring sustainability and social impacts of an investment in companies, are outperforming the broader market during the COVID-19 pandemic, which means new investments that have been invested in innovations and technologies, such as the ones in this paper, have been more resilient.

Given the emphasis on technological solutions, both literature and recent studies indicate that CE strategies may offer substantial benefits from cost reduction, work growth, creativity, competitiveness, and resource utilization in both developed and developing countries [42]. At the beginning of the 21st century, there was a desire to examine the acts performed to change the socio-economic climate in which we work, to reach a better degree of well-being for all people. In the light of the Stakeholder

Principle, recognizing that an organization will often strive towards generating a positive impact for society, the development of the UN-SDGs has had a positive impact.

With the use of digital technologies and the ICT sector, there has been a significant acceleration towards circular economy. It has gained momentum in the 4th industrial revolution, by innovation, creating economic growth and employment opportunities, which are traits of the UN SDGs. Moving from the linear "take, make, and dispose" model towards a more CE model would create as much as $4.5 trillion by 2030 [41].

Below, we look at the different circular economy applications that have affected the achievement of SDGs [43]. We look at the different tools that were utilized in achieving circularity and sustainability, as well as at how digital technologies, when used together with circular thinking, affect the UN SDGs.

In recent times, some well-known companies and organizations have implemented circular models, which might seem small at first glance, but are effective in achieving the goals using a circular approach, namely:

- Timberland—From tires to shoes.
- Johnson controls—Recycled batteries.
- Aquazone—Water waste in to fertilizer.
- Schneider Electric—Increase product lifespan through leasing and pay per use.
- AB Inbev—Returnable glass bottles.
- Apple INC—Apple's iPhone disassembly robot is capable of dismantling an iPhone in 11 s and sorting through recycled materials for the parts. In doing so, Apple has collected materials worth about $40 million that can be reused for future goods.
- Michelin—Their systems called EFFIFUEL, vehicles use an IoT sensor environment to propose and educate on eco-driving techniques.
- EON ID—The first RFID tag for the industry in the shape of a thread that can be combined with textiles to enable recycling.
- Veolia—Memthane Technology turns 98% of drainage organics into biogas, producing 10% of Mars Netherlands plant resources per annum.
- Lafarge in partnership with UN SDG—Developing waste and industrial ecology strategies in factories based on the circular economy model, with the ability to better use byproducts and waste as raw materials and alternative fuels.
- PANGAIA—Recently launched a sneaker, which is made from repurposed grape leather, this comes from the waste in the Italian wine industry. Twenty-six billion liters of wine is produced annually, with waste of around 6.5 billion tons.

World resource usage was about 20 tons per/year in 2017. The construction industry generates the greatest quantities of wastes and uses the most energy. These figures are expected to double by the year 2050. Not to neglect the global effects CO_2 emissions. The building industry is one of the world's major economic industries. It hires about 7% of the world's working population and invests over $10 trillion annually on building products and services. Therefore, circular thinking in the built environment is of utmost importance, the idea of reusing, repurposing, and recycling building materials has a positive impact across the UN SDGs. In order to achieve this, tools such as LCC, LCIA, MCI, and materials passports can be used to achieve circularity throughout the entire life cycle of a building. At the same time, the sector seems to be lagging with regards to digitization, so in recent years with the help of the ICT sector, organizations have developed software, databases, and digital technology prototypes in order to carry out circularity assessments. We list some of these in Table 4.

Table 4. Software, databases, and prototype options available for the purpose of circularity.

Tools	Description	Citation
Embodied Carbon in Construction Calculator (EC3)	A free and easy-to-use tool that enables embodied carbon to be bench-marked, assessed, and reduced, focused on materials' upfront supply chain emissions.	https://www.buildingtransparency.org/en/
Circularity Calculator	Free service for designers to endorse model designs for a circular economy.	http://www.circularitycalculator.com/
Material circularity indicator (MCI)	Identified by the Ellen MacArthur Foundation as a free instrument used for measuring the circular economy of European products.	https://www.ellenmacarthurfoundation.org/our-work/activities/ce100/co-projects/material-circularity-indicator
Circular economy toolkit (CET)	A free measurement instrument that recognizes changes in the circularity of goods.	http://circulareconomytoolkit.org/
Thinkstep GaBi	This database covers numerous sectors, the information and software can be used for LCC, LCIA, and more.	http://www.gabi-software.com/international/databases/gabi-databases/
Schneider Electric	Calculators available online for a number of applications and "what if" scenarios, particularly circularity tools in this case.	https://www.se.com/ww/en/work/solutions/for-business/data-centers-and-networks/trade-off-tools/
Buildings as Material Banks (BAMB)	The materials passports network effectively labels materials digitally. It helps users to track the building cycle, from preparation to building, occupation, maintenance, upgrades, repurposing, and decommissioning, and the ability to manage the quality of materials and improvements and the performance of buildings.	https://www.bamb2020.eu/
MADASTER	Forum for the public passport of materials, which serves as an online database of materials in the urban environment. To register or digitally mark the parts of buildings, Madaster uses 3D scans and building information modelling (BIM) to register or digitally mark the parts of buildings.	https://www.madaster.com/en/our-offer/Madaster-Platform

Since data and digitization has become the norm in recent times, data centers have been put at the forefront. Data centers are huge consumers of energy and they are expected to use 200 terawatt hours (TWh), which exceed that of some countries. They contribute approximately 0.3% of overall global carbon emissions. This is expected to rise to 20% by 2030. The COVID-19 pandemic has added to this rise, with an increase in cloud computing, online meetings, databases, and IoT systems. Therefore, the call for sustainable data centers is of utmost importance in fighting climate change and achieving the UN SDGs. As discussed in Section 2.1 above, digital technologies have assisted in this cause, but what about circular models? Circular tools are a useful means to analyze data centers as well as transition towards a circular economy. To date, many well-known companies have adopted the approach, all towards achieving the goals; Amazon and Microsoft plan to go carbon neutral by 2050 and run completely on renewable energy by 2030. Companies such as FACEBOOK and GOOGLE monitor entire life cycles of their data centers, (raw material extraction → manufacturing → transport → use → end of use → reuse or recycling), hardware within their centres are refurbished and reused, parts are also sold off in second hand markets. The aim is to have clean technology systems for global data centres in accordance with the Sustainable Development Goals of the United Nations and the Climate Action Plan.

Research has shown that Europe's circular economy will achieve a net profit of (EUR) 1.8 trillion by 2030, by solving increasing problems related to capital, job creation, fostering innovation, and producing significant benefits towards climate change. These are all in line with the goals.

2.3. The Relationship between Digital Technologies and Circular Economy towards Achieving the UN SDGs

Given the promising signs of achieving the SDGs using the two mentioned technologies and innovations in this paper, the question remains, what does the future of 4IR digital technologies and its application in a CE hold? It is clear to say that technologies such as AI can act as an enabler towards a transition to a circular economy, whilst at the same time speed up the process towards solving some of humanities problems, i.e., the UN SDGs. They complement the talents of individuals and extend their capacity. It helps people to learn more easily from reviews, and to deal more effectively with ambiguity, and a deeper comprehension of plentiful data. We can use these technologies to enhance circular thinking across industries in three ways, namely:

- Circular infrastructure optimization
- Build circular objects, parts, and components
- Function circular business structures

We can further characterize digital technologies towards a circular economy and a sustainable future in three types: Digital technologies such as IoT, Big Data, Blockchain, and RFID help enterprises track capital and manage excess ability and usage. Physical technologies such as 3D printing, robots, energy recycling and processing, modular construction, and nanotechnology help businesses minimize the cost of manufacturing and products and minimize the environmental impact. Biological technologies such as bio-energy, bio based materials, biocatalysts, hydroponics, and aeroponics help businesses move away from fossil fuels.

With the use of AI and machine learning, they can analyze data patterns using neural networks and facial recognition, therefore, a more automated approach. We can also imagine machines, humans, and materials communicating with each other via wireless sensors; this can be achieved using IoT platform, which would allow for smoother and faster data exchange throughout lifecycles. Data is readily accessible in cloud-based platforms for remote usage and control. This can be achieved by digitally marking materials and components from the beginning of its life cycle, this data can be stored in cloud-based platform databases, and can be used for tracking and traceability for safety and sustainability purposes [44].

To date, there have been a number of researches, prototype solutions, case studies, and future prospects where the partnership of digital technologies and circular economy have been used in order to achieve sustainability, some of which can be found here [11,45], based on perspectives from more than 40 interviews, a partnership with experts from the Ellen MacArthur Foundation and Google, with global consulting firm McKinsey & Company supplying analysis and analytical assistance, as well other researchers and publications.

3. Challenges and Solutions

These technological advances and innovative techniques may not be a silver bullet for all of humanities problems. However, they have the potential to be a powerful tool in the toolkit to achieve the UN SDGs [24]. The UN's recent report showed much progress for some of the goals (#1, #3, and #7), whilst for other goals (#4, #5, #13, and #14) there has been insufficient progress [40].

Whilst technologies such as the ones discussed in this paper do show positive impacts towards the goals, there have been studies done that show that they have negative impacts. In a recent study [46], these technologies had a 79% positive impact on the SDGs, whilst 35% showed a negative impact across all the goals. Within developed countries, such as the EU, concepts such as CE has found momentum. However, in low and middle-income nations this is not the case. Major differences exist in the perception of whether the implementation of CE activities can make a meaningful contribution to economic growth, employment, and sustainable development [18].

This short fall and lack of application is due to:

- Lack of government interventions;
- Policies in the form of cross-departmental collaborations and incentives towards businesses.
- Economic, social, and environmental impacts on local communities need to be further assessed;
- Education;
- Tech companies require and need to collect more data; and
- More talent is required to improve existing technologies.

The UN Global Sustainable Development Report of 2016 suggests that [47]: "Technology has greatly shaped society, economy and environment. Indeed, technology is a double edged tool, while technology progress has been a solution to many ill's and problems, it has also added ever new challenges."

4. Conclusions

In this paper, we have looked at the impact of 4IR digital technologies and circular thinking on the United Nations Sustainable Development Goals. We came to understand the recent strides in research and applications, and looked at future advances being taken with the use of emerging technology and circular thought in achieving the UN SDGs.

After reviewing literature for this paper, it is our opinion that technology and developments like these have changed the world. Since these developments started escalating a few decades ago, the shape of today's industries, hospitals, communication, education, as well as virtually every other part of human life has changed dramatically. Overlooking the value of all these developments would be an error.

Bringing together the concepts of 4IR digital technologies and circular economy, with international organizations, collaborating with multiple stakeholders from politics, industry, academia, and the civil society, we can help ensure that the global growth is inclusive, sustainable, and aligned to delivering the SDGs. The creation and application of the two ground-breaking strategies provides new possibilities for people around the world to better their lives, and the best ways to incorporate justice, privacy, and protection into these structures. Yes, it is clear to say that there are some drawbacks as discussed in Section 3, but the solutions are available.

It is fair to conclude that there is room for possibilities in this research field, considering the amount of ongoing initiatives globally towards achieving the SDGs. Sustainability and efficiency measures have grown using a number of methods in recent years, but they are not sufficient in achieving the goals. Therefore, the circular economy definition and 4IR emerging innovations together with their relevant tools offer opportunities for creativity, the development of value, and a positive impact towards sustainability and achieving the SDGs.

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