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Achieving Environmental sustainability through the adoption of industry 4.0: an exploratory case study within the information technology industry

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Abstract — **In the present-day competitive business landscape, integrating Industry 4.0 has transitioned from a choice to a necessity for companies striving to maintain their edge. Given the automation functions of IoT, the data management and transformation capabilities of AI, and the traceability benefits provided by Blockchain, this imperative is now more evident than ever. While widespread interest in Industry 4.0 is prevalent, the uncertainties surrounding the implementation process pose notable challenges. For this reason, in this paper, we present a single case study of a firm that operates in the information technology market to showcase the implementation process and how they overcome the challenges of digital transformation. Furthermore, the effect of this implementation on environmental sustainability experienced by the company and three of its customers was discussed.**

***Index Terms* — Industry 4.0, Artificial intelligence, environmental sustainability, Digital transformation**

I. INTRODUCTION

In recent years, many firms have invested heavily in Industry 4.0 to achieve a variety of objectives. Due to different factors including the pandemic, Industry 4.0 has recently acquired acceleration on a global scale (Ahmad et al. 2022). A set of highly disruptive technologies transforms a global system, allowing the world to become more interconnected and fostering economic growth and competitiveness. Unlike Industry 4.0, Industry 3.0 focuses on the automation of machines independently; however, by integrating the physical and virtual worlds, Industry 4.0 focuses on the end-to-end digitalization of all physical assets and their integration into digital ecosystems. With regards to the capabilities presented by Industry 4.0, the ecological realm stands out as a significant dimension that these innovative technologies can influence in multifaceted ways (Burritt and Christ 2016). When organizations adopt an active approach toward environmental regulation, innovative technologies can bolster environmental action's economic and social outcomes. These cooperation relationships are known as win-win situations or the Porter hypothesis (Adams et al. 2016; Foo et al. 2021; Porter and Linde 1995).

Given the significant advantages afforded by adopting I4.0 technologies, particularly in an increasingly competitive global environment, it is of great interest to both researchers and practitioners that so many companies are still reluctant to adopt these technologies more broadly (Chiarini, Belvedere, and Grando 2020) Koh, Orzes, and Jia 2019; Tortorella, Giglio, and van Dun 2019). This resistance is largely justified in the literature; the adoption of industry 4.0 is not trivial, it is rather associated with a chain of challenges and obstacles that needs to be addressed. Even though the integration of Industry 4.0 technologies provide numerous advantages, much work remains (Dalenogare et al. 2018). In 19 different countries, only 14% of CEOs have complete assurance in their companies' ability to adapt to the changes ushered in by Industry 4.0 (Raj et al. 2020) and only four out of ten firms, on average, have made significant headway in the adoption of industry 4.0 (Bauer et al. 2016).

The uncertainty of outcome is playing an important role in this regard as well, and many industrial businesses may undervalue Industry 4.0 technologies (Bai et al. 2020). Efficient and comprehensive assessment methodologies and decision-support systems can assist manufacturing organizations in properly implementing and comprehending Industry 4.0 technology, especially when the larger economic ramifications are considered. These larger ramifications include environmental as well as socioeconomic problems (Frank, Dalenogare, and Ayala 2019).

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The preponderance of Industry 4.0 implementation case studies concentrates primarily on the economic implications, which do not fully capture the range of possibilities afforded by Industry 4.0, especially in the light of all the challenges associated with Industry 4.0, there is a significant need for successful case studies focusing on the environmental aspects of Industry 4.0, as environmental concerns continue to grow in significance for firms across industries (Zangiacomi et al. 2020). Several researchers have highlighted the possibility and necessity of forging a new trajectory for environmental development (Parajuly and Wenzel 2017) (Sousa-Zomer and Cauchick Miguel 2018). Even if there is a disconnect between environmental sustainability and I4.0 (Baccarelli et al. 2017), I4.0 has the ability to improve operational competence, improve data control operations, optimize energy use, and reduce waste from processes and machines (Ivanov, Dolgui, and Sokolov 2019; Thoben et al. 2017).

This paper aims to fill these gaps in current research, by relying on data from a single case study of a firm within the information technology industry that successfully implemented industry 4.0, the main objective is the examination of the approaches adopted to overcome the challenges encountered during the implementation of Industry 4.0, along with the environmental accomplishments attained through such digital transformation. This objective is guided by the following research questions:

- *What specific challenges does a firm in the information technology industry encounter during the implementation of Industry 4.0, and how do these challenges differ from those emphasized in the literature?*
- *In the context of the information technology industry, what strategies and approaches are adopted by the selected firm to effectively and efficiently overcome the identified challenges associated with Industry 4.0 implementation?*
- *How does the successful implementation of Industry 4.0 contribute to environmental sustainability within the information technology industry?*

In this paper, we present the case study of a multinational corporation that is a leader in Industry 4.0, it is also considered as one of the largest providers of Industry 4.0 technological solutions. The paper discusses first the challenges encountered by the firm during the digital transformation phase, the methodology followed to overcome these challenges, and the effect of Industry 4.0 technology on environmental sustainability. Three of the firm's customers were also invited.

The paper is organized as follows: Section 2 reviews the relevant literature on I4.0, section 3 presents the methodology followed to achieve the paper’s objective, section 4 showcase the results and discussion and section 5 is the conclusion.

II. LITERATURE REVIEW

In 2011, Hannover fair, Germany, marked the start of a new era in manufacturing with the introduction of Industry 4.0 (Hozdić 2015; Kagermann 2015), a paradigm shift that continues to reshape the whole industrial processes (Hassoun et al. 2022; Melnyk et al. 2023). Industry 4.0 allows the production chain to generate more intelligent decisions and improves communication across the supply chain (Lu, Zhao, and Liu 2024). The initial focus of Industry 4.0 was on the incorporation of digital technology into factory-level production procedures (Barata, Rupino Cunha, and Coyle 2019). However, the most current research takes a value chain-focused approach when defining the boundaries of Industry 4.0 (Benitez, Ayala, and Frank 2020). These boundaries have reached the environmental aspect both in the literature and in practice. Based on the ecological modernization theory (EMT), environmental issues that arise from economic growth can be mitigated by increasing resource efficiency through technological advancements, such as green supply chain practices, which simultaneously improve the organization's financial and environmental performance (Tang et al. 2022). In this scenario, environmental preservation is viewed as an opportunity rather than a challenge, backing the principles of "economizing ecology" and "decolonizing economy"(Khan et al. 2021). Research scholars and experts from various fields have examined by what criteria companies can integrate environmental issues into their organizational matters, using theoretical frameworks such as ecological footprinting, triple-bottom-line, ecology in industry, environmental efficiency, and life cycle management

(Luthra and Mangla 2018). However, it is also important to investigate the relationship between each individual Industry 4.0 technology and environmental sustainability (Manavalan and Jayakrishna 2019). This section of literature review will examine how specific Industry 4.0 technologies can be used to reduce environmental impacts and promote sustainability in manufacturing and production processes.

A. Artificial intelligence for environmental sustainability

The artificial intelligence (AI) technology is a key driver of the fourth industrial revolution, which is facilitating the shift towards a digital economy (Liu, Liu, and Lee 2024). Machine learning algorithms are improving AI applications in various fields, including banking, healthcare, and manufacturing (Giudici, Centurelli, and Turchetta 2024). Urbanization, civilization, and unsustainable practices and procedures have led to the emergence of artificial intelligence-based environmental sustainability solutions(Stupariu et al. 2022).In particular, Artificial intelligence (AI) exhibits substantial potential in the domain of energy management (Batista, Melício, and Mendes 2017).The AI detects the characteristics and generates accurate predictions without human intervention. In this regard, (Mocanu et al. 2016) presented an AI model that estimates the energy needed for the individual appliances and distribution, in addition to the planning and management of building energy usage. AI algorithms in conjunction with traditional forecasting methods can improve crude oil price forecasting precision (Hamid M 2023).(Chemali et al. 2018) introduced a way to calculate the battery's state of charge based on AI, same for energy management of households by (Coelho et al. 2017) and photovoltaic energy production, modelling, and optimization (Entezari et al. 2023). The global market for artificial intelligence in energy management is predicted to exceed $12,200.9 million by 2024, up from $4,439.1 million in 2018 (Ahmad et al. 2021).

Based on an online near-infrared (NIR) identification model technology presented by (Du et al. 2022), the AI solutions is expected to tackle the bottleneck issue of complex waste textile sorting and provide an intelligent, efficient, and non-destructive sorting technology for waste textile sorting and high-value application. In the food industry, meat represent 13% of food waste, which is estimated by 1.3 billion tons (Shahbazi and Byun 2020). Meat spoilage accounts for one-third of greenhouse gas emissions (such as CO_2) and 75 % of the land occupied by wasted food (Hülsen et al. 2022). In this regard, an Artificial intelligence model was developed by (Amin Amani and Sarkodie 2022), the model was employed to train an image classifier algorithm to distinguish between fresh and rotten consumables. The proposed AI system distinguished between fresh and spoiled meat with 100 percent accuracy. The AI has potential uses beyond energy management and waste management, the water shortage contribute directly to three of the world's top 10 environmental problems (Harper 2020). AI based model exhibited 82.64 percent accuracy in assessing the purity of cooling water in accordance with the renewable water concept(Salem et al. 2022).

B. Blockchain for environmental sustainability

Blockchains are encrypted ledger networks where only registered users can view their data (Patil et al. 2024). Considering that green practices are no longer optional for organizations, process tractability is more essential than ever (Hofmann and Rüsch 2017). Transparency and tractability features of Blockchain, can be included in every aspect of environmental sustainability (Mishra and Kaushik 2023). Circular economy, which lies at the heart of environmental sustainability, can potentially overcome the barriers to successful implementation through the use of blockchain technology, by an enhanced business models based on collaboration and prosumerism, transparent supply chain traceability management, increased collaboration and coordination in supply chain ecosystems, and superior reliance on supply chain ecosystems (Erol et al. 2022). (Kouhizadeh, Sarkis, and Zhu 2019) proposed a novel model that combines blockchain, circular economy, and product deletion. Their research found that the linkages between these three concepts have significant managerial and practical implications for various stakeholders, such as governments, communities, supply chains, companies, and individuals.

Food waste is one of the most severe issues that harms the environment, 6% of total greenhouse gas emission worldwide is generated by food waste (Tonini, Albizzati, and Astrup 2018).However, Blockchain has a huge potential to reduce the food waste problem (Dey et al. 2024). In this context, (Dey et al. 2022) proposed a multi-layered Blockchain-based framework that employs machine learning, cloud computing, and QR codes to address the issue of food waste. The framework, known as SmartNoshWaste, is implemented in a decentralized Web 3.0 enabled smart city. Specifically, the application focuses on reducing waste associated with potatoes in the United Kingdom, a food item that is commonly wasted. At each stage of the supply chain, every stakeholder, including consumers, can access and trace the food data. A machine learning algorithm processes and manages the data collected by the app, demonstrating that the Blockchain-based platform can reduce food waste by 9.46 percent.

(Strepparava et al. 2022) found that the stochastic nature of renewable energy production requires cutting-edge technology for the market to clear in pseudo-real time. Blockchain opens up new possibilities for decentralized market architectures. To that end, the authors proposed a market mechanism based on dynamic prices and dependent on real-time energy production or consumption in the local grid. This method was tested on 18 residential buildings in Southern Switzerland, and the results showed that the market worked without issues while avoiding excessive resource usage. (Zhu et al. 2024)Studied how Blockchain is increasingly used in low-carbon supply chains, allowing consumers to follow the manufacturing process of carbon-neutral merchandise.

C. Internet of things for environmental sustainability

The Internet of Things (IoT) has sparked widespread interest among researchers as they seek to understand its potential applications in a variety of industries (Singh 2023). The utilization of Internet of Things (IoT) has emerged as a promising solution for enhancing environmental sustainability in the predominant area of waste management (Pardini et al. 2019). IoT's ability to track waste materials offers a practical approach to boost the efficacy of municipal hazardous waste management, resulting in minimal waste and a high efficiency rate of up to 95.09% (Xu and Yang 2022).(Chen 2022) proposed an approach for smart waste management integrates Internet of Things (IoT) and machine learning algorithms. By deploying IoT-powered devices in waste containers, real-time information about waste production can be obtained. Image processing is used to analyse the amount of waste in disposal sites, offering insights into waste and recycling trends. The suggested approach achieved an accuracy ratio of 96.1%, a cost-effectiveness ratio of 92.7%, a tracking rate of 89%, and an environmental production/recycle ratio of 91.9%, all of which surpasses the results of other methods according to trial data. In the context of circular economy and IoT, (Turner et al. 2022) proposed a set of parameters to evaluate the circularity of a produced asset throughout its lifespan. Specifically, they developed a model for automotive parts that relies on IoT sensors and a central component to generate automated maintenance processes. The tool employs sensor outputs, problem codes, and predictive models to recommend a dynamic repair method for technicians. Additionally, end-users can provide text replies and diagram comments, which serve as an additional data source for the auto-circular simulator.

The IoT has a wide range of environmental benefits beyond waste management. For instance,(Parvathi Sangeetha et al. 2022) developed a hybrid IoT system comprising remote-controlled devices, GPS, and Radial Function Network (RFN) to manage groundwater storage and transportation for a farmer's field while also monitoring soil humidity, pressure, and temperature in the farmland. Furthermore, the implementation of artificial intelligence and machine learning has a significant impact on enhancing energy sustainability in IoT networks (Charef et al. 2023).

D. Additive manufacturing and environmental sustainability

Additive manufacturing (AM) is the method of creating 3D objects layer by layer using a source of heat and inputting substance from a digital design model (Laleh et al. 2023). AM is a promising technique for sustainable manufacturing (Gonçalves et al. 2023). This is particularly noticeable given that 3D printers reduce the use of surplus material and, consequently, waste (Agnusdei& Del Prete, 2022).Numerous research studies have focused on the potential advantages of additive manufacturing techniques for promoting sustainability across various domains(Liu et al. 2022). This is substantiated by the increasing amount of studies examining the environmental impacts of additive manufacturing (Saade, Yahia, and Amor 2020). The materials used for 3D printing can be degraded without the requirement for a large-scale industrial composting plant, unlike many other artificial materials (Javaid et al. 2021). Additive manufacturing allows both the reduction of waste and the reuse of finished products (Al Rashid and Koç 2023). The material's lightweight and inexpensive nature makes it suitable for additive manufacturing as a replacement for plastic(Jiang & Fu, 2020). The lightweight feature of the additive manufacturing products also minimise the energy consumption (Fidan et al. 2024). In the construction business, the utilization of 3D printing technology has the potential to minimize waste and defects caused by improved quality control, thereby reducing the environmental footprint associated with the production and transportation of concrete (Adaloudis and Bonnin Roca 2021). By building a bathroom unit for example using 3D printers, a save of 34.1% on overall cost, 85.9% on CO2 emissions, and 87.1% on energy consumption was registered (Weng et al. 2020).

III. THE METHODOLOGY

Owing to the limited availability of current case study literature addressing the environmental sustainability implications of Industry 4.0, this research seeks to investigate how a specific firm navigated the primary challenges associated with Industry 4.0 implementation and subsequently assess the environmental impacts from both the firm's viewpoint and that of three of its customers. To achieve this, an exploratory single case study methodology was chosen.

Case study research is a well-established method for comprehending complex phenomena within their real-life contexts (Yin 2018). In this study, the complex phenomenon under scrutiny is the successful implementation of Industry 4.0 and its subsequent effects on environmental sustainability. Exploratory case studies are particularly adept at unravelling new and emerging phenomena, such as Industry 4.0, and their implications for environmental sustainability (Eisenhardt 1989; Flyvbjerg 2006). Opting for a single case study approach, we aim to delve deeply into the intricacies of the firm's strategy, providing a richer understanding than would be possible through the examination of multiple cases (Doz 2011; Miles and Huberman 1994; Stake 1995). In this paper, we articulate the challenges faced by the firm, expound on the strategies employed to surmount these challenges, and elucidate the factors contributing to the firm's successful digital transformation. Our reliance on a single case study enables us to attain a more nuanced and comprehensive insight into the specific strategy pursued by the firm (Figure 1 illustrates the paper’s methodology), thus adding depth and context to the discussion.

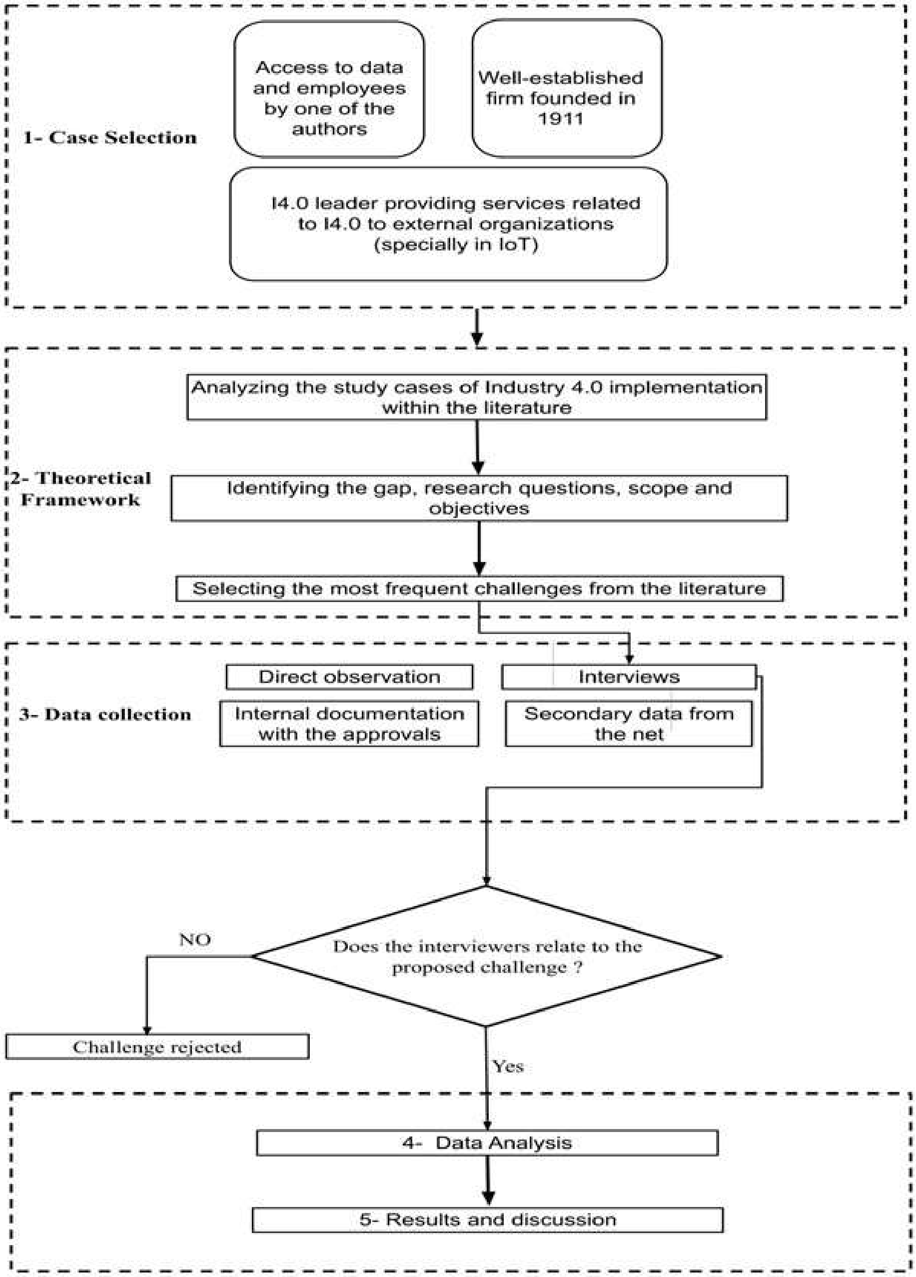

Figure 1: The paper's methodology

A. Case selection

The selected firm, founded in 1911, employs around 345,000 workers and is a leading player in Industry 4.0 services. The firm's selection was based on the following factors. One of the authors is an employee of the firm, which eased the arrangement of interviews, facility access, and thorough Industry 4.0 analysis. The firm's extensive track record of success and Industry 4.0 expertise make it an ideal study subject. Finally, as the firm is operating in the information technology sector and has been involved in digital solutions, especially IoT, AI and, Cloud, it promises insightful perspectives on implementation challenges, the strategies followed and the effect on the company, in our case the focus will be on environmental sustainability.

B. Theoretical Framework

In the following part of our approach, we shaped a guide for our dive into Industry 4.0 use. This meant looking at the literature to analyze how others' cases managed the challenges they faced. This showed us gaps, questions, scope, and what our own study should target. Also, we took the usual challenges from the literature as our starting spot and refined them more in our interviews.

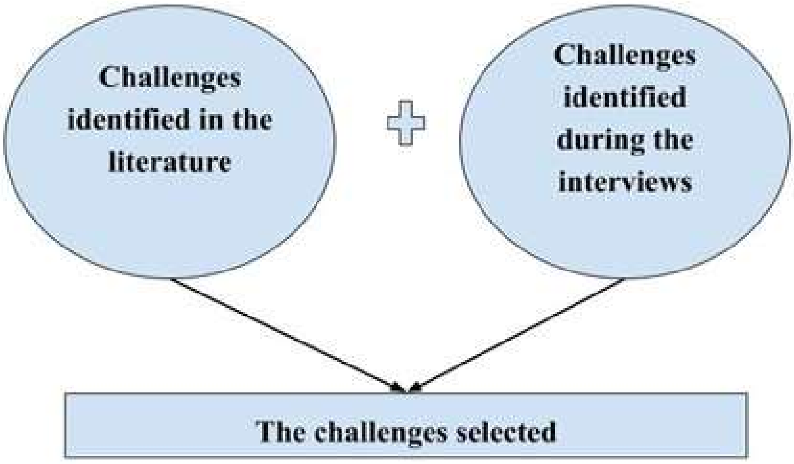

Figure 2: Challenges identification process

C. Data collection

We used a combination of direct observation, online interviews, internal documentation, and secondary data analysis to collect the required data. The observation component involved visiting the firm's premises and observing the operations and processes related to Industry 4.0 operations. For the interviews, we used a semi structured approach to gather insights from key stakeholders, who were involved in the implementation process and three of its customers. In Table 2, we provide a comprehensive overview of the interviewees' background and the length of the interviews. The interviews ranged between 30 minutes to 1 hour and 15 minutes. Notably, the interviewees comprise not only internal professionals with various expertises but also the firm’s customers who have directly benefited from the cutting-edge industry 4.0 solutions. The internal documentation was obtained with the firm's approval and included reports, memos, and other materials that provided information on the implementation process and the observed outcome related to the environmental sustainability aspects, which was later-on mixed with external data available on the net. Our data collection methods were informed by previous research on case study methodology (Yin 2018) and mixed-methods research (Creswell and Clark 2017), and were designed to provide a comprehensive understanding of the challenges, strategies, and outcomes of Industry 4.0 implementation in the context of the selected firm.

Table 1: The interviews details

Position	Number	Firm	Length (min)
Global Research Leader for Industrial products	**2**	**Firm under study**	**48mn & 39mn**
Business Development Executive	**1**	**Firm under study**	**65mn**

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Senior Research director	**1**	**Firm under study**	**32mn**
Global Application Modernization and Development Leader	**1**	**Firm under study**	**58mn**
Cloud Solution Architect	**2**	**Firm under study**	**36mn & 41mn**
Transformation Consultant, Cloud Advisory	**2**	**Firm under study**	**55mn & 47mn**
Industry 4.0 Architect	**1**	**Firm under study**	**78mn**
Chief sustainability officer	**1**	**Firm under study**	**45mn**
COO	**1**	**Customer A**	**37mn**
Project Manager	**1**	**Customer B**	**81mn**
Departmental manager	**1**	**Customer C**	**59mn**
SUM	**14**		**721mn**

D. Data analysis

Thematic analysis, a sophisticated and practical research instrument known for providing a comprehensive and detailed explanation of the data (Peel n.d.), was chosen to analyze the data collected from the research and identify the challenges mentioned in both the literature and our qualitative data. Firstly, the collected data was studied in depth, and then inductive coding was applied to identify the challenges that the study will be based on, drawing from both the literature and the qualitative data collected. To manage, organize, and efficiently analyze the data, the software NVivo was used. Finally, once the challenges were identified, we utilized the collected qualitative data to shape the strategies employed by the firm for the successful implementation of Industry 4.0.

IV. RESULTS AND DISCUSSION

A. Case description

The firm under study is considered one of the international corporate leaders in Industry 4.0 solutions. The firm not only successfully implemented Industry 4.0 technologies for its internal operations but also holds a sizeable position in providing digital transformation solutions. The firm under study lays the path for digital transformation for its customers by providing mainly artificial intelligence (AI) solutions, cloud and data management, Internet of Things (IoT) solutions, and 5G internet access.

To achieve the paper's objective, three customers of the company under study who have purchased technological solutions from the company were also invited. Customer A, a long-standing telecommunications client of the company under study, recently expanded its technological capabilities by purchasing an AI solution. Customer B, also in the telecommunications sector, has been a loyal client who initially adopted cloud solutions and later integrated AI solutions into their operations. In contrast, Customer C, operating in the energy sector, is a new client that recognized the value of cloud technology and swiftly engaged the company's services.

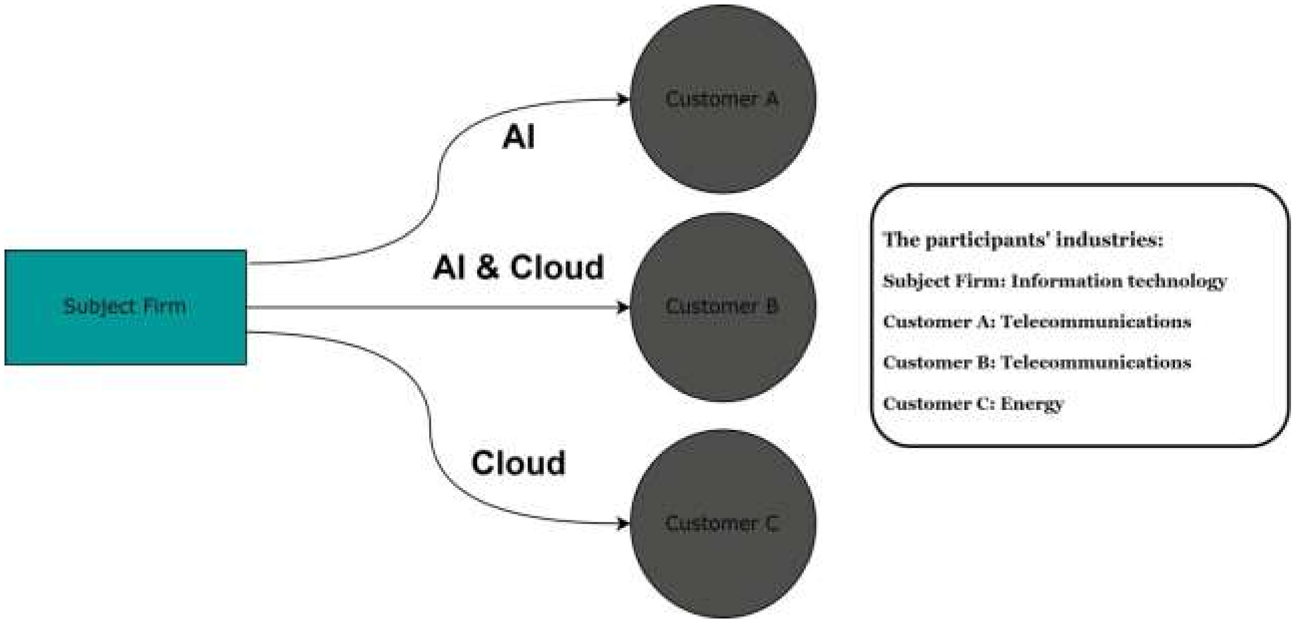

Figure 3: The firm under study and its customers

The data collected from the interviews with the three customers was not included in the challenges identification phase, as the customers invested in specific technologies and not entirely in Industry 4.0. Since the aim of the study is to provide high quality research for practitioners that describes the best practices to overcome the most common challenges, which is not the case for customers. For this reason, the data will be dedicated solely to discussing the impact of Industry 4.0 on environmental sustainability.

B. Industry 4.0 challenges

In the literature review of the paper, we captured five main challenges that we discussed in detail; however, in order to answer RQ1, we had to identify more than 28 challenges from the literature in total that can disrupt a company from pursuing its digital transformation strategy. The results were later projected on the qualitative data, and we ended up with the following six challenges. In the following paragraph, we undertake a comprehensive analysis of the challenges faced while also delineating the methodologies employed by the examined firm to successfully surmount these challenges, thereby providing a response to RQ2.

Constraints in Decision-Making

Despite being one of the first digital transformers within the industry, the firm under study has faced tremendous pushback from decision-makers during the first phases. In 2015, the firm was going through a rough transition from a hardware-based company to a company where 95% of its income comes from software and services. That period was described as ideal to implement industry 4.0 technologies. As the company was going through a radical change in its business model and operations, implementing Industry 4.0 will not be as turbulent as if the company were stable. Additionally, it can contribute to a successful transition. However, decision-making processes were impeded, and important decisions were continuously deferred, neglecting the critical aspect of implementing digital solutions. It was only when the situation became untenable that the company realized the urgency of embracing Industry 4.0 technologies as the sole viable solution.

"*As we were the first to consider industry 4.0 within the information technology industry, the decision-makers exhibited uncertainty regarding the digital transformation, especially with the ongoing internal switch from hardware to software. Finally, an IOT department was implemented in the Switzerland site, and only* *after the success that this department has achieved; the company demonstrated significant commitment and financial dedication to the adoption of Industry 4.0*” (Senior Research Director)

The decision-makers will naturally aim for the sustainability of their company; in this case, both the pressure of the company’s transformation and the success of IOT have led them to take the risk of diving into the realm of Industry 4.0. One of the aspects that the decision makers had to consider during that period was the organizational culture. Since the company was already operating in the IT sector, the cultural change did not face as much pushback as the other aspects, the firm’s culture has always supported innovation, agility, collaboration, and continuous learning.

For the firm under study to assist its customers in overcoming this barrier, a collection of endorsements and experiences from other companies is available, illustrating the diverse impacts of Industry 4.0 on various aspects of their operations, both in the medium and long term. Given that investment in Industry 4.0 necessitates substantial financial commitment and entails high risk and uncertainty, access to transparent information about the experiences of other companies often empowers decision-makers to proceed confidently with the digital transformation process.

Data abundant, untapped value

Manufacturing data is often affected by biases, inaccuracies, and outdated information due to the challenging conditions during data gathering, the presence of incompatible proprietary systems, and the dispersion of walled operational data across multiple databases in various formats. Well-structured data that can be transformed into information is the core of Industry 4.0. According to a report by the firm; manufacturers are currently underutilizing their data resources. For instance, a typical contemporary manufacturing firm operating a single production line with 2,000 separate pieces of equipment, each equipped with 100 to 200 sensors capturing data every second, may generate an astounding 2,200 terabytes of data each month. Companies often employ alarm systems to collect data and identify production anomalies for quality control, but, on average, 90% of the manufacturing data collected is utilized.

The firm under study has built a solid data-driven structure that focuses on five main areas:

Unlock the latent power of data

To optimize digital technologies for a successful manufacturing process, a structured internal data management capability plays a crucial role. Standardized data architecture, an enterprise database governance framework, centralized data storage facilities, and smart data loading are all used to improve data structures. The firm under study has progressed beyond centralized data models by implementing a semantic model which is a system that organizes data in a way that reflects its fundamental meaning.

Attain cyber resilience

In contemporary manufacturing cyber security, encompassing both IT and OT, adopting a "zero trust" methodology becomes imperative. This approach entails treating all sources behind the firewall as untrusted, requiring cybersecurity teams to assume the presence of potential attackers both internally and externally. Consequently, all network traffic should be viewed with suspicion. For this reason, thorough authentication and authorization of each party (users and their devices) are mandatory before allowing any communication. Furthermore, to give or retain access to apps and data, continual security validation of their setup and posture is required.

Establishing an Integrated Enterprise Architecture

To fully embrace Industry 4.0, manufacturers must implement a hybrid multi-cloud IT infrastructure. The cloud implementation allows smooth connections and workload optimization. Real-time data acquired from factory floor sensors, devices, and equipment becomes important for other manufacturing assets and may be shared across several parts of the company's software system; including ERP and other business management programs.

At the shop floor, standardized hybrid cloud architecture effectively manages required IT workloads such as OT-IT integration, edge analytics, OT safety, and both new and standard applications. Data acquired from different plants may be consolidated, cleaned, and regulated, enabling for cross-factory insights, KPI illustration, and optimization while preserving full control and data integrity across factories, organizations, clients, and suppliers.

Elevating Manufacturing Excellence through Technological Advancements

The company under consideration has upgraded its raw material management structures, management of warehouses, and maintenance management applications. In addition, AI is being integrated into expenditure evaluation, contract negotiations, strategic procurement and more services that can generate a tremendous amount of data, so that the AI can learn from the patterns within the data, so it can provide the most efficient strategy, for each case.

The firm under study overpasses its competitors because of one main reason, which is the high value extracted from the technological facilities. The integration of Industry 4.0 was a core reason for increasing efficiency, productivity, and safety.

Synergizing Digital Innovations with Manufacturing Operations and Management

To a significant extent, the firm under study has integrated its digital strategy with its manufacturing plan. The firm recognized at an early stage the potential of Industry 4.0 technologies and the uses of data and digital technology to fuel innovations and transformation in production.

As a result of this alignment, the firm found itself in a favourable position to update its plant applications and network, establish seamless connections between data, applications, and processes for operational efficiency, build a robust platform to manage plant data and facilitate analytics, and expand it utilization of edge analytics and technological facilities.

Lack of qualified skills

When a company's employees lack the ability to properly utilize the technology they are purchasing, it paralyses their capacity to first take advantage of the technology and then invest in other technologies (Breunig et al. 2017). As most Industry 4.0 technologies are new, successful implementation requires a substantial change in the workforce. According to (Gehrke et al. 2015), the employees' qualifications and talents in a future factory must meet two basic aspects: technical and personal. IT skills and knowledge of expertise in information processing and analytics, statistical skills, organizational and process understanding, and the capacity to deal with current interfaces (human-machine/human-robot), Regarding personal skills, they include self-control, time management, flexibility, the capacity to work in a team, social skills, and communication skills. When one of our interviewees was asked about this challenge, his answer was:

"*We were aware of this when our business began its journey toward digital transformation since the market lacked the resources necessary to satisfy the needs of Industry 4.0, a brand-new industry. For this reason we created a unique educational facility as a testament to our dedication. This institution has since blossomed across our five main plants. It serves as a model for free/online education, encouraging the growth of critical competencies for our workforce. The institute is dedicated to offering a wide range of courses related to IoT, cloud computing, coding, AI, Big data, and all the technological expertise necessary to navigate the years to come with five different languages.*" (Business Development Executive).

As the company is investing heavily in training its employees to be adequate for new technologies and to be able to adapt to any change, it has simultaneously created a strategy to maintain a healthy environment for its employees. The three fundamental principles of the firm are: diversity, inclusion, and equity, and it regards these values with great seriousness. The company offers an extensive array of additional activities and allocates a budget for recreational purposes to ensure a harmonious balance between work and personal life for its employees. Finally the firm puts forth a significant effort to analyze in real-time the resignations, why they happened, and how they can fix it.

Integrating Information Technology (IT) withOperational Technology (OT)

The evolution of Industry 4.0 poses the challenges of the integration of IT and OT, the opening of OT networks to the Internet, and the network of an IT organization. As a result, the manufacturing environment faces a variety of structural problems and emerging cyber-security related threats. The typical manufacturing firm can be divided into five main levels; the physical processes, the intelligent devices that are the actuators, the process sensors and analyzers, the control systems, the manufacturing operations systems that manage the production workflow, and finally the business logistics system. The first two levels are usually referred to as the OT, and from level 3 to level 5, the IT. In order for contemporary businesses to operate effectively, essential components are OT and IT—two distinct yet interlinked technologies. While IT assumes responsibility for managing and processing data, OT takes on the role of overseeing and automating physical processes.

Addressing contemporary challenges in the business landscape involves a strategic integration layer that merges IT and OT at the plant level. This integration fosters seamless connectivity between a wide array of protocols, facilitating the deliberate deployment of applications. The shift towards "OT Infrastructure as Code" is fortified by contemporary cloud deployment models. Enhanced manufacturing Key Performance Indicators (KPIs), including overall equipment effectiveness (OEE), gain substantial advantages through direct oversight of OT elements, enabling advanced applications for more intelligent operations. This makes it possible for businesses to maximize OEE. This might be accomplished by minimizing unexpected downtime by predicting asset breakdowns, prescribing repair approaches, and optimizing maintenance schedules utilizing telemetry from shop-floor sensors and machine learning (ML).

Industry 4.0 Investment Intensity

One of the most common challenges is the high investment in Industry 4.0’s implementation and the high barrier to exit. Companies that want to embrace Industry 4.0 projects will need to increase their anticipated annual capital investments by 50% over the following five years (Geissbauer, Schrauf, and Koch 2014).

“*When we made the decision to invest in Industry 4.0, we were fully aware of the substantial financial commitment ahead of us. Our goal was simple: achieving a substantial return on investment as quickly as possible to ensure our company's ongoing financial strength for sustained operations. Relying on our IT background we could gain high expertise and knowledge regarding Industry 4.0 technologies, and we became one of the leaders of Industry 4.0.This approach not only helped us to succeed within the market, but also to become leaders in industry 4.0 implementation. Our successful journey in mastering these technologies played an important role in creating massive marketing campaigns and eventually attracting new clients who are interested in our technological solutions. We don't just talk about what we can do; our achievements speak for themselves*.” (Senior Research director)

Taking the step from being an Industry 4.0 consumer to an Industry 4.0 provider ensured a high ROI for the company, which allowed further investment in research and development within the field. Now the firm is operating with a strategy that allows any new successful innovation to be not only used internally but also generate a high return from selling it to external entities. Furthermore, the company had created multiple partnerships in which they collectively invested in a certain technology to share both the expertise and the financial burden.

Lack of awareness about I4.0:

The company under study doesn't see a lack of awareness about Industry 4.0 as a major hurdle. Instead, they're pointing out that many of their customers, before diving into digital transformation, simply didn't have a clear grasp of what Industry 4.0 meant.

"*One of our foremost objectives is to promote the advantages of Industry 4.0 among our potential clients. It never fails to astonish us how limited the knowledge is among other businesses when it comes to Industry 4.0. Our edge in the market for Industry 4.0 related solutions rely heavily on our marketing campaigns. This is crucial because a large number of companies truly lack a clear understanding of what Industry 4.0 entails.*" (Project Manager)

Environmental Sustainability effect Through Industry 4.0 Case Study

Sustainability often stands as a main objective within each corporate strategy, a guiding principle that shapes every endeavor undertaken by a firm. The term sustainability includes three main aspects: social, economic, and environmental aspect. Regrettably, the environmental dimension often finds itself in the shadows due to the absence of instant and direct benefits. However, because of the escalating intensity of regulations and penalties surrounding environmental considerations, businesses have taken proactive steps to conscientiously mitigate their impact on the ecosystem.

In 2020, the firm under study held a roundtable discussion with experts and stakeholders about the potential of data and digital technology to enhance environmental sustainability. The event drew over 25 people worldwide from government, the commercial sector, academia, and non-profit groups. The discussion led to multiple conclusions, one of the main topics that were discussed is that the environment is full of data, the rivers flow alongside, storms encircle, and the earth teems with life. In numerous ways, the advent of what is generally referred to as big data—large data sets defined by their speed of generation, frequently in real-time, as well as their diversity and granularity—should be viewed as just an extension of how humans interact with the environment around us. Earth is a big data source. Since nature provides this large amount of data, there are two opportunities that can be seized to enhance environmental sustainability. The first step is to gather and compile environmental data across industrial sectors, government agencies, and Non-profits in a transparent and accessible manner. Second, that data must be transformed into quality information.

Drawing on the company's strong technological expertise, a strategic move was made. By utilizing software on the cloud and AI applications powered by advanced machine learning and deep learning, the company initiated a significant effort at five of its main sites. As a first step, prioritizing the gathering of useful data concerning the company's environmental impact was crucial.

Over a span of more than six months, meticulous work was undertaken to collect data. Three primary aspects became prominent and demanded attention: waste management, CO2 emissions reduction, and energy management. Different technological tools were employed to address these environmental challenges. In the next section we discuss each challenge and explore the role of Industry 4.0 technologies to overcome them.

Waste management:

Although more than 90% of the firm's activities are software-related, waste remains a significant concern with regard to environmental sustainability. Notably, over 70% of the waste generated by the company originates from electrical and electronic equipment (WEEE). Such wastes are among the most hazardous for both workers' well-being and the environment (Burns, Sayler, and Neitzel 2019)

In its previous approach, the company predominantly outsourced waste management activities to third-party providers. These providers undertook treatment and recycling in separate workshops. Unfortunately, the unregulated recycling and disposal of WEEE, involving manual dismantling, open burning, and acid treatment, led to severe environmental contamination. This contamination negatively and massively impacted the health of local inhabitants in areas where third-party providers operated.

In order to solve this issue, the firm has implemented an in-house system based on IoT and cloud services which has allowed the company to achieve a circular economy (CE). The system contains four main layers that are interconnected through the internet of things: the physical layer, communication, services, and applications. The physical layer is the level of the floor, which contains the disassembly segment, which has been installed with several robots and sensors. The application layer plays the perception role; it takes real-time data throughout the production history and transfers it to the communication layer via field connectors. Meanwhile, the physical layer's control section will receive information from the communication layer and carry out the physical action accordingly. The objective of the communication layer is to send information from the physical layer to the internet. The service layer collects and manages the information received from the communication layer. The top application layer makes use of the features of the previous layer, allowing users to conduct activities like prediction, monitoring, logistics and control.

The Cyber realm acquires operational data starting from the foundational physical layer, encompassing parameters like robotics. Simultaneously, it issues directives to the Physical layer, facilitating the establishment of the Cyber-Physical System (CPS). Regarding services, data undergoes analysis utilizing intelligent algorithms and cloud computing, which eventually influence the decision-making processes. The realization of a comprehensive, cloud-centric remanufacturing approach for the sustainable management of Waste Electrical and Electronic Equipment (WEEE) is the ultimate objective. In this context, real-time data is gathered and seamlessly conveyed via an Internet of Things (IoT) infrastructure.

Within this intelligent disassembly framework, the employment of cloud computing permits the exchange of disassembly plans and the reciprocal transfer of data. By invoking the existing WEEE model from the cloud, the local robotic systems can directly execute disassembly tasks, obviating the need for repetitive self-learning cycles with human intervention. Moreover, in instances where the model is unavailable in the cloud's knowledge base, the local robots possess the capability to construct an independent disassembly model. This technology also extends services such as predictive maintenance and early error detection for physical devices. Subsequently, the finalized model is uploaded to the cloud, fostering collaborative sharing among other users engaged in disassembly activities.

CO2 emissions reduction

Following the tremendous acceleration that happened in recent decades, carbon dioxide (CO_2) emissions have climbed to catastrophic levels in the last century. Since manufacturing isn't the primary focus of the company, its CO_2 emissions were not as significant as those of its peers. Nonetheless, the company has embarked on a journey to minimize its impact on environmental sustainability. Furthermore, customer B has also stated that AI-related applications were used to reduce CO_2 emissions. The basics of the system for both the firm under study and customer B are based on AI and cloud-based solutions. The companies used both artificial intelligence and cloud technology to establish a predictive system for monitoring CO_2 emissions, through this innovative system, both companies gained deep insights into certain areas related to CO_2 emissions that can be improved. By analyzing a set of big data, the system identifies ways and trends that enable the identification of emission hotspots. The system not only highlights potential issues but also provides the company with actionable solutions. Furthermore, the system goes beyond detection, offering possible solutions for high-emission zones. The use of both AI and cloud technologies brought a powerful system for prediction and CO_2 emission mitigation. The results from both companies are promising and the AI learning capability makes the system more effective over time.

Energy management

The firm under study and the three customers have all used industry 4.0 In one way or another to achieve energy efficiency. The customer C stands as a leader in this regard; as they are operating in the energy sector, the use of technological solutions to manage energy consumption was inevitable.

"Since the company operates within the energy sector, our main focus is to provide the most energy-efficient solutions to our customers, but that should start internally. Through the strategic implementation of additive manufacturing for specific product lines, we've effectively curtailed energy usage during manufacturing processes. In tandem with this, we've harnessed simulation methodologies. We cautiously present new tactics to simulations before applying them which allows us to anticipate their influence on energy usage." (Customer C representative).

The company under examination, along with its three prominent clients, is firmly committed to effective energy management. While each entity employs distinct strategies, a common thread unites them: a reliance on advanced technological solutions. For instance, the subject company has adeptly interconnected a substantial portion of its operations through the Internet of Things (IoT), which resulted in a reduction in daily operations that contributed directly to energy efficiency.

V. CONCLUSION

The literature is highly lacking in case study articles that specifically examine the implementation of Industry 4.0 and the methodologies used to overcome the obstacles to its implementation. This paper aims to fill this gap through a thorough qualitative investigation that includes the input of 14 experts centered on a single case study involving an information technology firm and three associated customers. The results showed that Constraints in Decision-Making, Data abundant, untapped value, Lack of qualified skills, Integrating Information Technology (IT) with Operational Technology (OT), Industry 4.0 Investment Intensity, and Lack of awareness about I4.0 are the challenges that are most frequently discussed in the literature and approved by the interviewees as challenges that they faced or that their clients have faced. Furthermore, the paper illustrates how the firm under study has surpassed these challenges and could successfully implement Industry 4.0 and become one of the leaders in the market.Furthermore, the effects of Industry 4.0 on environmental sustainability from the firm's and its customer's perspective was discussed. The discourse centered on three pivotal domains directly influenced by Industry 4.0 implementation: waste management, reduction of CO2 emissions, and efficient energy management. The results showed that AI is the most used technology when it comes to environmental sustainability, as the environment is a source of unlimited data, the AI power of machine learning and deep learning allow the firms to manage these data and make use of it, prediction of certain events, proposing adequate solution and the unstoppable data monitoring were the main AI capabilities that effected the environmental sustainability of the firms. The findings reveal AI as the predominant technology harnessed for advancing environmental sustainability. Given the environment's vast wellspring of data, the prowess of machine learning and deep learning within AI empowers enterprises to effectively harness and leverage this data. Anticipating specific events, offering tailored solutions, and continuous data surveillance emerge as primary AI capacities profoundly influencing firms' environmental sustainability efforts.

We acknowledged the limitations of our research. Using one specific case of a firm may restrict the findings' generalizability.We recognize that our approach solely takes into consideration inductive generalizability, but despite this, we think that our findings have significance in terms of external validity for two reasons.The first reason is that the firm under study is a leader in the information technology sector that operates as a multinational enterprise with a global footprint. This characteristic positions it as a valuable exemplar for other companies, irrespective of their countries of origin.Secondly, the company's Industry 4.0 leadership is evident through dedicated technology centers and the provision of solutions to major global corporations.

The single case study is a suitable methodology when the research discussed the societal change brought by technologies. In particular, the use of a single case study is acceptable when the issue addressed is crucial, severe, unusual, or revelatory (Dubé and Paré 2003). Given this, in upcoming research, the inclusion of additional single case studies involving diverse variables becomes imperative.Such studies can offer professionals a variety of scenarios from which to take inspiration when developing their digital transformation plans.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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Doseganje okoljske trajnosti s sprejetjem industrije 4.0: raziskovalna študija primera v industriji informacijske tehnologije

Povzetek - V današnjem konkurenčnem poslovnem okolju se je vključevanje Industrije 4.0 spremenilo iz izbire v nujnost za podjetja, ki si prizadevajo ohraniti svojo prednost. Glede na funkcije avtomatizacije interneta stvari, upravljanje in preoblikovanje podatkov z umetno inteligenco ter prednosti sledljivosti, ki jih zagotavlja tehnologija veriženja blokov, je ta nujnost zdaj bolj očitna kot kdaj koli prej. Čeprav prevladuje široko zanimanje za Industrijo 4.0, pa negotovosti, ki spremljajo postopek izvajanja, predstavljajo pomembne izzive. Zato v tem članku predstavljamo študijo primera podjetja, ki deluje na trgu informacijske tehnologije, z namenom prikazati proces uvajanja in premagovanja izzivov digitalne preobrazbe. Poleg tega je bil obravnavan tudi učinek na okoljsko trajnost.

Ključne besede - Industrija 4.0, umetna inteligenca, okoljska trajnost, digitalna preobrazba