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Industrial internet of things (IIoT): opportunities, challenges, and requirements in manufacturing businesses in emerging economies

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Abstract

Industry 4.0, often known as the Industrial Internet of Things (IIoT), offers manufacturing businesses tremendous financial prospects and challenges. In this empirical study (based on an inductive qualitative research approach), we combined a literature review and an expert interview to look at the latest advancements in emerging technologies for manufacturing transformation and the requirements and approaches that manufacturing firms in emerging economies must employ to complete this transformation. Based on our findings, we developed a thorough overview of factors associated with IIoT and identified areas for additional study to contribute to the IIoT transformation agenda. The results of this study can guide stakeholders, particularly managers of manufacturing businesses and researchers. The literature study results posit state-of-the-art studies on how the implementation of IIoT technologies can drive the transformation of manufacturing businesses in emerging economies.

Keywords: Industrial internet of things; manufacturing; digitalization; emerging economies

1. Introduction

The Internet of Things (IoT) paradigm has important applications in industrial environments. The Industrial Internet of Things (IIoT), also known as Industry 4.0, is an emerging technology that can revolutionize

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manufacturing and production by using a significant number of networked embedded sensing devices and integrating cutting-edge computing technologies [1,2].

As a result, managers globally are boosting their IT investment significantly [3]. Businesses' existence may be dependent on their usage of new technology. According to literature, new technology is assisting businesses in improving their performance and driving more sustainable solutions [3,4]. The increased use and dependence on digital technology have resulted in substantial economic and social development changes. By linking goods and services to digitized business opportunities, these technologies may help organizations become more competitive. For example, changes in manufacturing processes, distribution, and firm organizational structures have occurred due to technological advancements in production and resources management [5–8]. Companies may use digital technology to enhance resource flow, value creation, and capital attraction in real-time, allowing for business transformation. Companies might also apply digital technology to optimize and transform their operations, such as managing inventory, supply chain, fabrication, etc., [3,4]. Importantly, digital technology enables businesses to reinvent how producers and consumers interact and can be achieved by enhancing consumer awareness and trying to track materials [9]. Industry 4.0 include increasing human-machine interaction, tracking, and self-recognition of components via intelligent robots and optimizing manufacturing based on Internet of Things (IoT) connectivity [10]. The concept of IoT gained popularity after the Hannover Fair in 2011 as a nascent engineering strategy.

While literature has demonstrated the commercial potential of IoT, the Industry IoT (IIoT) research, particularly in engineering sciences, is still in its early stages of development [11]. There is a theoretical gap in technology acceptance, and utilization since existing literature has overlooked applications, prospects, and reviews. The issue is relevant in this respect because it is necessary to investigate the use of digital technology to establish successful economic operations threatened by changing sustainability standards and the natural course. This extra emphasis stems from the need to promote emerging technologies (both hardware and software) in corporate operations. The said technology may significantly influence business processes and can modify how they are carried out, impacting the role and importance of small and medium-sized enterprises (SMEs). IoT applications have ultimately impacted our society, adding value to business operations. IoT includes instruments for examining customer behavior, attitudes, consumption, and decisions. With the use of IIOT technology, it is possible to combine all of this data, including sensor output, user input, service provider information, and more, to deliver precise and efficient real-time responses, all of which have consequences and call for research into strategic planning. Moreover, RFID, geolocation, and sensor networks are all emerging technologies that are likely to expand further (according to reports, by 2025, there will be more than 25 billion linked devices, including houses, phones, automobiles, and factories) [12]. Unfortunately, few studies investigating concerns of IIoT in manufacturing in developing economies like Nigeria, and South Africa, adopted approaches developed by scholars in developed economies, as if developing nations operate in the same culture as their counterparts.

The manufacturing sector in underdeveloped countries has seen a slow and low implementation of digital technologies compared to those in developed countries [13], making it increasingly difficult for businesses and necessitating further research. Similarly, Okundaye et al. [14] observe that the pace of digital technology adoption between emerging and large economies is enormous. The delayed adoption of IIoT and intelligent technologies in most emerging economies have slowed economic progress [15]. As a result, given that firms have little knowledge of these smart technologies, any effort to learn how these devices may be adequately utilized will increase their awareness and guide their decision-making thought processes. The present article aims to investigate the essential success variables influencing the adoption of IIoT and digital capabilities, to assist companies and academics in effectively exploring them. The authors investigate what is available in emerging economies such as Morocco, Nigeria, and South Africa, which have a high potential for future manufacturing exports, as well as Western methodologies and strategies based on expert opinions of professionals from the United States of America.

Further, the authors proffer an understanding of IIoT enabling technologies in the built environment to benefit organizational development practitioners and manufacturing innovation experts. Overall, we highlight the opportunities, challenges, and proliferation of IIoT for manufacturing business excellence. The paper contributes to the existing literature on the application, performance, and prospect of the industrial internet of things to drive future manufacturing. It discusses strategies to accelerate Africa's capability and other emerging economies to become competitive.

2. Background

The modern and ground-breaking technology of industry 4.0, also called IIOT, is brought by IoT on industrial automation, which evolved from the commercial to the industrial level. The IIOT is paving the path for a speedy transition to Industry 4.0, a collection of business activities reshaping manufacturing for the future generation. IIOT enabled industry 4.0 can result in enhanced efficiency, high quality, lower costs, and safety [11,16]. IIOT will greatly facilitate tasks like factory assembly, administrative, quality management, and scheduling. It is anticipated that the IIOT's technology would increase the usefulness of unique brands and operating models like on-demand 3D printed products and machines-as-a-service (real-time operations) [15]. By identifying early signs of breakdown and halting their progression, the industrial IoT may protect industrial systems from downtime. By integrating IoT sensors into production systems, operators can accurately and quickly understand what is happening with the equipment. The IIoT provides the required tools and a framework for worldwide Internet Protocol (IP) interconnection. They can communicate with other devices on their network using the same architecture and protocols. Machine learning and big data technology can be supported by IIOT, as well as programmable logic controllers (PLCs) and supervisory control and data acquisition (SCADA). Data on quantities like pressure, temperature, vibration, flow, level, etc., can be gathered and used in the process control unit to improve operations. Experts in IIOT posit that these technological advancements will promote sustainability and green innovation, enhance supply chain management, and significantly increase manufacturing design, planning, sourcing, fabrication, delivery, and serviceability operations.

2.1. IIoT digitalization trend

Traditional manufacturing plants are being transformed into smart ones because of the widespread use of cutting-edge technologies like the IIoT and cyber-physical systems (CPS) [17]. The merging of these advanced technologies and integrating physical and virtual systems are the hallmarks of digital transformation. Although digitization is not a new phenomenon, its complexities are constantly evolving. Undoubtedly, digital transformation procedures are determined by the personnel and the resources available to them. As such, technology and know-how are crucial to the shift to digital. IoT can upend business realities and result in considerable operational benefits and high-quality goods and services.

Moreover, a shift in the big data paradigm is anticipated as a component of developing a competitive edge through data mining critical to a company's survival across many industries (business intelligence). At this level, big data utilization is forecasted to grow exponentially to predict the future sales of goods or services, forecast consumer behavior and trend in real-world and digital environments, and pinpoint cybersecurity concerns. According to Peter [18], there are three main categories in which to classify the cybersecurity-related issues that prevent organizations from adopting new digital technologies: (i) awareness and knowledge; (ii) integration of old and emerging technologies; and (iii) time, and resources devoted to cybersecurity. Robotics is another industry that is expected to grow rapidly. Robots will increasingly be employed not merely to replace human labor but also to interact with humans. Robots are expected to evolve to become more autonomous, flexible, and cooperative.

2.2. IIoT – enabled business strategies

Although much has been promised in "big data" and "digital manufacturing," many firms face outmoded IT infrastructures. The advent of IIoT manufacturing capabilities, such as the internet of production [19], will better transform the SME business model. Literature posits proven ways that may help firms obtain more value from digital-enabled business strategies and IIoT technology [20,21]. Rethinking the fundamentals of analyzing, executing, supporting, and utilizing technology innovations offers the most opportunity. In reality, innovation activities are frequently separated from the operational components of a company that they are most equipped to assist [22]. While many organizations strive to have as few fatalities, either due to pollution or poor safety practices and malfunctions, as possible, they fail to realize that when evaluating a potential technology, they must understand its capabilities and limitations.

For example, sensors on any device may be able to assess the system's performance through data points and issue warnings as needed, but they cannot predict why or when the system will collapse. Instead of simply providing data, predictive maintenance aims to create a strategy to forecast based on it (probabilistic). Thus, the system promptly predicts when a part will break and requests or orders the item for replacement from the maintenance staff, preserving the unit's productivity and profitability. As such, an early appraisal of the commercial viability of IIoT technologies is necessary.

The most significant barriers to using digital technology in business are on the structural and process levels [23]. Even if many innovations may not initially meet the market demand, the technology's maturity is also a significant factor. Starting a new enterprise is detrimental when there is no ready-to-use technology to drive the business goals. Hence, it juxtaposes why businesses fail to leverage potentially game-changing technological advancements. While pilot studies and prototyping are the most popular methods for evaluating new technologies, they typically lack an assessment of current technologies and explicit knowledge of interrelatedness and fundamental complexity. As such, it gives rise to the questions. Are the auxiliary or necessary technologies available, do the employees have the relevant expertise, and do they work in the preferred sociological condition, for example? Undoubtedly, strategies for accelerating business development are critical and require us to deviate from conventional practices by ushering in the IIoT technologies [15]. For enterprises to become competitive, stakeholders must modify their core strategies to harness their worth. While the process necessitates a double investment in time and risk, it can result in a more significant potential benefit for business excellence.

Furthermore, on the technological front, businesses will need to deploy cutting-edge software practices like Agile, RAD, DevOps, and other system development life cycle protocols, as well as solid data maintenance and management procedures. Efforts on the "first mile," or how to gather and process data, and on the "final mile," or how to ensure that the insights supplied by the digital technologies are translated into the behavioral patterns and processes of the enterprise. As such, it will need to be taken into consideration by businesses.

2.3. IIoT and manufacturing in emerging economies and from the African perspective

The urgency to industrialize Africa and invest in her human capacity to assimilate big data and access accurate data while gathering information for strategic decisions guided by advanced technologies to transition individual, corporate and governmental businesses cannot be overemphasized. The application of innovation such as IIoT in manufacturing is faced with several limitations, including the uncertainty of the performance of the technology and data theft, which has become a critical area of research in recent times and calls for protective measures [11]. Beyond CPS, IIoT also depends on embedded systems, cloud computing, edge computing, general smart factory-related technologies, and related software. During the past twenty years, the scientific and industrial agenda has undoubtedly been characterized by a mix of networked embedded systems and wireless sensor networks [24]. Regarding the IIoT device's sensitivity to dangers from both cyber and physical security aspects, several viewpoints are pertinent. Cybersecurity refers to technology processes and practices designed to protect network devices, programs, and data from attacks or unauthorized access [25]. It guarantees unauthorized access or infiltration. Sadly, this is yet to see the light of day in most African nations and other developing economies because such initiatives are mainly developed, managed, and maintained by foreign corporations and sponsored by foreign governments. Certainly, the cyberspace of Africa, from the perspective of manufacturing, is under threat of foreign invasion due to brain drain and exportation of its labor force (ICT and data science opportunities, among others, are lucrative in the diaspora) and slow technological advancement. Consequently, leaving room for cyber harking in developing economies (e.g., Nigeria, South Africa, etc.) and affects their industries and economic growth. This has increased the vulnerability of SMEs in the continent and led to the liquidation of several manufacturing companies that have struggled to stay in business (deficit of technology and shortage of knowledge, resource, and data).

3. Methodology

To improve the quality and usefulness of our findings, we applied various methodologies, including literature reviews and expert interviews.

3.1. Literature review of academics and practitioners

Following current best practices in operations research, a systematic literature study based on content analysis is conducted, as described in [26–28]. We adopt the three consecutive phases of material collection, category selection, and interpretation. We defined the search criteria and obtained the literature (material) to be investigated by consulting a wide range of academic literature and written communications (practitioners' literature), such as websites, encyclopedias, and newspapers (topics of relevance to the study). Aside from the search terms (applied to title, abstract, and keywords), the material collection is limited to English-language publications. This study's search period is restricted from 2001 to January 1, 2022. Scopus was chosen as an appropriate online database since it comprises scientific papers from international journals such as Science Direct (Elsevier), Springer, Emerald, IEEE, and Taylor & Francis, among others. To find as many articles as possible relevant to our research questions. We used the following defined research terms: ("industry 4.0" OR "Industrie 4.0") AND ("industrial internet") AND ("digitalization") AND ("smart manufacturing" OR "smart factory" OR "smart production" OR "smart manufacturing" OR "internet of things" OR “Cloud” OR "big data" OR "artificial intelligence" OR "additive" OR "digital" OR "cyber-physical"). A total of 76 relevant publications were found (following exclusion criteria) after a sample of 345 documents that initially fulfilled the criteria were filtered and validated against the keywords and content. The selected publications are reviewed to address the scope of IIoT in SMEs, with a focus on manufacturing businesses in emerging economies.

Furthermore, we looked at more than 87 pieces of practitioner-focused literature. The next phase was a practical screening to find any articles that weren't pertinent. After removing duplicates from the retrieved articles, we could locate 24 English publications in total. To discover the themes relevant to practitioners, we used an inductive method of literature coding. Each publication was then categorized according to its topic, article type, publishing type, and content.

3.2. Expert interview

We identified and interviewed selected experts because of their experience with many organizations during their career paths. We discussed our research questions without going directly to the individuals within the organization itself. There are numerous methods for completing qualitative interviews, such as group, semi-structured, unstructured, and structured interviews. The professional career network LinkedIn was used to choose the participants, applying the search criteria from the literature research to find pertinent candidates. After that, we looked over each candidate's profile to ascertain their experience doing business in the scope of the study, level of knowledge (based on current and previous jobs, projects that have been completed, and length of employment, for example), and origin and requested their participation via telephonic. To give the participants the freedom to voice their perspectives and share their experiences in the field of IIoT, we employed semi-structured interviews with open-ended questions. In addition to adopting a uniform definition for the research terms, we also asked targeted questions about the study's focus. After that, we applied Myers and Newman's [29] suggestions for listening techniques and improvisation. Out of the 49 eligible interviewees, twenty-one participating SME experts in the manufacturing industry were selected from Morocco, the United States, Nigeria, and South Africa. The findings are summarized in the sections that follow, and propositions have been developed in light of them to highlight how IIoT concepts might aid in changing the business strategies of SMEs.

RQ: How can implementation of IIoT drive the transformation of manufacturing businesses in emerging economies?

To answer the RQ, we identify the digital functions and technologies capable to drive IIoT and the potential opportunities. We focus on mitigating the challenges facing manufacturing and investigate the strategic requirements for manufacturing businesses to transform. As such, we seek to address the study RQ by integrating and triangulating the academic and practitioner literature with the results of expert interview data. This is consistent with validating the findings based on the literature and semi-structured interview, as reported in the section below.

4. Discussion and recommendation for future research

4.1. Lessons learned from literature

We presented an IIoT technology adoption in manufacturing, depicted in Fig. 1, based on the conclusions from the literature analysis and by adapting earlier contributions by Boyes et al. [30] and Malik et al. [31]. The concepts listed below have undergone extensive research and discussion [32–34]. Identified examples of IIoT-enabled technologies include but are not limited to cybersecurity, cyber-physical systems, cloud computing, edge computing, cognitive computing, mobile computing, big data, Artificial intelligence, 3D printing, advanced robotics, internet of things, machine-to-machine, and RFID technologies. Almost 75% of the literature we studied discusses the vital topic of collecting and analyzing big data. To effectively make sense of big data, one must examine it and get feedback to help make a strategic and informed decision. Aside from concern about the required skill to manage, interpret and apply this data appropriately, there are further issues about the security. Although cybersecurity and big data should be viewed as complementary fields, the latter is far less common in literature—only about 30% of the sample studies mention it. Less than half of the materials discuss the importance of IIoT in meeting various factory or client requirements. Over 60% of the publications emphasized the coexistence of machines and operators, with intellectual capacity or qualification playing a pivotal role. The collaboration of businesses with partners that may assist them in transforming and utilizing external knowledge connected to I4.0 is particularly encouraged [35].

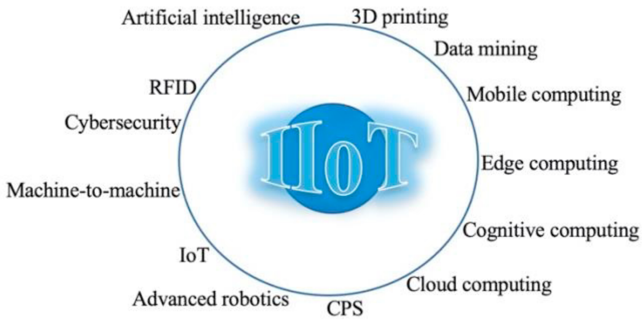

Fig. 1. Key IIoT technologies

Furthermore, from the review of practitioner-focused literature, we categorized six implementation success factors for IIoT: boosting computer processing power and communication bandwidth; developing deep learning and machine learning technology design and implementation centers or stations; cloud technology; enhancing the level of public and municipal digital services; increasing the human resource capacity to assist and grow developing economies' digital technology economies; the use of cloud computing in the economy and the enhancement of data availability and quality, both of which are essential for the creation of artificial intelligence technologies. We discovered that most practitioner articles adopt a descriptive approach by discussing or reporting on IIoT cases. Four overarching themes could be seen in the practitioner-focused literature: (1) benefits of IIoT, (2) results of a survey of IIoT adopters, (3) analysis of emerging trends in industries, and (4) industry 4.0 success stories with a focus on IIoT for advanced manufacturing. Discussing the opportunities for firms transitioning to IIoT-enabled technologies is the most important of those four issues. Over 70% of the literature suggests that operational costs, performance improvements, and increased control or adaptability are the driving factors for an IIoT proliferation decision.

Additionally, digitalization in manufacturing can increase visibility with remotely controlled devices, and human behavior factors can be eliminated with more sophisticated services. However, these interactions may vary between diverse domains. Moreso, these advantages come with some drawbacks, which we will discuss briefly below. While it is evident that IIoT will create new business opportunities, important issues must be addressed both from the social and technical standpoint. The fear of increased expenses, established structures, privacy, and resistance to change were cited in literature to raise social worries about IIoT systems. Several possible unfavorable effects were identified during our interviews with experts, including the following:

- Data security and the question of confidentiality, authenticity, and integrity of data;
- Cultural behavior and the fear of the emergence of new risks;
- User acceptance of the technology;
- And complexity and ease of understanding and applying technology.

These challenges could also be considered opportunities for more innovation and future research. On the technical challenges, the prevalent issues in IIoT technology development concern in manufacturing range from cybersecurity, standardization, the right to oblivion, data integrity, etc.

- Most operational processes are delicate and require privacy. Confidential information about product models, optimization data, or personal information must be treated with care.
- Data Chaos: several devices, when connected, communicate with each other and share information. This may cause traffic and wastage of channel bandwidth, leading to congestion control and affecting the correct data.
- Architectural design: the IIoT architecture necessary to handle the needs and advance the application of IoT technologies in manufacturing operations also raises concerns. Primarily to serve a specific purpose for which it is meant.
- Data Mining: the dataset in manufacturing operations is vast. There is a need for a developing approach to mining data and the tools for processing and analysis.
- Quality of Service: These network protocols measure the overall performance and provide multiple services. As such, the cause of any delay can affect the bandwidth, elastic traffic, throughput, sampling rates, etc.
- Data Visualization: the option of choosing between 3D visualization techniques or the application of Liquid Crystal Display (LCD) technology, Cathode Ray Tube (CRT), or Light-emitting Diode (LED), etc., becomes a challenge.
- Challenges of Cloud Computing: As integrated IoT and cloud applications continue to gain prominence, it enables the coordination of various services on different platforms. However, it also promotes a "multiple stack holders' situation."

4.2. Perception of IIoT and Prospect in emerging economies according to experts

IIoT implies ways to integrate digital technologies with a focus on how businesses might use them to fuel competitive business models, new markets, and long-term success. On the one hand, the social context for manufacturing has undergone significant changes, such as market globalization, consumer personalization, and societal and environmental sustainability. On the other hand, technology is evolving from dedicated machines to intelligent devices with many roles and autonomy. With the introduction of new cutting-edge technology, there is further potential to develop a proactive approach to production. Hence, introducing smart sensors in the industry, in particular, can increase the volume of data gathered, opening up new opportunities for production system improvement [36]. Real-time monitoring and automated data analysis in manufacturing enterprises can provide product tracking and predictive maintenance using IoT, CPS, and Blockchain. In addition, several IIoT technologies, like 3D printing, advanced robotics, and AR/VR, to name a few, can improve flexibility and mass customization possibilities, which strengthens a company's value proposition. Although, the application of IIoT necessitates, in addition to large capital cost, a change in culture and organizational structure. Transdisciplinary workplaces and proactive dialogues are also required to innovate existing processes. Businesses must request resources and input from various sectors that may not necessarily fall under a particular industry's purview to foster partnerships within and between sectors.

The emphasis is on emerging economies to develop ways to understand and deploy IIoT technologies in their manufacturing sector and address among the earlier listed drawbacks: unwillingness to let go of old techniques; outdated organizational structure and experts, lack of commitment to technological improvement; worries about bringing new ones; and concerns about sustainability. According to interviewees who have supported or conducted IIoT transitions, many firms chose to initially abandon the previously adopted business models before introducing new strategic, business-critical capabilities driven by digitalization.

4.3. Factors associated with IIoT transformation in emerging economies

Nascent approach and methodologies to implement measures to address various challenges IIoT adoption and deployment must be met. There is expected to be an overreaching directive to manufacturing businesses to transition to digitalized operations while providing assess to digital capabilities and technical skills or training to assist them. Government and various stakeholders can begin by subsiding and easing licensing processes for manufacturing businesses. Location and access to IIoT technology prototypes are necessary to help adopted understand and explore the technologies. Public information sharing (enlightenment campaign) in the form of information dissemination about advanced technologies and prospects can go a long way to mitigate negative cultural behavior. It is also critical to organizational development programs for all tiers of employees to enhance their digital literacy. As such, raise awareness of the possible benefits of implementing Industry 4.0 technology. The need to establish a sustainable network for foreign experts to guide access to funding programs to stimulate corporate investment in the manufacturing sector of emerging economies can help the application and operationalization of IIoT. Organizations must begin proactive leadership and administrative capabilities in Industry 4.0 and support businesses in upskilling their present workforce by examining the skills needed and directing them to the proper resources. The digital functions must adapt to face the challenges of IIoT, including new internal organizational models, new collaborative efforts, and consistent organizational operating units. These advances can result in a progressive transformation of roles and capacities of today's digital services and create new structures, processes, methodologies, and regulatory frameworks for IIoT transformation in manufacturing.

5. Conclusion

Our objective for this paper was to determine how IIoT transformation can impact manufacturing enterprise performance, focusing on emerging economies, reviewing available literature, and gathering insights from experts on the same topic. Additionally, we aimed to understand the aspects of the IIoT transition by identifying opportunities, challenges, and requirements for manufacturing and research. We conducted an academic and practitioner-focus literature review on the scope of the study. We cross-linked the themes to facilitate an expert interview with professionals in the field to support our findings. The experts confirm that although IIoT is gaining prominence in diverse industries, it is observed that CEOs and IT managers in manufacturing are uncertain about how to go about with the challenges of digitalization and so have become reluctant to take actions that can support their business to grow.

Moreover, many IIoT initiatives lack the requisite structures, processes, and capabilities to generate business innovations. Furthermore, they are frequently seen as being too bureaucratic, inflexible, and not consistent with their business model. The argument for IIoT transformation is that companies that want to progress in the evolving digital era must exploit the implementation of digital technology, rethink their business strategies and transform their operations. Three main areas of focus for organizations transforming into digital enterprises:

- It is recognizing and exploiting the disruptive potential of IIoT technologies.
- Developing and managing digitally enabled manufacturing.
- Launch IIoT transformation.

By combining academic and practitioner-focused literature with expert interviews, we could identify requirements to extend the existing body of research on the impact of IIoT on manufacturing, focusing on emerging economies. As such, the current wave of digitalization can tremendously impact the manufacturing sector: CPS, big data, IoT, edge computing, and cloud computing all have a substantial impact on operations, products, services, and business strategies. Additionally, during the expert interviews, two new reasons emerged that were not present in the literature but are critical to the impact of IIoT transformation and recommended for future research, namely the transdisciplinary workplaces in the IIoT transition and the need for proactive dialogues. Finally, our research is limited by the possibility of missing key experts in the subject. A potential non-response bias resulted from us omitting additional opinions because not all of the contacted experts were interested in participating in the interviews.

Furthermore, throughout the literature retrieval, we concentrated on a few databases, leaving the possibility of missing further publications that were only available in other databases. Despite the constraints mentioned earlier, we are confident that our contribution follows a sound and ethical research methodology and benefits both the academic and practitioner communities. In summary, our research supports the three key requirements for digital function on the cusp of the fourth industrial revolution era, according to literature [37,38], to launch IIoT transformation in emerging economies to bolster manufacturing through design-innovate-transformation capabilities.

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