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ORIGINAL RESEARCH

5G supporting digital servitization in manufacturing: An exploratory survey

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Abstract

Digital servitization is a business model transformation process enabled by the use of digital technologies to create or improve industrial services and product-service offerings by creating value and competitive advantage increasing customer satisfaction and loyalty as well as company revenue streams. 5G networks can enable digital servitization of manufacturing by providing faster, more secure, and more reliable communications between machines, devices, and humans. This paper explores the impact of adopting 5G technologies on servitization and identifies the services that can benefit most from 5G networks. The research consists of two parts: a literature review of the technologies currently used in the design and provision of industrial services that could benefit from 5G networks and an exploratory survey involving manufacturing companies that have started the digital servitization journey. The main results emerging from the research suggest that 5G can profoundly impact services supported by Augmented Reality, Cloud computing, and Cyber-physical systems, mainly concerning maintenance, workforce training, machine diagnosis and monitoring.

KEYWORDS

5G, digital servitization, smart pss, wireless communication networks

1 | INTRODUCTION

Servitization refers to the transformation of traditional manufacturing firms business models from selling products to offering integrated product-service systems (PSS) [1]. In recent years, an increasing number of companies have started to offer servitized business models [2] selling integrated solutions that include both the physical product and a set of services – such as installation, maintenance, repair, and upgrades [3, 4] – that are designed to enhance the value of the product, better meet customers' needs, as well as generate new revenue streams, thereby strengthening the relationships with the customers and loyalty [5]. Most recently, the transition towards servitization has been boosted by technological advances, particularly in data analytics, the Internet of Things (IoT), and Cloud Computing (CC), enabling new digital services [6, 7]. Therefore, the paradigm of *digital servitization* has been conceptualised as the development of a servitized business model towards the adoption of digital technologies [8], promoting, for example, a transition towards product-service-software solutions that enable value creation through monitoring, control, and optimisation [9]. Therefore, the need to ensure fast, reliable and safe communication networks is emerging in a context where data is crucial to support digital servitization offerings.

To this purpose, 5G networks are expected to revolutionise the manufacturing industry by enabling faster, more secure, and more reliable communications between machines, devices, and humans that, in turn, will boost more efficient, adaptable, and cost-effective operations [10]. Indeed, 5G technology is characterised by three basic features, namely enhanced mobile broadband (eMBB), ultra-reliable low-latency communications (URLLC) and massive machine-type communications, that can support real-time applications and massive data flows between several devices simultaneously [11]. Even though some 5G networks are starting to be studied and adopted in manufacturing contexts, their application to support specific PSS offerings is still needs to be explored, both in the scientific literature and industrial practice.

To fill this gap, this article investigates whether 5G networks can have a significant impact in the context of servitization. The aims of this study are twofold: (i) first, this paper provides a theoretical characterisation of the expected impact of 5G networks on industrial service offerings. To achieve this goal, this paper proposes a literature review of scientific and grey literature about 5G and servitization. (ii) Second, through an empirical investigation, this research explores if expectations are met in practice. The second part of this study is therefore based on an exploratory survey research involving 36 servitized industrial companies. The goal of the exploratory survey research is to determine how businesses are addressing the topic of digitalisation and the possibility of integrating 5G to support services, if there are already instances in which 5G is used to support services, and if there are other technologies that are not being considered that could represent an opportunity. In addition, the survey results will be compared with the findings in the literature to determine if manufacturing companies have already considered the findings of the studies or if there is still a lack of knowledge regarding the integration of 5G into support services.

The paper is structured as follows. Section 2 presents a general background about digital servitization and 5G to clarify the current gaps in the literature and practice and support the objective of this work. Section 3 presents the methodology of this research, highlighting the methods used to identify the services that could be enhanced by 5G and the exploratory survey research. Section 4 and 5 report the results of the conducted investigation. Section 6 discusses the main insights emerging from the research. In Section 7, conclusions are drawn, limitations are reported, and future research directions are envisioned.

2 | BACKGROUND

In this section, we provide the background concerning digital servitization (Section 2.1), 5G main characteristics (Section 2.2), and the relationship between 5G and servitization with a particular focus on the gaps to be filled (Section 2.3).

2.1 | Digital servitization

Servitization is defined as "the transformational process of shifting from a product-centric business model and logic to a service-centric approach" [12]. Digital servitization is an emerging idea that underlines the interplay between digitalisation and servitization. It refers to utilising digital tools for the transformational processes of companies undertaking the abovementioned shifting [13]. Digital technologies related to a business's service orientation include IoT, CC, cybersecurity, mixed reality, Additive Manufacturing (AM), simulation, artificial intelligence, and Cyber-physical systems (CPS) [8]. Exploiting these technologies, digitalisation significantly impacts businesses, upstream and downstream activities, networks, and ecosystems, even if the shift towards smart goods and processes requires several adaptations from a technological and organisational point of view for companies who struggle with this transformation [14]. Digitalisation may also produce profound changes in interfirm transactions, power relationships between companies, and strategic identities (e.g., manufacturing firms becoming more like software companies) [9], therefore having the potential to speed the servitization journey by enabling different opportunities of value creation from data driven services [15]. At the same time, digital technologies can enhance different service categories [8], ranging from base to advanced one, according to the definition provided by Baines and Lightfoot [16].

Recently, the convergence of studies in the field of digital servitization – that is, more focused on the companies' transformation journey - and PSS - that is, more focused on how the combination of products and services can bring benefits for customers - lead to the development of new concepts, such as smart PSS (SPSS), digitally-enhanced PSS, digitally-enabled PSS [15, 17]. They represent integrated systems that combine physical products, smart technologies, digital and non-digital services, and digital business models to create customer value [18]. Generally, these systems use sensors and data analytics to monitor and analyse product usage and performance, which enable proactive maintenance, customisation, and continuous optimisation of services [19]. According to the different data journeys that characterise the design of digital services, different customer value is created and specific benefits emerge, including increased efficiency/efficacy, focalisation, and cognitive and social benefits [15]. Remote monitoring and control through SPSS can enable manufacturers to continuously supervise production processes, allowing for real-time adjustments, and reducing the need for on-site personnel [20]. Services enabling manufacturers to monitor and optimise product quality in real-time also result in fewer defects and improved customer satisfaction [21] while through remote process monitoring and control and predictive maintenance downtimes can be reduced, improving overall production efficiency [15]. Also, digital technologies can be deployed to increase customer satisfaction and loyalty by enhancing the design of customised and personalised products and services [22]. In addition, considering the perspective of service providers companies adopting new SPSS offerings can broaden their portfolio of revenue streams [23] and reduce costs by optimising the service delivery processes [8].

Therefore, given the manifold benefits that can be envisioned, the continuous development of sophisticated and optimised digital service offerings requires high attention both from academic and industrial communities.

2.2 | 5G main characteristics

Currently, industrial networks are based on the integration of complex heterogeneous systems. About 90% of industrial communication is based on wired technologies, such as EtherNet, PROFINET, and ModbusTCP protocols, while wireless communication, such as the one offered by Wi-fi, has become attractive only in recent years, supporting the requirements of reconfigurability and modularity in modern factories [24]. The 5G constitutes the latest generation of mobile communication technology developed to upgrade the reliability and speed of data exchange, and represents a significant leap forward in the world of telecommunications in industrial systems. The main features of this new technology can be summarised as follows [25–27]:

- The data transfer rate turns out to be much higher compared to 4G. The maximum theoretical speed will be 10 Gbps (Gigabits per second), thus allowing a considerable quantity of data to be transferred and handled simultaneously.
- Ultra-Reliable Low-Latency Communication will allow ultra-responsive connections. Latencies of less than 1 millisecond will be reached, and ultra-high reliability (up to 99.999%) and network availability will be guaranteed.
- Power consumption is lower compared to previous technologies. "Stand-by" (sleep) modes can save up to 50% energy, compared to the maximum 20% savings of 4G technology.
- Connection density, that is, the number of devices connected simultaneously and the data flow that can be handled, is around one million connections per square kilometre.
- 5G frequencies will exploit new enlarged spectrum bands, that is, possible frequency bands ranging from 30 to 300 GHz.

Considering the characteristics mentioned above, 5G has the potential to support manufacturing industries. However, 5G in the industrial context is still under-researched, and few applications exist, thus requiring further investigation [28].

As with any significant technological transition, the Information and Communication Technologies industry has gained knowledge over time. There is a significant potential and earlier focus on consumer market (B2C) 5G services than initially projected, with verified but later uptake of industry (B2B) uses cases. The reasons for this change over time include generally adopted scope changes, and more evolved perspectives on technical competency levels, organisational impediments, and the inertia and regulations surrounding legacy system replacement cycles [25]. Real-time automation offers up to 107 billion US dollars in value, while connected cars provide up to 89 billion US dollars [29]. The spread of 5G will likely significantly impact industrial businesses, resulting in much quicker and more precise operations. From a commercial perspective, 5G offers several options to increase a company's efficiency and long-term expenses, all indicating that it will be a revolutionary advantage for the manufacturing sector. However, the effective deployment of such a system, especially in the manufacturing industry, would need a massive change in financial, social, and security measures, which will all take time to find a solution [28].

2.3 | 5G and servitization: a gap to be filled

Despite the potentiality of 5G, the current literature and industrial practice have not yet focused on the opportunities of adopting 5G specifically to support the shift to servitization or the improvement of current SPSS offerings. Considering the 5G characteristics described in Section 3.2, it is possible to envision some main advantages concerning the development of 5G-enabled SPSS that require further exploration.

1. High-speed connectivity: 5G networks can provide high-speed, low-latency connectivity, enabling real-time communication and data transfer between connected devices and systems. This aspect can improve the performance and reliability of already implemented SPSS in monitoring and controlling machines and equipment.
2. Massive communication: 5G networks can offer significantly greater bandwidth than previous generations of wireless networks, enabling more devices and systems to be connected simultaneously. This benefit can allow for the expansion of SPSS to include more devices and services.
3. Improved reliability: 5G networks can provide more reliable and stable connectivity, reducing the risk of data loss or network interruptions. This characteristic is crucial for SPSS, which relies on consistent data flow and communication between devices and systems.

Even if all these benefits can be generally related to the 5G networks characteristics, to promote their wide adoption, it is of utmost importance to better point out which product-service offerings can be improved and the other involved digital technologies that exploit 5G. Indeed, 5G networks are successful if they are appropriately integrated into the manufacturing and service infrastructure, and combined with other digital technologies. Otherwise, several challenges could emerge that prevent companies from undertaking targeted investments. Based on what has been already observed in the manufacturing context [10], typical challenges that can be encountered vary from the need for significant investment in both infrastructure and software technology, which are especially critical for smaller businesses or organisations, to the lack of specific skills and expertise in areas related to wireless network management, cybersecurity, and data analytics.

For these reasons, this paper aims to provide a clear overview of the application of 5G networks in the service field, pointing out the related technologies and embracing the industrial perspective by involving service stakeholders. In the following sections, the methodological approach and the obtained results will be extensively discussed to finally illustrate the true potential of the application of 5G to support digital servitization.

3 | METHODOLOGY

To fulfil the above-mentioned gap, in this research, we adopted an exploratory survey research method to provide an overview of the applications of 5G networks in the service fields, and to understand how the technologies related to 5G can help the servitization process. Indeed, exploratory survey research takes place during the early stages of research into a phenomenon, when the objective is to gain preliminary insight on a topic, and can help to determine new facets of the phenomenon under study as well as to provide preliminary evidence of association among concepts [30]. Exploratory surveys are an excellent vehicle for measuring a wide variety of unobservable data, such as companies' preferences and behaviours [31]. An additional advantage of the exploratory survey methodology lies in its ease of replication, even over extended periods of time. This characteristic facilitates longitudinal analysis, which is particularly valuable for studying dynamic processes as they unfold and evolve [32].

We opted for a structured questionnaire survey (i.e., ask respondents to select an answer from a given set of choices) self-administered by e-mail. Considering the aforementioned strengths of the survey methodology, this type of survey option represents a suitable choice. Furthermore, it offers the advantages of being cost-effective and unobtrusive, despite the tendency for relatively low response rates [33]. Survey methodology also has some disadvantages. In particular, surveys are affected by bias due to the low response rate (*non-response bias*), the respondent sample (*sampling bias*), the fact that many respondents tend to avoid negative opinions or embarrassing comments about their companies (*social desirability bias*), the respondents' motivation, memory and ability to respond (*recall bias*). Consequently, a robust survey research process is needed to prevent and overcome the above-mentioned biases. This process regards studied topic identification, sample definition and questionnaire creation. To ensure replicability and consistency in the application of the survey methodology, we have followed the guidelines proposed by [30] for the implementation of survey research and operations management (Figure 1).

Stage 1 Link to the theoretical level

As shown in Figure 1 the first step of the research regards the establishment of a link to the theoretical level (i.e., the scientific literature) in relation to the problem to investigate: the role of 5G in servitization. To this purpose, a literature review analysis was conducted to understand the main trends and gaps in the scientific literature reviews and based on them the starting point for building a survey addressed to industries already servitized.

The literature review was conducted on Scopus and Web Of Science, two of the main scientific literature databases. Scopus and Web of Science databases were used in the analysis because most academics recognise them as two of the most complete bibliometric databases of scientific and technical peer-reviewed literature [34]. However, since the topic is relatively recent, it was decided to include grey literature and reports from companies directly involved in developing 5G or its applications to be as comprehensive as possible. Moreover, we decided to start the analysis in 2019 since Release 15, the first full set of 5G standards, was delivered at the end of 2018 [35]. In Table 1, it is possible to see the inclusion criteria used for the literature review research. The results of this step are presented in Section 4, where the four main technologies related to service and 5G are identified and extensively discussed.

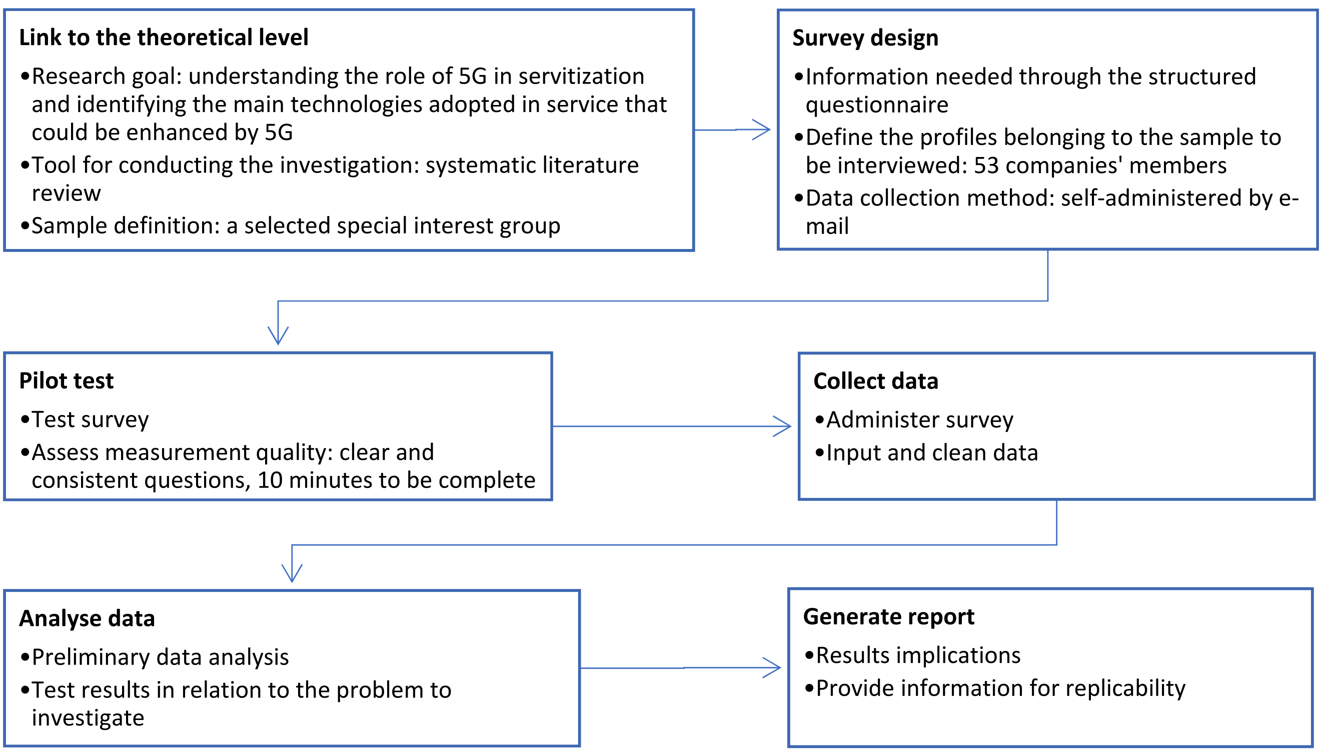

FIGURE 1 Research methodology adapted from [30].

TABLE 1 Literature review inclusion criteria.

Inclusion criteria	Description
Keywords	5G* AND service* OR servitization* AND technology*
Language	English
Document types	Articles, conference and grey literature
Source types	Peer-reviewed journals, conference and grey literature
Subject areas	Business, management, accounting; engineering; computer science; decision sciences
Time interval	2019 – 2022

In this phase, the sample for the study was carefully defined as well. Specifically, a non-probabilistic sampling approach was employed to gather information that is specifically relevant and available only from special interest groups [36]. This sampling strategy was chosen to ensure that an adequate range of the phenomena of interest is included, without strict statistical requirements for a minimum number of responses [37]. This approach entails identifying and selecting individuals or groups who possess specialised knowledge or extensive experience with the phenomenon under investigation [38]. The chosen special interest group selected refers to manufacturing companies involved in the ASAP Service Management Forum - ASAP SMF (www.asapsmf.org). The Forum has been active since 2003 as a research community where scholars and managers collaborate in developing and sharing knowledge and experiences on the servitization of industrial companies. ASAP Service Management Forum community includes 53 companies.

Stage 2 Survey design

In this stage, based on the results of the previous stage, the questionnaire for the survey was designed. The 15 questions include contents concerning digitalisation related to the services provided and aspects of introducing 5G to support technologies for services.

In this stage we also identified the professional figures, within the 53 companies in the ASAP Service Management Forum community who would be the most likely to respond to the questionnaire. The respondents included in the ASAP SMF were selected based on the following criteria: a) they should be in executive roles (e.g., managing directors, service directors, service managers) and responsibilities in firms operating in different industries to facilitate sector-independent discussions; b) they should have been acknowledged for their expertise in servitization; c) their companies have already started the journey of digital servitization; d) there should be at least a given amount of participants with previous or current work experience in smaller firms to obtain solutions in line with the paper's objectives; e) they have an express interest to contributing to scientific research and predisposition to collaborate with their peers and academic researchers. The sampling and the respondent's choice are helpful in avoiding sampling bias. Moreover, to avoid social desirability bias, in the questionnaire there were no direct questions about company performances, employer satisfaction or more in general about personal opinions. We have opted for self-administered questionnaire by e-mail.

Stage 3 Pilot test

To avoid recall bias, the survey was tested by three of the most representative companies in the sample (i.e., in terms of years of belonging to the group and operating in the servitization sector, a high degree of technological maturity concerning digital services). The goal of this pilot test was to guarantee the readability and the consistency of the questions, to avoid the non-response bias due to non-understanding of the questions and to verify the time necessary to complete the whole questionnaire. According to the feedback provided by the respondents some questions have been reworded to be clearer and more understandable. Furthermore, it was found that the average duration for filling in the questionnaire by the three companies included in the pilot test was 12 min.

Stage 4 Collect data

The data collection process lasted 30 days. During this period, 36 out of 53 companies answered the questionnaire (74% response rate), considered statistically acceptable [30]. After the data collection, the answers have been checked to exclude incomplete answers.

Stage 5 Analyse data and Stage 6: Generate report

Finally, the questionnaire results were compared to the literature analysed in Stage 1. Cross-tabulation survey data analysis was performed as well [39]. The results of the empirical analysis involving industrial companies are reported in Section 5, where the survey answers have been reported and analysed in the light of the gaps identified in Section 2.3, which are finally filled by the research outcomes, further developed in Section 6.

4 | 5G SUPPORTING DIGITAL SERVITIZATION

As suggested by the first stage of the adopted methodology, the investigation of the role of 5G in servitization, conducted through a literature review, aimed at finding the main research trend and gaps in this field to have a scientific-grounded base on which to build the questionnaire for the companies working in this domain. As a result of this phase, the applications of technologies that benefits from 5G networks that can be used to enhance the design of smart product-service offerings and the deployment of more efficient digital services delivery emerge. In particular, four main technologies have been identified as the most cited in the literature and have been therefore deepen to understand the broad spectrum of possibility to adopt them in relation to 5G to design and deliver digital services. The technologies are Augmented Reality (AR), AM, CPS and CC. In the following, the related services are shown and the potential improvement driven by 5G adoption are presented. The results of these section are useful to identify the main opportunities that industrial stakeholders will be asked to evaluate in the survey.

4.1 | 5G in augmented reality-based services

Augmented Reality technology improves the immersive and interactive experience between users and machines by combining stimuli from human senses with digital perceptions, enabling users to freely navigate the actual world and see together virtual models [40]. Augmented Reality has already disrupted product design, manufacturing, and maintenance [41]. The use of AR in the industrial sector is significant because it considerably enhances communication in product design and products development and accelerates the creation of products and processes in a variety of industrial applications [42], thereby requiring high data transmission rates, low latency, security, and excellent coverage to ensure an acceptable quality of experience, which ultimately translates to a high rate of technology acceptance. In this context, the higher frequency characteristic of 5G eMBB and software design network architecture led to greater bandwidth and quicker transmission rate than 4G. 5G wireless-based Edge computing (EC) systems carry the potential of revolutionary benefits in the area of AR-assisted work [43].

In the service sector, AR permits the remote assistance of apprentices by experienced professionals and provide training to many apprentices simultaneously [44]. Detailed specifications or process instructions may be delivered through AR or speech to boost efficiency and productivity, minimise mistake likelihood, and shorten the time required for on-site training/learning on the job and enabling risk-free simulations of hazardous or risky jobs or even catastrophic occurrences [42]. Considering services related to maintenance and repair, 5G allows fast, dynamic, and simple access to machine information and process models, allowing a technician to quickly go from step to step without having to download new models or reference paper instructions [41]. Eswaran et al. [45] suggest a system architecture to assist technicians in performing AR-guided diagnosis, maintenance and repair, pointing out that 5G networks currently offer adequate AR features to support these applications. Augmented Reality can support maintenance technicians in exchanging information, creating AR-based digitalised data reports, capturing machine failure images, text, video, and audio, easy to share with other specialists, and using cloud platforms.

Finally, service teams can also employ AR to monitor operations in real-time utilising data provided by digital twin and analytics tools, as well as promoting the implementation of digital assistants, enabling voice interaction between plant personnel (with spoken inquiries) and the service assistance system to obtain up-to-date and competent responses. In this regard, 5G would be a crucial facilitator to provide reduced latency between inquiries and responses, allowing both a distant human expert and an automated service assistant to give real-time, live, peer-to-peer support utilising on-screen video. Moreover, 5G technology enables sub-meter indoor localisation, therefore unleashing the potential of several AR applications depending on the user's location, and by offloading data storage and processing to an edge cloud platform, the hardware on the 5G-based AR headsets might be reduced. A direct effect of the last modification is the possibility to miniaturise the AR headset's hardware, resulting in lighter and more ergonomic devices [41], able to overcome current challenges about AR applications in service provisions related to wearability [46].

4.2 | 5G in additive manufacturing related services

Additive Manufacturing is a manufacturing method involving layer-by-layer material deposition onto a substrate. Such a technique permits the production of high-complexity components, and as a result, it is commonly used in economic sectors that demand individualised products or geometry-driven performance [47]. The AM technology is based on a computerised three-dimensional solid model that is produced, then converted into a standard AM file format and finally sent to an AM machine, where it can be modified in the orientation and size to be fabricated on the AM machine by adding successive layers [48].

The number of services associated with AM continues to increase. Some of them are directly related to digital products, such as designs available for download in end-to-end marketplaces or PSS solutions related to New Product Development based on AM, suitable for B2C and B2B customers. Other services, such as preparation and optimisation or production scheduling, are often covered under a Software-as-a-Service (SaaS) contract. Some technology organisations provide training, counselling, technical support, reverse engineering and 3D scanning as part of their full-service offerings. Advisory, research, and certification are key services for high-tech businesses that need rigorous system validation [47]. Even though the vast majority of service business apply AM applications for rapid prototyping, some may be able to handle low-volume productions, which is often outsourced, that could boost the concept of "Manufacturing-as-a-Service" (MaaS) [49]. Also, applications like on-demand printing of spare parts, direct deposition repair, and even availability contracts for the prompt delivery of utilities and consumables may significantly impact the long-term viability of a PSS. Therefore, AM implementation in the service sector can affect two major fields of benefits concerning economic profitability and environmental performance [50].

Recently, several authors highlighted the need to promote smart AM by developing proper architectures to manage the massive amount of data generated during AM processes [51]. In particular, the development of digital twins, exchanging data in real-time with physical objects, has the potential to affect the AM process in several ways, including the optimisation of process parameters, the identification and monitoring of quality problems, the reduction of the computing load required for multi-scale modelling [52]. Therefore, in the context of smart AM, 5G characteristics like low latency, high transmitting rates and greater bandwidth could prove successful implementation. Additive Manufacturing systems that use 5G and IoT to run artificial intelligence applications have started to be designed and show high potential also in the service sector [53].

4.3 | 5G in cyber-physical systems related services

Cyber-physical systems are one of the core components of smart manufacturing. They combine the physical and cyber worlds through communication networks, offering advanced monitoring and control of real-world processes and computational capabilities [54]. Cyber-physical systems relies on the combination of many technologies that range from hardware (e.g., sensors) to software (e.g., wireless communication networks) and can involve multimodal human-machine interfaces (HMI) [55].

In manufacturing contexts, CPS are employed to acquire data by the physical devices to diagnose, self-adaptation and entire self-heal processes [56]. Indeed, real-time data analysis can provide information about the equipment's current status and detect complex correlations utilising big data analytics [57], thus enabling many services related to monitoring, diagnosis, maintenance and repair that can provide customers increased flexibility, efficiency, and technical availability. Through data analysis, other services based on prediction, adaptive control and optimisation of product/system can be deployed [8]. Herterich et al. [55] present a taxonomy of all the industrial service scenarios involving CPSs, that involve all the product/service lifecycle phases. Expected impacts of introducing CPS in the service field also concern service technicians, who can exploit more powerful mobile work support systems, such as wearable devices, providing vital information that may improve service efficiency. In any case, since the involvement of humans has high relevance in the provision of CPS-based services, the development of mobile HMI (HMIs) could often be critical due to the necessity to develop customer-specific interfaces and due to the wireless implementation of such HMI in reconfigurable and adaptable cyber-physical production systems [58].

The 5G mobile communication standard is the technology solution that fits the criteria for high-performance wireless communication in CPS and related HMI. 5G is designed to enhance the primary capabilities of a mobile network's core. Utilising network slicing and private networks, 5G technology may accommodate the needs of current HMIs in production systems and enables HMI's essential mobility and scalability for interacting with many machines via a single input interface [58]. Additionally, since different machines and equipment involved in monitoring services could generate different data streams, 5G leverage distinct network slices to satisfy different devices' requirements.

4.4 | 5G for cloud computing and edge computing

The CC architecture offers network access to a shared pool of computing resources, such as servers, apps, and sensors. According to the National Institute of Standards and Technology definition [59], CC has the following five characteristics: i) Self-service on demand, namely computational capabilities may be offered based on the actual requirement; ii) broad network access, namely all required tasks and capabilities, such as frequent updates or computations, are accessible through CC; iii) resource pooling, namely computational resources are pooled in order to serve a more significant number of organisations. Users are allotted resources based on their needs and desires; iv) rapid elasticity, resources may be offered scalably and automatically based on user demand; v) metred service, namely CC, can control and optimise available resources. In summary, CC enables the use of resources on demand based on the ideas of software, platform, and infrastructure as a service. It is very scalable and allows many concurrent users to use this technology.

Additionally, existing computer resources are no longer necessary on the consumers' premises, saving space and reducing administrative work. As a further step, CC can be combined with EC, described as data processing at the network's edge before sending the processed data to the cloud. Integrating EC and CC has many advantages, including decreased reaction time, enhanced processing efficiency broader connection of several devices [60].

Through the years, the adoption of CC contributed to the development of cloud manufacturing that combines CC technology with service-oriented architectures to link users' needs to resource providers who can fulfil those needs along all product development life cycles [61]. In the servitization context, cloud manufacturing offers a new business model that facilitates the transformation of the manufacturing sector from production-oriented to service-oriented, enhancing the adoption of a pay-per-use approach. Cloud manufacturing services consist of design as a service, production as a service, simulation as a service, assembly as a service, testing as a service, logistics as a service, management as a service and integration as a service [62]. Using many cloud manufacturing services, consumers may request on-demand, customised services that meet their needs. In other words, when some users have a creative idea for a conceptual design, they may get all necessary production services until the finished product is delivered. This aspect benefits many tiny businesses that lack pricey manufacturing facilities and those major firms with idle manufacturing capabilities.

The upcoming 5G technology for cellular communication gives the possibility to utilise all the benefits of CC, mainly supporting EC-related applications [63]. In particular, considering services that are related to the IoT and data management, which are generally offered relying on cloud infrastructure, 5G and EC can facilitate computational and storage resources near data sources, which can be used for processing purposes, reducing IoT data and signalling, ensuring a fast response to user requests or enabling new services [64].

5 | SURVEY RESULTS

This section presents the results of the exploratory survey. The main objective of the survey is to fulfil the gap discussed in Section 2.3, concerning the identification of the most promising application of 5G networks in the servitization and the perception of companies towards its adoption. Therefore, also in accordance to the main insights emerging from the literature, the survey was designed to collect information about two main domains:

1. *Servitization and digitalisation.* The company approach to servitization was assessed through the identification of the current service offerings (based on a selection of the services classified by Gaiardelli et al. [4], while the company journey towards digitalisation and digital servitization emerged also through the identification of the most adopted technologies referred as relevant in the background [7, 8]. These results are reported in Section 5.1.
2. 5G *and servitization.* The industrial perspective about 5G and impacts on servitization was assessed by discussing the potential digital services reported in Section 4, related to the four technologies: AR, AM, CPS, CC. These results are reported in Section 5.2.

5.1 | General perspective about servitization and digitalisation

The surveyed sample comprises mainly manufacturing companies (64%) in different industries such as machinery and electromechanical, but also automotive and handling systems. The rest of the sample is composed by other industries like utilities (14%), service (8%), chemical companies (5%) and others (Agriculture, Food, IT). Regarding the company size, 61% of the sample includes large companies with more than 250 employees, followed by medium companies (22%) with 50–250 employees and small companies (17%) with less than 50 employees. Since the survey aimed at exploring the strategical use of 5G to improve service offering, most respondents cover managerial positions in service (28%) and operations (22%) area. Another 22% of the experts are Chief Executive Officers or Business Directors. Remaining respondents belong to Sales, R&D and Supply Chain areas.

The first questionnaire section aimed at overviewing the current service offerings that the companies provide to their customers (Figure 2). It is possible to observe that most respondents provide maintenance services on the product in the form of corrective maintenance (when a problem occurs, the company takes corrective actions), preventive maintenance (periodic maintenance to avoid damages or failures), and predictive maintenance (using sensors that monitor parameters and give alerts when there are risks of damages). The majority of the sample also provides monitoring and diagnosis services to control the products' capabilities and parameters. Another frequently provided service is related to training performed by the companies to their customer, enabling people to learn the functionalities of the products. Nearly half of the sample (exactly 19 companies, equivalent to 52.8%) offer product and process design services, allowing customers to receive customised solutions that precisely meet their requirements.

Cloud services like data management and storage are provided respectively by 17 and 13 companies. In this case,

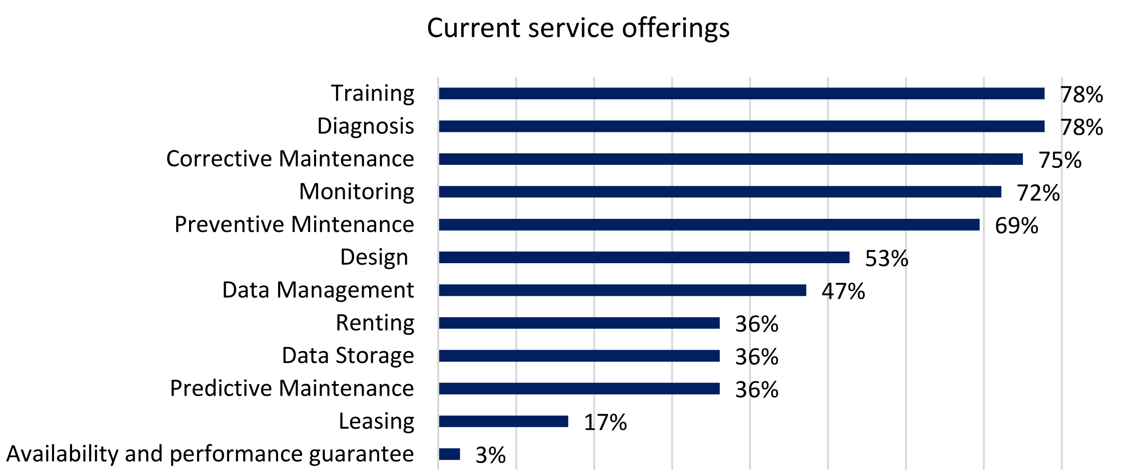

FIGURE 2 Percentage of surveyed companies offering services.

companies offer platforms and servers where customers can store and manage their data. The less offered services are renting and leasing. It is interesting to notice that most of the services provided by the companies that answered the survey are product-oriented services like maintenance. In contrast, only a few companies within the sample provide user-oriented services like leasing and renting that are specifically related to the use of the service under consideration.

Identifying the presence of result-oriented services is a challenging task. For instance, services like monitoring and diagnosis can be considered result-oriented if they enable the company to offer solutions and effectively manage performance based on performance indicators. However, it is important to note that this specific aspect was not explicitly examined in the survey.

By asking, "Is the digitalisation process important for manufacturing?" we explored the attitude of companies towards digitalisation. The results show that 80.6% (29 companies) of the respondents consider the digitalisation process highly significant to manufacturing. The remaining companies have answered with a value of two or three on a scale from 1 – a little to 4 – a lot, but none has answered 1. When examining each individual business, it is noteworthy that none of the respondents indicated a lack of investments in digitalisation or expressed no plans for future investments. On the contrary, all the respondents confirmed that they have either made investments in digitalisation (21 companies in the sample) or are currently doing so (15 companies). This outcome suggests that all the companies in the study view digitalisation as an essential and indispensable step.

Considering specific digital technologies that could be employed in services, the results show that most companies have invested in different technologies, particularly in fields such as CC, cybersecurity, data analytics, and IoT (Figure 3).

Also considering only the subsample constituted by the 64% of companies working in the manufacturing sector, it has been observed that there is no difference in the ranks of the most offered services and adopted technologies, as they are reported in Figures 2 and 3.

5.2 | 5G applications, benefits, and challenges

A section of the survey aimed at gauging the perspectives of industrial stakeholders regarding the integration of 5G to support services. While there may have been a clear and unified opinion regarding the significance of incorporating digital technologies in the context of digitalisation in manufacturing, the results diverge slightly when it comes to this aspect.

Indeed, most experts agree on introducing 5G to support services. In a scale from 1 (not important) to 4 (extremely important), 19 companies answered 4 and 10 companies answered 3. Around 20% of the sample believes that the introduction of 5G to support services is little significant or even completely unimportant. Similar to the question regarding investments in digitalisation, businesses have been asked if they have implemented or are planning to implement 5G technologies to support services. None of the respondents has already introduced it, and the vast majority (25 companies) does not want to introduce the technology now. However, there is a relatively small portion of the sample composed of 11 companies that is really considering the introduction of 5G to support the services provided.

At this point, it is important to understand how the companies perceive the importance of the 5G features that can benefit service offerings. A list of possible benefits has been proposed and respondents had the possibility to express the opinion from not important at all [1] to extremely important [4], or selecting the option "I cannot assess" highlighting a lack of information or competence about the specific theme.

In Table 2, the results are shown, reporting the mean score and the standard deviation for each benefit, to understand the ones are more appreciated and which are considered irrelevant by the respondents and furthermore assessing the consensus by the whole sample.

The first benefit analysed is the low latency guaranteed by the implementation of 5G. According to the literature, URLLC (ultra-reliable low-latency communication) is one of the key pillars of 5G networks, and it is evident that this is a highly

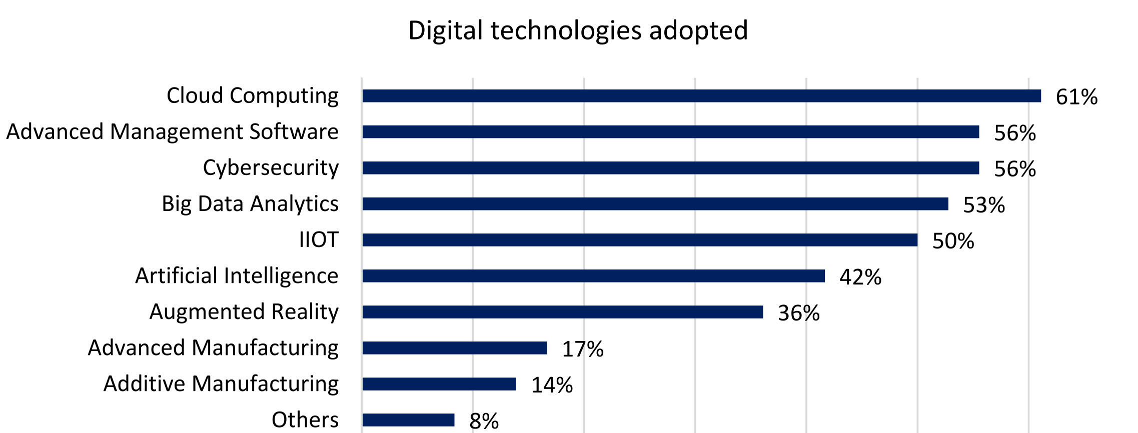

FIGURE 3 Percentage of surveyed companies adopting digital technologies.

valued benefit among respondents, that also shared a common opinion (lowest standard deviation). Also, the capability of connecting a large number of devices enabled by machine-type communication is appreciated by companies. Due to the increasing number of sensors and automation of systems, there is the necessity to have a network that can manage all these devices, and 5G represents a potential solution to this problem for the most of the respondents. Considering increased speed of download and upload guaranteed by 5G, it emerged that 18 companies out of 36 gave the maximum score to this benefit, thus providing an average score of around 3. In this case, the answers' distribution is a little bit wider, but it is important to consider that 4 companies cannot evaluate the benefit. Quite the same result for the fourth benefit proposed, namely the possibility to manage high volumes of data, on which higher consensus emerge. Finally, the last benefits scored by the respondents are reliability, that is related to the ability to maintain the technical specification overtime, and the ultra-wide broadband, for which five companies answered “I cannot assess”, meaning that there is still a lack of knowledge about this characteristic.

After investigating potential benefits, companies were asked an opinion about possible challenges about the implementation of a 5G infrastructure. The analysis is conducted according to the same rules as for the benefits, with scores ranging from 1 (not important) to 4 (extremely important) and the calculation of simple statistics to provide a rank, reported in Table 3.

The first challenge refers to the current knowledge about 5G. Most of the sample agreed that there is still a lack of expertise about the argument and competences, standards and knowledge may still not be completely well-established. A bit lower score is obtained by the complexity of integration of 5G infrastructure with current architectures, that could require major efforts in terms of adaptation, new machineries and device adoption, as well as different workflows. It is important to notice that none of the respondents has answered “1 – not important”, meaning that in any case and in any industry (within the sample) the investment of this integration is a factor that must be considered. Quite related to this challenge, cost of creating the 5G infrastructure is considered a critical aspect that companies must evaluate. Less importance is given to cybersecurity challenges. In this case, a higher standard deviation showed that there is a big portion that retains this aspect determinant (10 companies that answered 4) and another big portion that cannot evaluate this aspect or score it low. Finally, there is wide consensus about risks related to privacy and health, potentially generated by 5G infrastructure.

The final step of investigation aimed to understand how companies would face the integration of technologies enabled by 5G to support the provision of services and how much these services would improve with 5G integration. A list of possible services supported by digital technologies, such as the ones discussed in Section 4, has been proposed to the respondents, asking them to rate each service from 1 to 4, or alternatively, “I cannot assess”. The results are reported in Table 4.

The service that is expected to be majorly improved by the 5G is the remote assistance where there is a strong majority (22 companies) believing that the introduction 5G can be decisive. Similar results regard training using AR, since low latency is determinant in order to perform training efficiently and most of respondents agree that 5G can improve this aspect. The third position is covered by CC-based data storage and data management services, that could benefit of 5G capabilities in terms of larger volumes of manageable data (also through EC). Also, predictive maintenance and remote guided maintenance obtained positive results: low latency guaranteed by 5G is probably a determinant to the expression of this preference since remote maintenance requires instantaneous actions and feedback. A medium level of expectations concerns the implementation of 5G to support automation of services

TABLE 2 Scores obtained by 5G benefits to support services.

Benefits	Mean	St. dev.
Low latency	3,22	1149
Great number of connected devices	3,08	1251
Download/Upload speed	3,03	1320
High volume of manageable	3,00	1287
Reliability	2,92	1360
Ultrawide broadband	2,89	1410

TABLE 3 Scores obtained by 5G challenges against implementation.

Challenges	Mean	St. dev.
Lack of expertise on the subject	3,06	1241
Complexity of infrastructure integration	2,75	1131
Cost of creating the infrastructure	2,56	1229
Risk related to hacker attacks	2,39	1460
Risk of privacy intrusion	2,36	1199
Potential risks to health	1,61	1202

TABLE 4 Scores obtained by services that can be enhanced by 5G.

Services	Mean	St. dev.
Remote assistance	3,28	1137
Training guided by AR	3,25	1025
Predictive maintenance	3,17	1082
Data storage/management through CC	3,17	1207
Remote guided maintenance	3,08	1251
NPD with AR	2,78	1198
Service automation through HMI	2,78	1376
CPS applied to remote monitoring and diagnosis	2,58	1481
NPD with AM	2,00	1352
Product customisation through AM	1,94	1372
Reverse engineering through AM	1,86	1334

through HMI and digital assistant and the design of new products using AR.

Even if remote activities have been already mentioned and, on average, the results highlighted that companies believe that 5G can significantly enhance technologies applied to remote services, in the case of CPS applied to remote monitoring and diagnosis, results are quite different and there was not a wide consensus among the respondents. While a great number of respondents believe that 5G can improve this service, on the other side there are lots of companies believing that it is irrelevant and another big portion that cannot evaluate the improvement. Finally, it is possible to observe that regarding digital services enhanced by AM, there is a most of the sample believing that the introduction of 5G would be completely useless or almost useless.

The survey results contribute to fill the gap between 5G and servitization discussed in Section 2.3. Indeed, the involvement of a sample of manufacturing companies allowed to understand which are the 5G features that are more promising to enhance the most common industrial service offerings. The surveyed companies demonstrated high relevance of low latency and massive communication, indeed recognising data exchange and device connection as the main aspects supporting services related to remote assistance and predictive maintenance. Despite this, in accordance to the literature related to the manufacturing context [56], the surveyed companies confirmed that lack of proper competences and the need to setup updated infrastructure supporting 5G are the main obstacle to its widespread implementation.

6 | DISCUSSION

6.1 | 5G-enabled services matrix

Following the descriptive analysis of the survey results, additional investigations were conducted to offer a comprehensive understanding of the potential of 5G in supporting the digital servitization of companies, benefiting both academic and industrial communities. Specifically, the search focused on identifying correlations between company characteristics and opinions regarding the implementation of 5G networks for service support. Upon finding no significant correlation between the perceived importance of 5G and factors such as company size, digitalisation inclination, and investments in digital technologies, further analysis was carried out to determine the most suitable applications of 5G in relation to the most commonly offered services.

To do this, for the most of the services reported in Figure 2, one or more digital services reported in Figure 4 have been identified, in order to create a list of the most promising 5G-enabled services (Table 5). These services reflect the applications that have been described in Section 4.

A matrix (Figure 4) has been constructed to visually depict the 5G-enabled services, with the vertical axis representing the current implementation of services (i.e. number of companies, within the sample, that already deliver the specific service), and horizontal axis representing the recognized potential for 5G integration (i.e. sum of the scores that have been assigned to the importance of the implementation of 5G to support digital services).

1. In the first quadrant of the matrix (Many Companies – High) there are services that are provided by most companies and, in the sample opinion, wherein 5G brings improvements. It is interesting to see that in this category belongs all the services that are provided remotely. For example, corrective and preventive maintenance are two kinds of services that are provided by a big portion of the sample and a possible improvement taken by 5G can be remotely guided maintenance, maybe with AR that helps the operator to make the correct actions. Looking at this result it seems that most of the companies that provide maintenance services would be willing to introduce 5G to improve this service. Regarding remote diagnosis and remote monitoring the results are similar and, with the introduction of 5G, these services can improve significantly. Finally, Training services can be supported by AR technologies that require low latency to perform better as well as the possibility to connect more devices to train more people at the same time. Thus, in this quadrant are present all the services whereby companies would probably invest in 5G related technologies.
2. In the second quadrant of the matrix (Many Companies – Low) there are services that are provided by most companies and, in the sample opinion, wherein 5G does not bring improvements. Here there are monitoring, and diagnosis services supported by CPS. The results of the survey indicate that most of the respondents already provide these services but, in their opinion, the application of a technology like cyber-physical system that can be enabled by 5G is not a great solution to improve monitoring and diagnosis activities.
3. In the third quadrant of the matrix (Few Companies – Low) there are services that are provided by few companies and, in the sample opinion, wherein 5G does not bring improvements. Here there are design services supported by AM. Specifically, the customisation of products and the development of new products through AM. Based upon the information explored in the literature, the 5G infrastructure can support AM activities through the implementation of digital twin. However, the matrix revealed that only a small portion of the sample provides design services, and 5G is not a determining factor for improving these services.
4. In the fourth quadrant of the matrix (Few Companies – High) there are services that are provided by few companies and, in the sample opinion, wherein 5G brings improvements. In this category it is possible to find design services, that are provided by few companies, but where the implementation of 5G to enable AR to support these activities is seen as an opportunity. The same concept is applied for the implementation of HMI to support predictive maintenance. Indeed, corrective and preventive maintenance services are already provided by most of the respondents, but not

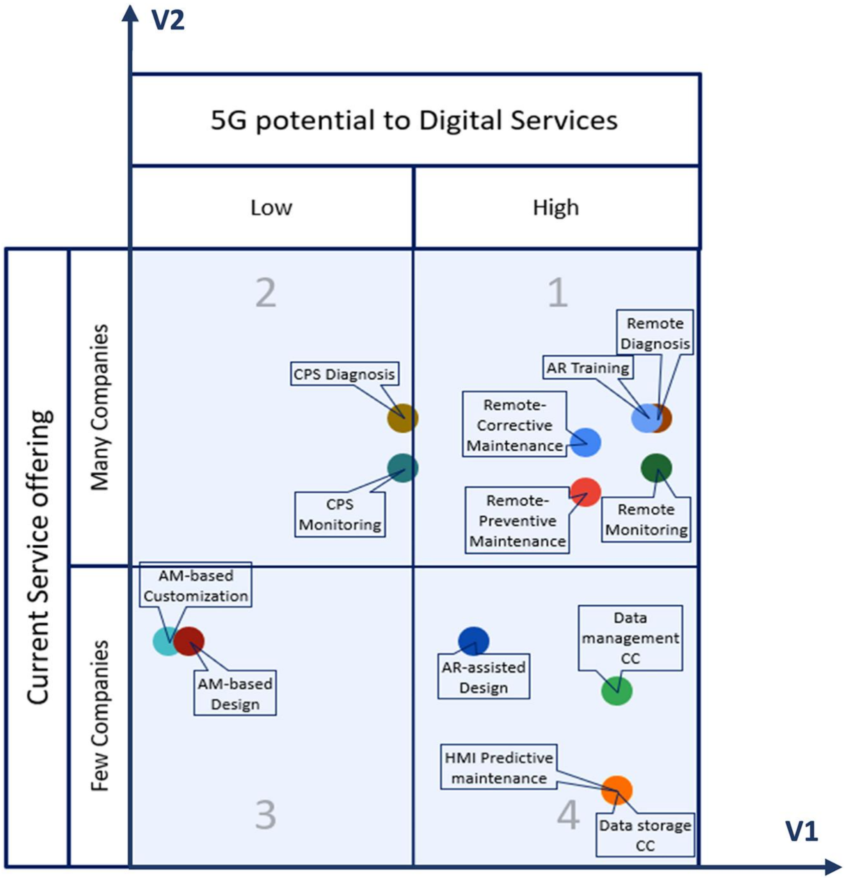

FIGURE 4 5G-enabled services matrix.

TABLE 5 Link between services already provided by companies and services that can be improved by 5G (V1 = number of companies, within the sample, that already deliver the specific service; V2 = sum of the scores that have been assigned to the importance of the implementation of 5G to support digital services).

Services	V1	Digital services	V2	5G-enabled services
Training	28	Training guided by AR	117	AR training
Diagnosis	28	CPS applied to remote monitoring/diagnosis	93	CPS diagnosis
Diagnosis	28	Remote assistance	118	Remote diagnosis
Corrective maintenance	27	Remote guided maintenance	111	Remote-corrective maintenance
Monitoring	26	Remote assistance	118	Remote monitoring
Monitoring	26	CPS applied to remote monitoring/diagnosis	93	CPS monitoring
Preventive maintenance	25	Remote guided maintenance	111	Remote-preventive maintenance
Design	19	Product customisation through 3D printing	70	AM-based customisation
Design	19	NPD with AR	100	AR-assisted design
Design	19	NPD with 3D printing	72	AM-based design
Data management	17	Data storage/management through CC	114	CC data management
Predictive maintenance	13	Predictive maintenance through HMI	114	HMI predictive maintenance
Data storage	13	Data storage/management through CC	114	CC data storage

predictive maintenance and the implementation of HMI can be a driver to perform this service. Same results also for data management and data storage supported by CC where 5G can improve the efficiency and the management of these services. This category is extremely interesting because it can be assumed that, on the one hand, there are services that most companies do not offer, but on the other hand, the implementation of 5G and the introduction of the above-mentioned technologies may be a key driver for companies that would add these services.

6.2 | Theoretical and managerial implications

From a theoretical point of view, this research presents a good basis for linking the main services offered by manufacturing companies with the technologies in which they have invested, and consequently with the most promising digital services that companies could offer in the future thanks to the benefits provided by 5G. This analysis made it possible to identify, through the 5G-enabled services matrix, which services are the most offered by companies and towards which the potential of 5G seems to be best exploited and which digital services are not yet widespread among companies but have a high potential for improvement thanks to 5G. Our research suggests that academic community should focus on these two families of digital services, in particular by continuing to study the evolution of the former and how to make the latter more adoptable, delving into their application barriers and how to overcome them.

With regard to managerial implications, the focus is always on the digital services present in the first two quadrants of the matrix. Indeed, the services in the first quadrant may soon become minimum requirements in the digital offering. It will therefore be important for companies to offer these types of services and to ensure that they are always up-to-date on current improvements and that they possess all the necessary skills and expertise to be able to offer them, in order to prevent them from becoming a gap with their competitors. The competitive advantage could instead come from the digital services offered in the second quadrant (i.e., data management and storage through CC; AR-assisted design and HMI predictive maintenance). These types of services have a good potential for improvement, but are not currently adopted by a large number of companies.

7 | CONCLUSION

The rise of servitization in manufacturing companies, driven by the need for differentiation and new revenue streams, has been facilitated by digitalisation. In this context, the advent of 5G has the potential to revolutionise the manufacturing industry by enhancing operational efficiency and increasing competitiveness. This research aimed to explore the impact of adopting 5G networks on PSS and digital servitization. To this end, a survey was conducted among industrial service providers to gather their opinions on digitalisation investments and the potential implementation of a 5G infrastructure to support their existing offerings.

The study conducted has provided significant findings that indicate the potential of 5G technology in improving the quality of services that utilise AR, such as maintenance, training, diagnosis, and monitoring. According to the respondents, there is a favourable inclination towards implementing 5G for these services, and it can result in significant improvements in their quality. In addition to this, implementing a 5G infrastructure can also lead to the enhancement of CC services, particularly in the areas of data storage and management. This is seen as a promising prospect for companies that have already adopted 5G technology and aim to further improve the quality of their service provision. By improving data storage and management, companies can ensure the security and accessibility of their data, which can result in better decision-making and ultimately, better services for their customers. Overall, the findings of this study suggest that 5G technology has the potential to revolutionise the way services utilising AR and CC are provided. It can lead to significant improvements in the quality of services, making them more accessible and user-friendly. Companies that are already utilising 5G technology should consider implementing it for these services to further improve their service provision and stay ahead of their competitors.

The main limitation of this study concerns the size of the sample that has been considered in the survey. Even if the number of involved companies is compliant with the requirement of exploratory survey research, a greater population may be considered for further survey analysis. Furthermore, this research focused on four main technologies that emerged from the literature review as the most suitable to be supported by 5G in service provision.

Further research paths can be envisioned. One possible avenue for future investigation is to focus on specific industries to determine whether 5G is more attractive or effective in some industries compared to others. In addition, further research could compare and evaluate the effectiveness of other technologies applied to services and determine which technology would gain the most advantage from the deployment of a 5G infrastructure. Finally, further studies could identify the barriers that may impede the development of these technologies, be they political, economic, social, or environmental. For instance, the research could examine government policies that promote or hinder the implementation of 5G infrastructure, the economic costs associated with deploying the technology, the social implications of 5G implementation, and the environmental impact of 5G infrastructure, which currently prevent the widespread adoption.

AUTHOR CONTRIBUTION

Chiara Cimini: Conceptualisation, Writing – Original Draft Preparation, Data Curation, Formal Analysis. **Alexandra Lagorio:** Methodology, Writing – Original Draft Preparation, Formal Analysis. **Roberto Pinto:** Writing – Review & Editing, Validation. **Giuditta Pezzotta:** Conceptualisation, Writing – Review & Editing, Validation. **Federico Adrodegari:** Writing – Review & Editing, Validation. **Sergio Cavalieri**; Validation, Supervision.

CONFLICT OF INTEREST STATEMENT

No conflict of interest to disclose.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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