Augmented reality for industrial services provision: the factors influencing a successful adoption in manufacturing companies

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Abstract

Purpose – This paper presents a model aiming to identify the factors influencing the adoption of augmented reality (AR) for industrial services.

Design/methodology/approach – The study combines a literature analysis with an empirical study conducted exploring how five large industrial companies are introducing AR for supporting the provision of technical assistance and industrial services to their installed base.

Findings – The authors identify four categories (task, workforce, context and technology) that combine 18 factors that manufacturing companies should consider when introducing AR technology to support industrial services.

Originality/value – This paper systematises the fragmented literature on technology adoption and in particular those works related to the factors affecting the adoption of AR in industrial services. Based on literature and empirical evidence, the authors propose a novel framework that can help companies in the selection of AR solution based on their specific applications and situations. This study therefore contributes also to the existing literature on the adoption of I4.0 and digital technologies in industrial services.

Keywords Augmented reality (AR), Digital collaboration, Remote collaboration, Industrial services

Paper type Case study

1. Introduction

Although not a new technology, augmented reality (AR) is receiving more and more attention for application to industrial context (Bottani and Vignali, 2019; Rapaccini *et al.*, 2014). In fact, AR can enable or facilitate a wide range of tasks such as assembling, maintenance and technical assistance of industrial goods (Flavián *et al.*, 2019). AR is also considered a key technology of digital servitisation (Paschou *et al.*, 2020), as it is expected to radically innovate how product specialists and field technicians can remotely collaborate in troubleshooting and restoring fault products (Jonietz, 2007; Siemon *et al.*, 2019). In addition, AR can be used to

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provide customers with interactive experiences and training about operations and maintenance of industrial equipment (GrandViewResearch, 2021; Porcelli *et al.*, 2013a). Although it appears from the literature that AR represents a breakthrough (Ebbesen and Machholdt, 2019), many firms are still often reluctant to invest in tools that appear not ready for massive adoption (Santi *et al.*, 2021; Adner and Kapoor, 2015). It is also claimed that the introduction of AR technologies can require changes to industrial organisation and processes (Ghosh *et al.*, 2021). These are the reasons why the payoff of these tools is still questioned, and industrial firms still prefer traditional tools such as phone calls, instant messaging, chats and forums to enable remote collaboration in industrial services. Last, there is limited knowledge about what should guide the definition of the right hardware features, software functions and technical requirements of AR tools for each specific application (Adner and Kapoor, 2015; Porcelli *et al.*, 2013a, b; Palmarini *et al.*, 2018).

To address these gaps, this paper provides a model to support the introduction of AR technologies in industrial services. The rest of the paper is structured as follows: Section 2 provides an overview of AR applications in industrial services. The literature findings offer an initial hint at the elements that characterise the adoption of an AR solution. Section 3 presents the research strategy and methodology adopted, here referring to both analytical-logical-deductive characterisation to conceptualise the use of AR in services and iterative-logical-inductive characterisation with attention to empirical research results then from the interviews conducted. The approach described has allowed us to theorise a model covered in detail in Section 4, describing the constructs derived from both the literature and interviews, finding that the main factors reflect the characteristics of the user, the task performed, the context in which the service task is performed and, of course, the technology required. Section 5 concludes the paper with some concluding remarks on the research and suggestions for further research.

2. Theoretical background

2.1 AR for industrial applications

AR technologies are expected to radically improve the ways industrial services are delivered by OEMs (Rapaccini and Porcelli, 2013). Basically, this technology enhances the perceptions of the real world, by providing its users with additional information such as graphics, texts, videos, 2D and 3D models (Boud *et al.*, 1999; Pathomaree and Charoenseang, 2005). These objects are superimposed on the user's field of view (FoV) via a variety of media. These include fixed and mobile screens, as well as head-mounted displays (HMDs) (Fox, 2010). As a result, an AR experience can be delivered by simple devices such as smartphones and tablets (hereafter, hand-held display (HHD)) or more complex tools such as smart glasses (hereafter HMDs). Information is overlaid onto these devices to create an interwoven experience and alter the user's perception of the real world. In fact, the overlaid information can integrate, change, or mask part of the real view (Farshid *et al.*, 2018). In multi-user application, AR can also enable some enriched forms of real-time collaboration between co-located or remote users. This is of paramount importance in the provision of field services to a dispersed base of industrial equipment. In this case, field engineers and technicians can greatly benefit from real-time information provided by experts from remote centres (Martinetti *et al.*, 2019; Mühlan *et al.*, 2021). For instance, technicians can use AR to verify that they have the required parts and tools before travelling to the customer site (Hung *et al.*, 2016). Some studies also confirm that AR-based collaboration brings better results when performing maintenance tasks than paper (manual–based) and phone support (Choi *et al.*, 2018). Scurati *et al.* (2018) present a methodology to convert maintenance actions into 2D symbols to convey instructions in AR tools, highlighting the lower mental load for the user. Moreover, De Pace *et al.* (2019) investigate how AR could lead to more effective training and a more satisfying work experience. The authors show how the instructions provided by the remote specialist greatly speed up and simplify field operations. This is confirmed by the study of Mourtzis *et al.* (2020) that investigates the benefits of delivering repair and maintenance services based on AR-enabled remote collaboration. Basically, AR can reduce human errors, improve technical training, speed up times for travel and equipment restoration (Iliano *et al.*, 2012). AR can also facilitate knowledge management as AR tutorials and procedures, once created, reduce the potential spill-over of knowledge due to generational change of field engineers (Funk *et al.*, 2017). The cost of technical training can also be notably lowered (Masood and Egger, 2019). Despite these opportunities, a systematised and comprehensive understanding of the factors that drive the implementation of AR in industrial services is still missing (Masood and Egger, 2020). The literature about successful cases is scant, and the adoption of AR-assisted maintenance in real-life applications is still limited be (Mourtzis *et al.*, 2020). Although the increasing interest (Siew *et al.*, 2019) it is still unclear how this technology can be successfully implemented and exploited in industrial service domains (Martinetti *et al.*, 2019). The next subsection summarises the factors that prevent or influence the adoption of AR technologies in industrial settings (Lau *et al.*, 2019).

2.2 Factors influencing the adoption of AR

The adoption of AR in industrial context can be affected by the typical factors that prevent the introduction and use of any new digital technology (Vieru *et al.*, 2015). These include the task-technology fit and the *ease-of-use* (Zhang *et al.*, 2018). Other factors are related to the characteristics of the workforce, such as *age* (Kim and Dey, 2016)*, digital skills*, and *experience* (Chalhoub and Ayer, 2019; Chi *et al.*, 2012; Funk *et al.*, 2017; Loizeau *et al.*, 2019; Stadler *et al.*, *2016*). Some others pertain the *digital leadership* (Saputra *et al.*, 2020) and the readiness and familiarity of the organization with digital technologies (Stadler *et al.*, *2016*). Few studies have specifically explored the *level of acceptance of AR technologies* in industrial settings (Cabero-Almenara *et al.*, 2019), confirming that the attitude and predisposition toward the intention to use AR technologies are impacted by the perceived usefulness and ease-of-use. Expectations that AR will bring an increase in productivity, precision and live feedback are in fact higher in case of sufficiently developed solutions, that also show greater easy to use. If these expectations are not fulfilled, acceptance will suffer (Guest *et al.*, 2018). A critical issue on which the literature debates concern the fit between the AR tool and the supported task. For instance, using AR for low-complexity task (e.g. routine maintenance) can be counterproductive, and technicians prefer conventional tools (Deshpande and Kim, 2018). This suggests that "AR methods could be more beneficial when applied to more complex tasks" (Alves *et al.*, 2019) and that for simple tasks the use of AR could increase rather than reduce the mental workload of the field force (Jeffri and Rambli, 2021).

Some studies investigate specifically the *hardware and software characteristics* of AR solutions for industrial applications, such as battery life, memory size, connectivity, wearability, etc. For instance, it is agreed that HMDs have not yet reached the required level of maturity (Keil *et al.*, 2019). Major problems of these devices are the small FoV, their weight, the need of good Wi-Fi connection for streaming content, the limited battery life, the limited display resolution and the difficulty of integrating them with other systems. Some studies claim that cybersecurity concerns when using AR in industrial applications should be also considered (Quandt *et al.*, 2018).

Other literature focuses on organizational factors and points out the crucial role of leadership when introducing digital technology – i.e. the so-called *digital leadership,* which is the attitude of company executives toward digital innovation (Saputra *et al.*, 2020; Zeike *et al.*, 2019). Porcelli *et al.* (2013a, b) point out that the potential of AR can be obtained if organization and operational processes are changed.

Finally, some works point out the problem of *cybersickness*, an ailment that originate from the intense use of wearable and immersive technologies such as AR and VR and that includes negative effects such as hallucinations, visual flashbacks, difficulty in distinguishing reality from reconstructed worlds, dizziness and blurred visions (Aromaa *et al.*, 2018; Han *et al.*, 2017;

Hughes *et al.*, 2020; Muñoz Morgado, 2018; Stanney *et al.*, 2020). Table 1 summarises the factors that influence the adoption of AR for industrial services, distinguishing four categories that will be further discussed in Section 4. The next section presents the methodology used in this paper to develop and validate the model.

3. Research approach

To complement and validate the findings shown in Table 1, we collected empirical material according to the guidelines of qualitative research (Miles and Huberman, 1994). Specifically, as shown in Figure 1, the research process adopted in this paper is based on the "iterative-founded" theory (Orton, 1997). This method combines empirical data with relevant literature to highlight aspects that have been overlooked by scholars and fill in the mentioned gaps. This approach is in line with previous studies that combine literature and expert interviews to develop a model for selecting additive manufacturing technologies (Sobota and van de Kaa, 2020). As suggested by Wacker (1998), we follow a 3-stage approach:

Category	Factor	Description	Reference
TASK	Task complexity	Defined by the level of cognitive demand to perform spatial problem-solving. More complex task consistently takes more time and effort to be concluded	Alves *et al.* (2019), Deshpande and Kim (2018), Jeffri and Rambli (2021)
WORKFORCE	Age	The effects of AR on mental workload differ between individuals of different ages	Kim and Dey (2016)
	Digital skills	Depending on the experience and age of the user, there may be different situations of familiarity with the technology, therefore there may be cases in which users are reluctant to new technological solutions	Chalhoub and Ayer (2019), Chi *et al.* (2012), Funk *et al.* (2017), Loizeau *et al.* (2019), Stadler *et al.* (2016)
	Experience	Work experience in each sector has a significant influence, as it also affects the complexity of the task perceived by the user	Chalhoub and Ayer (2019), Chi *et al.* (2012), Funk *et al.* (2017), Loizeau *et al.* (2019), Stadler *et al.* (2016)
	Technology acceptance level	How the attitude or predisposition one has toward the intention to use AR technology can influence successful adoption	Cabero-Almenara *et al.* (2019), Guest *et al.* (2018)
CONTEXT	Digital Leadership	Support of team members is given by upper management and by each team member. It's related to the appreciation by the leadership of digital skills and attitude toward digital innovation	Saputra *et al.* (2020), Zeike *et al.* (2019)
	Organizational processes	Organizational processes would need to be adapted to gain a significant advantage by supporting the task by AR. Hence, the achievement of the potential of AR can only happen if organizations are changed	Porcelli *et al.* (2013a, b)

Table 1.
Factors influencing the AR adoption

(*continued*)

Category	Factor	Description	Reference
TECHNOLOGY	Cybersickness	Form of motion sickness that occurs due to exposure to immersive environments, such as virtual reality (VR) and augmented reality (AR) applications	Aromaa *et al.* (2018), Han *et al.* (2017), Hughes *et al.* (2020), Muñoz Morgado, 2018, Stanney *et al.* (2020)
	Ease of use	Tool ease-of-use perceived by the end user. It must not complicate the performance of the activities or extend the time for carrying out the activities	Dishaw and Strong (1999), Zhang *et al.* (2018)
	Tool usability	Tool usefulness is perceived by the end user. It must fit the task	Dishaw and Strong (1999), Zhang *et al.* (2018)
	Hardware and software characteristics	The level of hardware maturity of AR technology solutions and the level of integration of the software with third-party systems influence the successful adoption and introduction of the AR solution	Dishaw and Strong (1999), Keil *et al.* (2019), Zhang *et al.* (2018)

Table 1.

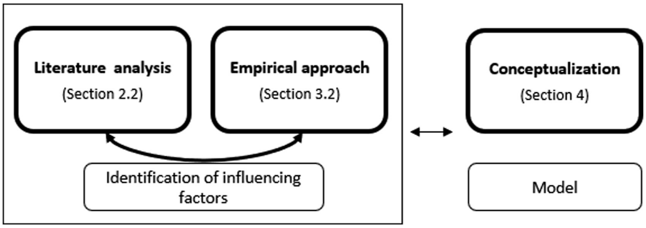

Figure 1.
Research approach

(1) Literature analysis with analytical-logical-deductive characterisation of the factors affecting the use of AR in industrial services (see Section 2 that summarises the findings and Section 3.1 that explains the methodology).

(2) Collection of empirical material through case base research of 5 industrial companies (unit of analysis) that are introducing AR to provide industrial services. Extensive interviews with 30 selected informants (unit of observation) among staff and field force and then iterative-logical-inductive analysis to extrapolate new factors from this empirical material (as described in Section 3.2).

(3) Theorisation of the selection model based on factors from both stage 1 and 2 (see Section 4).

3.1 Literature analysis

The findings discussed in Section 2 come from a thorough review of recently published papers in the field of operations management. We searched the Scopus databases using keywords such as "augmented reality", "industrial service", "assistance", "maintenance", "field service", "troubleshooting" and other variations. Contents that emerged from the literature was coded and grouped into thematic categories as shown in Table 1. These results provided some key constructs that helped in elaborating the interview script. Emphasis has been given to factors pertaining the digital skills and experience of the field force and to the effects that originate from its use. Factors related to hardware and software features were also under the lens, as well as the perception of ease-of-use and usefulness.

3.2 Collection of empirical material

3.2.1 Sampling criteria. In line with Voss *et al.* (2002), 5 large industrial firms operating in different sectors and introducing (or planning to introduce) AR technologies and applications for the provision of industrial services were purposively selected. Table 2 shows the characteristics of these cases as well as short descriptions of the AR initiatives. These companies were selected because they showed differences in relation to the progress of the adoption projects. This therefore helped to obtain broader perspective and richer empirical material. In sum, we had the opportunity of exploring the use of AR in different tools and configuration, for delivering technical assistance and remote support to both field engineers and end-users. We also observed the application of AR in training purposes.

3.2.2 Data collection. Annex shows the semi-structured questionnaire that has been used to interview the selected informants and gather information about benefits and shortcomings from the use of AR in industrial services. A total of 30 interviews were conducted, each lasting around 60 min. The respondents were selected to be representative of the professionals involved in field service and technical assistance activities. In fact, we interviewed 4 repair technicians, 3 lab managers, 1 help desk technician, 5 product specialists and 17 field engineers. On average, these respondents showed 15.8 years of experience in similar positions, in most cases (82.1%) in the IT, consumer electronics and digital systems industries. Respondents were interrogated about opinions and impressions from their (daily or sporadic, from pilot projects) use of AR technologies. Specifically, 6 respondents had used AR for training, 8 for receiving technical support for repair tasks in lab, 15 for receiving technical support in field interventions, 1 who had multiple experiences. To investigate the task complexity, we followed the Perrow's (1967) model, which uses two variables to characterise the fit between a task and a technology that can automate the task or support the workers involved: the degree of explicit knowledge about how the task is expected to be performed (i.e. *task analysability*) and the number of exceptions that can be encountered when performing the task, that deviates from its routine (i.e. *task variety*). The higher the number of exceptions and the lower the analysability, the greater the uncertainty that affect the task and therefore the risk of not achieving the desired outcomes.

3.2.3 Data analysis. As explained, we first used the findings from the literature review to originate as many codes as possible. These codes were integrated inductively on the base of the empirical material to detect both established and emerging constructs as well as their relationships. We iteratively compared the most relevant findings from the literature and those raised by the interviewees. This comparison helped in drafting the questions that allowed to explore the degree of complexity of the service tasks. At the end, this approach confirmed that the literature has partially—and in a fragmented way—covered some aspects that instead emerged from the case analysis. Table 3 shows the Extracts (E#) from the interviews that lead to the definition of new factors (in grey cells), confirmation or declination of the previous (theoretical) one. As a result, we developed a theoretical model that describes the factors that enable the adoption of AR technologies in industrial services. This model integrates concepts from literature and empirical research. Section 4 first systematise the mentioned concepts and then presents the model.

4. A model for the adoption of AR in industrial services

This section conceptualises a model that integrates the factors emerging from both the analysis of the literature (Table 1) and the empirical material (Table 3). Table 4 presents the model categories and provides a comprehensive overview of the factors that companies must take into consideration to effectively introducing AR technologies to deliver industrial services. Each category is further discussed in the following subsections.

Company	Description	Interviewees	Role	AR project description and application
A	A is the biggest Italian dealer of integrated sales, rental, and assistance solutions in the Mining, Major Works, Infrastructure, Construction, Energy Generation, Oil and Gas, and Naval Mechanics sectors. It's part of a holding company with other companies specialised in sales, short or long rental, in various markets: trucks, construction, logistics, and finance for leasing	3 from Italy	2 Product Specialists 1 Lab Manager	Head Mounted Display (HMD) tool for training, end-user technical support, and remote technical support for both basic-level users and skilled users
B	B, a large enterprise is one of the leading global providers of food service, beverage, and laundry solutions, serving a wide range of customers globally, from restaurants and hotels to healthcare, educational and other service facilities. In addition to their product offerings, aftermarket services are provided to customers throughout the equipment lifecycle	1 from Italy 1 from Sweden 2 from USA	2 Support for Service Technicians 1 Product Specialist 1 FSE	The project involves the daily use of a Hand-Held Display (HHD) for end-user technical support
C	C is the world's leading provider of machines, Automation solutions, and services to the tool and mold-making industry and manufacturers of precision components. C, a large enterprise, offers innovative milling, EDM, laser texturing, automation, and customer services solutions. The key segments they serve include the aerospace, automotive, medical, energy, information and communications technology, and electronics industries	2 from Italy 1 from Switzerland	1 Lab Manager 1 Support for Service Technicians 1 Product Specialist	The ongoing project foresees the use of a Head Mounted Display (HMD) for training
D	D, a large enterprise, is a world leader in the supply of systems and solutions for printing, printers' multifunction, office equipment, and document management services, both with a direct channel very important (8 branches in the area) and indirect (dealer network, its partners and service center on various levels)	3 from Italy 14 from Spain	1 Product Specialist 1 Help Desk Technician 15 FSE	The ongoing project implemented Head Mounted Display (HMD) tool for training in product repair and remote technical support

(*continued*)

Table 2.
Application cases

Company	Description	Interviewees	Role	AR project description and application
E	E has been recognised globally as a leader in the technology sector and is now ranked as one of the top 10 brands globally. It's a large enterprise in the wholesale of household appliances, and audio and video consumer electronics	3 from Italy	1 Lab Manager 1 Support for Service Technician 1 FSE	The concluded project foresees the use of a Hand-Held Display (HHD) for product repair and end-user technical support

Table 2.

Category	Interview excerpts (E)	Factors emerged from the empirical application
TASK	E1: "they take longer to open and consult the AR solution than to carry out the procedure itself" E2: "The time our technicians spend on repair is less than the time they would spend using the collaborative tool"	Task Complexity
	E3: " . . . many service tasks can also be carried out remotely . . . an inspection and our physical presence on site is not necessary . . . "	*Remote Work*
	E4: "it happens that there is a lack of codified technical documentation necessary to carry out our work'	*Codification*
	E5: "Sometimes the documentation of some dated machinery does not exist or is only on paper" E6: "Documentation is difficult to retrieve because it's on paper, especially for older machines'	*Recoverability*
WORKFORCE	E7: " . . . it's good for the novice technician . . . I've all experienced technicians with several years of experience" E8: "Many technicians do not use technical terminology . . . they are 'thrown into the fray'"	Practical/technical abilities
	E9: "sometimes it happens that the customer, seeing us wearing the smart glass, thinks that it's just a game and that we make him waste time" E10: "The client is often nervous because he wants to solve the problem for which he called us" E11: "we've customers who were happy to receive help remotely and to have been able to solve the problem independently" E12: "Customers seem more satisfied because I spend little time in solving their problems" E13: "I made my clients autonomous in solving their problems simply by helping them remotely through the AR app"	Theoretical technical competencies
	E14: "in my work I do not consider the AR solution useful and of 'added value'" E15: "for experienced people like my team you don't need such a tool" E16: "I was sceptical at first, but now I use it every time I need to connect with my colleagues while I'm to my customers"	Technology Acceptance Level

(*continued*)

Table 3.
Factors emerged from empirical application

Category	Interview excerpts (E)	Factors emerged from the empirical application
CONTEXT	E17: "it happened that there could be problems related to access to the structure both for problems with timetables, the need for accompaniment, and for problems such as parking or tight spaces"	*Accessibility*
	E18: "It often happens that we've to intervene in sites where there is poor Internet connection and brightness, such as galleries"	*Connectivity*
	E19: "in some environments I've difficulty to visualize the digital content" E20: "I happened to do an intervention in a submarine where the environment is not comfortable, both in terms of space and connection" E21: "in some environments I have low light and little connection, so I cannot use it"	*Comfort*
	E22: "remote customer support certainly allows us to avoid city traffic thus also reducing environmental pollution"	*Environmental impact*
TECHNOLOGY	E23: "it makes the diagnosis easier and more accurate" E24: "I see the instructions in a simple and clear way" E25: "the AR solution I tested was easy and intuitive but it's necessary to improve the content shown"	Ease of use
	E26: "in some contexts it cannot be adopted . . . often I have to use both hands so the tablet can only be an obstacle to operations"	Tool usability
	E27: "the level of maturity of the technology is still low" E28: "we had problems integrating the AR solution with our existing internal systems"	Hardware and software characteristics

Table 3.

Category	Factors
TASK	Task Complexity Remote Work Codification Recoverability
WORKFORCE	Digital skills Practical/technical abilities Theoretical technical competencies Technology acceptance level
CONTEXT	Digital Leadership Organisational processes Accessibility Connectivity Comfort Environmental impact
TECHNOLOGY	Cybersickness Ease of use Tool usability Hardware and software characteristics

Table 4.
Model

4.1 Task

The literature on service management (Benedettini and Neely, 2012; Zou *et al.*, 2018) agrees that certain tasks are affected by higher levels of uncertainty and arbitrariness about the actions that have to be taken to reach the desired outcome. Some aspects considerably influence the complexity of the service task (Aromaa *et al.*, 2018; Han *et al.*, 2017; Hughes *et al.*, 2020; Muñoz Morgado, 2018; Stanney *et al.*, 2020). Another factor on which the interviewees agree concerns the possibility of conducting the task from remote or not. Last, respondents believe that the adoption of AR could be greatly limited by the lack of digital readiness of the service department. In fact, converting huge amounts of paper-based information into digital contents, in formats that are specific for AR devices, could not be easily paid off. All these aspects are described in detail as follows:

(1) *Task complexity:* this is defined by the level of cognitive power to perform problem solving. A more complex task consistently takes more time and effort to be concluded. Some respondents argue that technology can enable faster intervention time; others, on the other hand, disagree, especially in the case of expert staff who already know how to manage the various technical intervention procedures independently (*E1, E2*).

(2) *Remote work*: This indicates how many and which activities could also be carried out remotely, that is, without any physical proximity between the technician and equipment (*E3*). It is said that some tasks (e.g. troubleshooting, diagnostic, inspection) can be performed remotely, with little additional effort (e.g. establishing VPN (Virtual Private Network) connections to the equipment upon customer's authorisation). In case the mantra is, as frequently the case, "We have always done it this way," the opportunities for doing work remotely have not been leveraged. Instead, implementing these modifications could be relevant before introducing digital collaboration technologies, such as AR.

(3) *Codification*: This refers to the presence of a base of technical documentation and codified knowledge to cover most situations that field technicians have to face in their job (i.e. delivering the service portfolio), irrespective if they are direct or indirect workforces (*E4*).

(4) *Recoverability*: This explains how much codified knowledge can be easily accessed and retrieved, for instance, from the company's internal, hybrid or cloud repositories and databases, to be consulted and shared with the aid of digital media. In the case where a large repository of documents is available, it is frequently hard for field technicians to retrieve the needed content (e.g. technical procedures, operations and user maintenance manuals, wiring or functional diagrams) in the little time they have to perform. This can be much more complicated if there is little aid when it comes to searching and crawling through documents among the numerous repositories. Another issue pertains to the formats used, making these documents scarcely readable in field situations (*E5, E6*).

4.2 Workforce

The model also incorporates some organizational aspects, such as the gap of digital skills of the workforce (i.e. digital literacy) and the level of expertise and technical abilities (Chalhoub and Ayer, 2019; Loizeau *et al.*, 2019). The literature stresses that mental load is highly influenced by the age of the individuals using AR technology (Kim and Dey, 2016). This has been partly confirmed by the interviewees, who, however, believe that nowadays factors such as digital skills and experience and, above all, the technology acceptance by end-users is more decisive and not strictly linked to the age of technicians. Hence, we have deduced the factors in this category as follows:

(1) *Digital skills:* a workforce that has, on average, less proficiency in using IT tools can prevent the adoption of AR technologies.

(2) *Practical/technical abilities*: less experienced workforce have a higher need for virtual collaboration and remote support. Some of the respondents argue that technology can enable faster intervention; others disagree, especially in the case of expert staff who already know how to manage the variety of procedures for field intervention (*E7, E8*).

(3) *Theoretical technical competencies*: A workforce that receives little procedural training (e.g. on system architectures, diagnostic methodologies, instruments and fix and repair operations) has a higher need for virtual collaboration and remote support. Many of the experienced technicians state that this solution can also help harmonise the working style of new hires with those who have more experience. Hence, the experience and background of the users themselves influence the effect of AR solutions (*E9, E10, E11, E12, E13*).

(4) The *technology acceptance level* of both the customer and end-user is critically important for the success of the adoption and use of AR technology. This aspect emerges from the literature (Cabero-Almenara *et al.*, 2019; Guest *et al.*, 2018), and the interviews show that from the customer's side, some declare a good level of acceptance of the technology, while others completely disagree (*E14, E15, E16*). This is presumably related to the context in which either technicians or customers operate.

4.3 Context

Factors related to the importance of *Digital Leadership* (Saputra *et al.*, 2020; Zeike *et al.*, 2019) and *organisational processes* (Porcelli *et al.*, 2013a, b) have emerged from the literature. However, the latter do not emerge explicitly from the interviews. We assume that this is because these cases were purposively selected to show interesting AR experimentations, promoted and encouraged by their leaders. Following this line of reasoning, we assume that this factor is indirectly validated. Instead, other factors related to working conditions emerge from our empirical material, which mostly depend on the location in which interventions are delivered. Based on what emerged from the interviews, the three new factors of the "Context" category have arisen as described below:

(1) *Accessibility*: In some cases, accessing the field site is not the smoothest experience because restrictions by the customer (e.g. access only within specific time slots, imposing companion required to access) or by the environment (e.g. no easy/internal parking). Such inconveniences could prevent the use of technologies that may increase the complexity the technicians must tackle during their activities (*E17*).

(2) *Connectivity*: Not every customer facility has adequate Internet connectivity; therefore, the use of digital collaboration platforms and AR technologies that require online connectivity is not possible. In effect, the FSEs of companies A, B and D confirm that, in some places such as tunnels or basements, technicians are required to work with an unstable Internet connection (*E18*).

(3) *Comfort*: Sometimes, the service sites have no conditions ideally required to perform the given tasks (e.g. situations of poor lighting, presence of noises and disturbances, traffic and even risks to health and safety) (*E19, E20, E21*).

(4) A new positive aspect not considered in the literature, which instead has emerged from the interviews, is the benefit in terms of *environmental impact* related to the reduction of the number of trips required by the technician to travel to the place of interest and reduction of time passing "stuck in traffic to reach customers" (*E22*).

Of course, the three context factors (*accessibility*, *connectivity and comfort*) characterise interventions at customer premises (in the field). In the case of on-site services (e.g. electronic repair lab, car workshop), that is, in case the product can be conveniently moved to the service facility, these factors lose their relevance because the service provider can ensure the best conditions in terms of comfort, accessibility and connectivity.

4.4 Technology characteristics

Finally, the characteristics of the IT solution adopted can also influence the outcome of the pilot projects. As in the literature (Dishaw and Strong, 1999; Zhang *et al.*, 2018), the respondents also affirm that the most appreciated feature of the AR solution is the ability to effectively superimpose and contextualise textual and graphic information on the scene of interest, as well as access, if necessary, digitised manuals that make the management of the intervention faster while also facilitating any fault diagnosis. Factors from the literature, such as ease of use, tool usability and hardware and software characteristics, are reconfirmed and argued as being important by the interviewees.

The following are the factors that characterise the "technology characteristics" category in detail:

(1) *Cybersickness* is a form of motion sickness that occurs because of exposure to immersive environments, such as virtual reality (VR) and AR applications (Aromaa *et al.*, 2018; Han *et al.*, 2017; Hughes *et al.*, 2020; Muñoz Morgado, 2018; Stanney *et al.*, 2020). The respondents do not pay much interest in this aspect, probably because of the brief time of use of the tool, unlike the literature studying it in depth in several application studies of AR technology in industrial service.

(2) *Ease of use* is where the tool must not complicate the performance of the activities or extend the time for conducting the activities (Dishaw and Strong, 1999; Zhang *et al.*, 2018). Almost all the interviewees find the technology simple and intuitive compared with the task performed (*E23, E24, E25*).

(3) *Tool usability* is a useful tool for the end-user, so the tool must fit the service task (Dishaw and Strong, 1999; Zhang *et al.*, 2018). The respondents confirm this aspect, agreeing on the need to evaluate the type of service task and commitment required by the technician before implementing the AR tool (E26).

(4) *Hardware and software characteristic*s are related to the level of hardware maturity of AR technology solutions and the level of integration of the software with third-party systems, indicating how this influence the successful adoption and introduction of the AR solution (Dishaw and Strong, 1999; Keil *et al.*, 2019; Zhang *et al.*, 2018). The interviewees confirm this aspect (*E27*): two interviewees believe that the technology is not yet at an important level of technological maturity, but the problems most frequently encountered could be overcome with little effort and encouraging users to increasingly increase its use to perceive its potential. The level of integration of AR solutions with pre-existing company systems is considered critical to the success of pilot projects (*E28*).

5. Discussion and conclusion

5.1 Theoretical contribution

Manufacturing companies are increasingly adopting digital technologies such as AR, to deliver industrial services (Flavián *et al.*, 2019). The COVID-19 pandemic has significantly accelerated this trend (Nagel, 2020; Papagiannis, 2020; Rapaccini *et al.*, 2020). Unfortunately, a big deal of uncertainty still affects the implementation of these technologies. Through a comprehensive review of the literature combined with in-depth case-based research, this paper provides a model showing the relevant factors to consider in the selection, design and configuration process of AR technologies to deliver industrial services. Using theory-building empirical research (Meredith, 1993), the current study contributes the literature on AR adoption in industrial settings, which is fragmented and scant.

The model groups 18 factors into four categories, namely *task, workforce, context and technology characteristics*. This set provides a more holistic view of AR selection compared to the existing frameworks and could serve as a starting point for future studies on the selection of AR tools, but also I4.0 and digital technologies in general, in industrial services. 11 factors have been derived from the literature on this subject (Table 1), confirmed by our cases and related to: (1) the characteristics of the end-user, such as age and digital skills being in close connection with each other; (2) the hardware and software characteristics that influence the outcome of the pilot projects; and (3) the task complexity, given that the AR tool could slow down the carrying out of simpler tasks, which are generally completed quickly by the technicians in full autonomy.

Among the factors that emerged from the empirical research, there are seven new ones (in bold in Table 3) concerning (1) the level of digitisation, which refers to the presence of a base of technical documentation and codification knowledge of the task that field technicians have to face; (2) the environmental impact related to the reduction of the number of trips required for remote technical support for the field service technicians and (3) the working conditions related to the location characteristics in which interventions must be delivered.

The connectivity and the level of digitisation (i.e. codification and recoverability) factors are certainly not new in the digitization literature, but they are still little explored and evident in the literature dealing with the adoption of an AR solution in industrial service delivery. In fact, interviewees stressed a lot on these points, referring to the difficulties often encountered during pilot projects.

Even if the application studies examined dealt with different AR in industrial services (remote technical support for the field service technicians, end-user technical support and training), the identified factors were almost common to all interviews, although perceived differently (i.e. for the remote technical support for the field service technicians are crucial the working conditions, especially in terms of light conditions and Internet connection).

5.2 Managerial implications

From an industrial perspective, the adoption of the developed model by companies can enable them to carry out a timely analysis of all factors related to their AR project.

In particular, the study of the factors can make it possible to carry out a pre-project analysis in which understanding the factors that could lead to a lack of success of the project and which strengths to work on in order to design a better service and create a greater level of acceptance of the new technology within the project team.

Furthermore, the model can be used throughout the design and implementation of new services that exploit the AR technology to analyse the feedback and the perceptions of field technicians and then improve the technology and the delivery service processes so that AR actually becomes a facilitating technology for the filed service activities.

5.3 Research opportunities and limitations

By analysing the state of the art and the industrial practices with regard to the adoption of AR technologies for industrial service delivery through the proposed model, it is possible to highlight which are the most critical success factors for industrial companies in the implementation of this technology and which are the main research gaps, which future research could focus on. Table 5 shows an outline of the main evidence that emerged, which is then commented on.

Category	Factors	Industrial Success Factors	Research gaps
TASK	Task Complexity		
	Remote Work		
	Codification		
	Recoverability		
WORKFORCE	Digital skills		
	Practical/technical abilities		
	Theoretical technical competencies		
	Technology acceptance level		
CONTEXT	Digital Leadership		
	Organisational processes		
	Accessibility		
	Connectivity		
	Comfort		
	Environmental impact		
TECHNOLOGY	Cybersickness		
	Ease of use		
	Tool usability		
	Hardware and software characteristics		

Low relevance — High relevance

Table 5.
Relevance of the emerged factors

In general, from the interviews, as well as from the literature, we have shown that the most critical constructs are often related to the workforce, which is still greatly influenced by age, seniority, work experience and schooling of field technicians, with which companies must deal with.

Aspects from the empirical research that are linked to the environmental context in which the technician will conduct their task are still poorly understood by the literature and may deserve further investigation.

The factors to consider are those related to *user acceptance* and *organisational processes* adaptation, which are crucial success factors, especially as highlighted in the literature (Cabero-Almenara *et al.*, 2019; Porcelli *et al.*, 2013a, b; Guest *et al.*, 2018). User acceptance is not only a success factor, but the lack of it is a serious challenge to overcome. This is one of the aspects that deserves to be explored especially from the customer's side, often closely connected to the context in which either technicians or customers operate.

Linked to this aspect, a set of complementary technologies, such as smartphones or tablets, must be kept in mind, which enable instant messaging, photo and document sharing and video calling and that are now widely used in private life, and many users may prefer them to new learning technology, such as AR tools (Pejoska *et al.*, 2016).

Because of the significant implications of organisational adaptation and compatibility of technology with successful implementation, future research could focus on how to adapt the processes for AR, how to align it with current systems or how to ensure the health and safety of the operator using those systems to achieve acceptable scalability of the AR solution in industrial contexts, considering the factors resulting from this research. Furthermore, especially in field service, the workplace significantly influences the choice of AR tools: for example, DPI may need to be worn, so some types of smart glasses may not be used, or even in places where technicians need to use both hands to work, an HHD solution may not be optimal. As an initial validation, we can confirm that, although from profoundly different industrial sectors, our respondents have revealed commonalities in the adoption of AR technology in the service sector, allowing us to identify the factors not yet explored and deepened by the literature.

This study comes also with some limitations, such as the limited number of respondents and cases, which prevent the generalisability of our model to other sectors and AR applications. The next developments in this stream of the research include validating quantitatively the model, verifying that the solutions adopted by the selected companies conform to the identified factors and insights into adopting technologies other than AR.

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Further reading

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Annex

Job position and experience

(1) Company you work for

(2) Job position in the organisation

(3) Years of experience in this and similar position

(4) Tools that you are equipped with for your daily work

Customer Service tasks performed

(1) In which customer service tasks do you spend, on average, most of your working time? Give freely your estimated percentages.

- . . . field intervention for planned maintenance at the customer premise
- . . . travelling
- . . . equipment installation and configuration
- . . . audit/field inspection
- . . . fix and repair: field intervention (on-site/customer premise)
- . . . fix and repair: repair centre (on centre/laboratory)
- . . . managing rolling stocks of spares and consumables
- . . . modernisation and updates services
- . . . training
- . . . paperwork
- . . . retrieving and consulting manuals, maintenance procedures, wiring diagram
- . . . looking for and setting up the needed tools (software/hardware)
- . . . other: ___________

(2) For the most relevant service tasks (i.e. those that employ you most), please tell us:

- What is the occurrence of unexpected events? Please refer to the following scale: 1. Very common (they happen always). 2. Common (they happen frequently). 3. Uncommon (they happen, but infrequently). 4. Rare (in my memory, they've happened quite a few times). 5. Very rare (they rarely happened)

  What are the triggers of these unexpected events? Please discriminate about the following:

  - Out-of-design operating conditions of equipment/products
  - Failure modes of equipment/products whose action plans (i.e. remedies, problem-solving scripts, maintenance routines) are unknown (to the best of your knowledge) because you've been not trained (they are not documented/codified)
  - Action plans (i.e. remedies, problem-solving scripts, maintenance routines) are known, but they cannot be implemented because of a lack of resources (time, tools, parts, etc.)

- Peculiar customer behaviours and/or unpredictable organisational practices
- Customer's requirements and facility configurations
- Other environmental factors (give examples, e.g. traffic conditions)

- In those cases of the above-mentioned unexpected events, how do you struggle to solve them?
  - Check guidelines, service manuals, documents
  - Ask colleagues (practical expertise)
  - Ask product specialists
  - Do workaround/trial and error
  - Do not solve directly but escalate to others
  - Other: ______________
- How much the occurrence of unexpected events/situations that prevent you from accomplishing your task, could be reduced by the following:
  - Increasing training, documentation and scripts
  - Increase collaboration among experts
  - Other: _______________
- In case you were requested to operate in a dark room and have to hold in one hand a torchlight for the entire duration of the task (e.g. to see, read, use the phone, etc.) how much this would affect the following [please refer to the following scale: 1. Very much 2. Much 3. Moderately 4. Slightly 5. Not at all]:
  - The length of the task
  - The quality/outcome of the task
  - The feasibility of the task
  - Your health and safety condition
  - Other: ____________

Augmented Reality

What do you know about augmented reality applications? In case you know, or have tried, what is your perception? Do you think that these could help to improve customer service tasks? In this case (yes or no), why?

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