Final published version of this article: *European Journal of Innovation Management*, Vol. ahead-of-print No. ahead-of-print

Article publication date: 9 November 2023

DOI: https://doi.org/10.1108/EJIM-02-2023-0118

Publisher: Emerald Publishing Limited

Exploring SMEs innovation paths with augmented and virtual reality technologies

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Abstract

Purpose Augmented Reality (AR) and Virtual Reality (VR) are increasingly recognized among technologies potentially driving the digital innovation of Small and Medium-sized Enterprises (SMEs). Nevertheless, the implications of AR/VR adoption in innovation processes have received little attention to date, with the need to explore the issues facilitating a systematic implementation in the SMEs context. This study aims to investigate the possible innovation paths of SMEs as a result of AR/VR adoption.

Design/methodology/approach We performed a multiple case study research, involving six Italian SMEs in manufacturing and service sectors that are investing in AR and/or VR solutions and are digitally innovating thanks to these technologies.

Findings AR/VR solutions lead to different types of innovation in SMEs, i.e. for innovating product or service offerings, business processes or even the business model, when AR/VR extends to the company business logic. SMEs demonstrate being able to leverage internal sources with the essential commitment of top management and low resistance of employees in all kind of AR/VR-enabled innovations. Conversely, they involve different external innovation sources according to the type of innovation pursued. Organizational issues emerged as more relevant than technological issues.

Originality This study explores the impact of emergent technologies in the innovation process along with multiple perspectives, degree of complexity and strategic importance in the SME context.

Practical implications Results contribute to literature on digital transformation of SMEs and provides managerial guidance on innovation sources and organizational issues to be considered to effectively deploy AR/VR solutions into specific innovation paths.

Keywords: Augmented Reality; Virtual Reality; Small- and medium-sized enterprises; Digital transformation; Innovation management; Multiple case study

1. Introduction

Firms are increasingly forced by pressing challenges to become adaptive and create increased value for customers to remain competitive (Porter and Heppelmann, 2015). The need for flexibility and faster time to market calls for transformed production and innovation processes, with a high level of connectivity and integration between business processes and systems, organizational groups and stakeholders (Fatorachian and Kazemi, 2018; Müller et al., 2018). The higher level of integration can also be enabled by the new functionalities of the digital technologies (Del Sarto et al., 2022; Jardim-Goncalves et al., 2017). Digital transformation is shown to facilitate the innovation of products, services, and processes for value creation and co-creation, supporting all customer journey phases (Matarazzo et al., 2020).

Among key enablers of digital innovation, Augment Reality (AR), and Virtual Reality (VR) solutions are growing in the last decade thanks to the recent developments and the widespread availability of (mainstream) technologies such as smart and wearable equipment, smartphones, tablets and tracking technologies (Bottani and Vignali, 2019; Guo et al., 2019). Both technologies have been introduced since the beginning of the twentieth century (Baus and Bouchard, 2014), but they are now increasing at a very fast pace with the development of different systems scattered among businesses, academia, and sciences (Evangelista et al., 2020). On the one side, AR and VR and their enhanced multi-experience interaction are recognized among the top strategic technology trends for the upcoming years together with Artificial Intelligence and Machine Learning (Van Kuiken, 2022; Visch et al., 2022), and the most

important technologies associated with the digital transformation of companies (Rindfleisch et al., 2020). Also consumers tend to be recently open to the new developments of virtualizing physical goods (Rauschnabel, 2021). On the other side, real-world applications in specific areas (such as product design), and novel data-centric options are needed to be integrated into innovative value propositions to redefine industry practices (Bottani and Vignali, 2019; Saura et al., 2021). The technologies that allow the interaction between the digital and physical worlds are indeed bringing disruptive opportunities in pervading and even originating new business models (Del Sarto et al., 2022), and also increasing competitiveness and labor productivity (Cirillo et al., 2023).

In particular, Small and Medium-sized Enterprises (SME)s can potentially exploit many AR/VR solutions opportunities. The significant advantages of AR/VR include convenience, economy, good interactivity and security (Baus and Bouchard, 2014), and their adoption could be extended at different levels, including innovation processes, and operational and organizational structures (Fatorachian and Kazemi, 2018). SMEs could effectively leverage interactive solutions to expand their innovative potential and transform their customer value proposition, as their business strategy is often based on flexibility and reactivity to customers and suppliers (Cirillo et al., 2023; Moeuf et al., 2018). Nevertheless, the introduction of new technologies and practices is always risky in SMEs: they encounter barriers such as the lack of necessary resources, skills, commitment, and proper understanding of digital opportunities also due to a lack of tradition in R&D (Giotopoulos et al., 2017; Radas and Bozic, 2012). In particular, financial constraints represents one of the most relevant issues that innovative SMEs have to face in the market (Chiappini et al., 2022). Literature also recognizes that VR and AR solutions feature a high complexity in structure (integrating both hardware and software) and supporting tasks such as data collection, training and deployment (Baus and Bouchard, 2014; Guo et al., 2019).

Along with this line, there is the need to explore effective ways and issues in the digital implementation patterns of SMEs (Müller et al., 2018). First, the process behind the adoption of AR/VR solutions and the respective implications on innovation management has received little attention to date, with a disruptive potential that has still to be unleashed (Guo et al., 2019; Ibrahim and Obal, 2020; Rindfleisch et al., 2020). Second, there emerged differences in the effects of digital enablers on the innovation of SMEs (Somohano-Rodríguez et al., 2020). Further research is requested to investigate the current level of use of AR/VR systems, and how they can be applied more systematically, accelerating their implementation in different industrial scenarios (Burova et al., 2022; Jalo et al., 2022; Palmarini et al., 2018). Third, organizational issues are recognized more relevant than the technical aspects of the industry, but their importance has not been reflected the same extent in the literature (Masood and Egger, 2020). By enhancing physical-digital interactions, AR/VR can radically transform organizational activities and structures, with the need of further research on potential issues and changes that their adoption can bring (Jalo et al., 2022).

This study aims to explore the effective patterns of adoption of AR/VR solutions in the innovation process of SMEs, in terms of specific outcomes and organizational issues. Therefore, the research question guiding the investigation was: *How are SMEs innovating as a result of AR and VR adoption?*

The rest of this research is organized as follows. Section 2 reviews existing AR/VR solutions applications in the industry, the major challenges of these technologies, and how they are disrupting the innovation process. Section 3 introduces the methodology adopted in this study, i.e. the multiple case study. Results on the adoption patterns of AR/VR in SMEs from the cases are presented in Section 4 and discussed in Section 5. Finally, Section 6 depicts some conclusions.

2. Theoretical background

2.1 AR/VR applications in manufacturing and service industries

AR and VR solutions can create a virtual representation of a complete system and its interactions differently. VR generates virtual scenarios where the users can interact with virtual elements (Cruz-Neira et al., 2018). AR works in real scenarios, augmenting certain information through virtual elements and allowing interaction with these elements (Carmignani et al., 2011). More recently, Mixed Reality (MR) also emerged as a mixture of VR and AR that combines virtual and real worlds with the integration of 3D elements into the user's perception of the real world (Rauschnabel, 2021; Sung et al., 2021). In general, scholars refer to all of them as AR/VR as they enable adopting and accessing virtual elements in real-world operational tasks.

The current applications of AR/VR technologies are scattered across various fields, including military, health care, education, tourism, construction, and transportation (Baus and Bouchard, 2014; Huang et al., 2016; Palmarini et al., 2018; Wang et al., 2013). These tools have a high potential for various purposes and application scenarios. They are financially advantageous, easy to use, safe and suitable for performing tasks too dangerous in the real world (Baus and Bouchard, 2014; Bottani and Vignali, 2019). Moreover, they provide the end-user with a multi-sensory simulation of diverse scenarios with entertainment and psychological elements (Baus and Bouchard, 2014; Huang et al., 2016) that increase the possibility of acquiring new skills and learning new activities (Danielsson et al., 2020; Roldán et al., 2019).

In manufacturing, AR/VR solutions are primarily adopted for supporting assembly and maintenance operations, including all tasks to restore functionalities of a product or equipment in asynchronous collaboration between dispersed departments (Burova et al., 2022; Palmarini et al., 2018). They can be specifically used to train inexperienced users in assembly/disassembly tasks regarding safety procedures and to learn new activities (Danielsson et al., 2020; Roldán et al., 2019). VR systems can also be applied in the collaborative design and presentation of

objects, the virtual manufacturing and testing of products, and the development and validation of complex products (Roldán et al., 2019). Existing applications such as smart glasses show advantages in terms of time required to complete a given task and the number of errors and failures per employee by providing specific virtual guidance and instructions when performing on-site tasks (Bottani and Vignali, 2019; Hao and Helo, 2017). Other VR-based tools analyze human factors, e.g. ergonomic issues and performance characteristics, in the manufacturing context (Alexopoulos et al., 2013). With the extension of 3D models to the supply chain, the data on market demand, planning activities and product availability can be displayed in real-time to operators and managers (Dalmarco and Barros, 2018), and specific logistics steps, such as order picking, evaluated (Rejeb et., al 2021).

The use of immersive technologies has also profoundly changed the provision of services and customer consumption experiences (Sung et al., 2021). Most diffused uses include information dissemination, marketing and communication with targeted customers, and training (Huang et al., 2016; Roldán et al., 2019; Wang et al., 2013). Customer engagement is particularly enhanced with AR applications that show the results of services and provide customers with an immersive experience (Batat, 2021; Matarazzo et al., 2020). These solutions can even support personnel servicing customers with monitoring, operating, and the service information content (Porter and Heppelmann, 2015) and simulate how products appear if customers purchase them (Chandra and Kumar, 2018, Matarazzo et al., 2020). User-centric AR/VR products are designed to better meet customer needs, with the integration of value-added services improving the data-centric digital strategies of SMEs (Bu et al., 2021; Saura et al., 2021).

Despite the fast pace of technological advancements in the last decade and the tremendous implications of AR/VR in all these fields, most of these applications are still in their pilot stages and considered relatively new (Danielsson et al., 2020; Guo et al., 2019). They are defined as

more sophisticated than other technologies by SMEs, with market entrance barriers that still prevent them from a common use (Wendt et al., 2022).

2.2 AR and VR as disrupting technologies in the innovation process

The potential extent of digital transformation in the different stages of the innovation process challenges managers in considering the adoption of new technologies like AR/VR for everyday operations (Appio et al., 2020; Ibrahim and Obal, 2020). AR/VR is now considered disruptive since it can profoundly change the internal processes of new product or service development, from conceptualization to manufacturing or delivery, or even the business model, and often requires support in integration to operations and existing information systems (Ibrahim and Obal, 2020; Jalo et al., 2022). In this case it is a technology-push or inside-out product innovation, with companies that commercialize a new good that incorporate a AR/VR technology to fulfill customer needs either better than existing products, or even customer needs that could not be fulfilled with existing products (Bucherer et al., 2012; Snihur and Wiklund, 2019). For example, the value of existing products can be enhanced by an AR layer that increase authenticity with additional features, in manufacturing machines but also common objects as clocks (Rauschnabel, 2021). With service innovation, companies introduce new value-added options, customize or even radically change their service products by collecting both user-generated and AR/VR system-generated data to create augmented user experience, where people access and interact with information visually (Bu et al., 2021). The introduction of AR/VR systems to support specific workers' efforts in production and distribution processes, also with the introduction of new methods or work organization benefitting from a seamless integration of the real and the virtual, lead to a process innovation (Danielsson et al., 2020; Snihur and Wiklund, 2019). The changes and innovations to be introduced in the production and delivery processes seem to less important in the SMEs context, with limited financial

performance and fundings (Madrid-Guijarro et al., 2013). A higher commitment is required in business model innovation, with companies applying AR/VR to even lead to an industry breakthrough: they expand the company value offering with more comprehensive differentiation from the competition and broader effects on the overall operational model (Bucherer et al., 2012), even with a business model entirely entailing the AR/VR versions of product and/or service offerings (Rauschnabel, 2021).

SMEs that show a dynamic aptitude to operate in complex environments, adapt their structures to market changes, and be ambidextrous are demonstrated to be abler to leverage emerging digital technologies to innovate more than their competitors (Del Giudice et al., 2020). Moreover, SMEs need to be able to overcome financial constraints hampering their ability to undertake innovation paths exploiting, e.g., public innovation support measures such as R&D subsidies, subsidized loans, and R&D tax credits (Harrison, et al., 2022; Chiappini et al., 2022). Recent works report that the more the company adopts innovative technologies, also supported by direct innovation subsidies, the more likely it is to obtain external funding such as bank or equity financing (Pellegrina et al., 2017; Mushtaq et al., 2022).

The unique characteristics of interactive technologies are demonstrated to help companies in their innovation practice as they can develop the capacity to experiment in-depth, involve more people in the innovation process, and augment talents (Griffith and Alpert, 2022). These capabilities are fundamental, considering the higher learning costs and organizational inertia that often occur with adopting a radical tool or technology in a process (Ibrahim and Obal, 2020; Zabel and Telkmann, 2020). Nevertheless, the ways digital transformation impacts innovation processes are still considered complex and ambiguous, and technologies like AR and VR can “augment” product, service and business performance in multiple ways (Appio et al., 2020). On the one side, adopting new technologies has positively impacted the innovation of both processes and services (Lyytinen and Rose, 2003). AR/VR solutions, in particular, can

improve development performance and have a high potential for SMEs to gain a competitive advantage or even seize niche markets (Guo et al., 2019). On the other side, introducing radical technologies presents risks and possible negative impacts, such as employee resistance and slowing down or interruption of the development process (Ibrahim and Obal, 2020). The perceived complexity of AR/VR technologies require employees to familiarize with them, overcoming the inertia and resistance towards adoption with dedicated and available personnel for R&D on this field or even recruitment of new resources with AR/VR expertise (Jalo et al., 2022).

Both technical and human factors are limiting the use of AR/VR technologies in everyday work (Evangelista et al., 2020). Personnel should be involved in tasks that range from data collection and processing (both user-generated and system-generated content), programming, and modelling, to knowledge management, deployment and maintenance (Guo et al., 2019; Palmarini et al., 2018). This multitude of tasks, especially when aimed at product and service development, could lead to the need of drawing on various sources of innovation to benefit from a convergence of multiple technologies and domain knowledge (Wang et al., 2013). There is also a lack of human-machine interaction standards and unified norms; thus, enterprises can rely on few references for the deployment of AR (Danielsson et al., 2020). This deficiency could limit the openness of top management to AR/VR solutions and their willingness to invest in them beyond the necessary change in work culture (Rejeb et al., 2021). Companies should also take into account that different innovation outcomes drive the need of integrating various elements, components and sub-systems of multiple layers to realize human-machine interaction, with development patterns of hardware and software that are also highly diversified (Baus and Bouchard, 2014; Palmarini et al., 2018; Wang et al., 2013). Integration issues are also encountered in including heterogeneous data from enterprise processes in a unified information model that is provided as input to the AR/VR solution (Jardim-Goncalves et al.,

2017). Wellness implications and acceptance from employees must be considered as both devices and software have to be well-suited to operational activities, with a necessary collaboration from operators to ensure successful functioning (Rejeb et al., 2021). Nevertheless, the organizational capabilities facilitating the delivery of specific digital innovation outcomes are less explored (Ramdani et al., 2021).

3. Methodology

Aiming to explore the role of AR and VR adoption in SMEs' innovation processes (Rindfleisch et al., 2020), we adopted a multiple case study methodology (Yin, 2013). Considering the focus and the goal of our study, we selected SMEs that are investing in AR and/or VR solutions and are digitally innovating thanks to these technologies. We adopted a purposeful sampling method (Patton, 2002) to select heterogeneous cases in terms of firm industry (both manufacturing and service industries), role in the value chain (tiers and types of products or services provided) and objectives of adoption of AR/VR solutions, and homogeneous cases in terms of markets (business-to-business) and country. We selected six Italian SMEs operating in a business-to-business market of manufacturing and service industries and based in northern Italy. Among main industrialized countries, Italy has encouraged SMEs to adopt I4.0 enablers, aiming to push their innovation attitude and improve their business models, with the application of a set of consistent and different measures implemented by the Italian government across all sectors (Del Giudice et al., 2020; Zangiacomi et al., 2020). These measures have promoted investments in innovation and competitiveness, at the regional and national level, including tax credits for education and vouchers for digitalization, with a growth of domestic orders, especially in the acquisition of machinery, and better awareness on the ability to exploit the opportunities offered by technologies like AR/VR for competitiveness and employment (Cirillo et al., 2023; Zangiacomi et al., 2020).

The multiple case study design allowed cross-case comparison to recognize emerging patterns of relationships among constructs and investigate a contextual phenomenon (Yin, 2013; Eisenhardt and Graebner, 2007), as the implications of AR/VR adoption in the transformation of SMEs' innovation process. Moreover, the multiple-case study allows for confirming or not with each case the inferences drawn from the others according to replication logic (Bingham & Eisenhardt, 2011). According to Rowley (2002), a number of six to ten case studies is suitable for this kind of research.

The six companies effectively embraced a strategic approach or at least a project towards the use of solutions such as helmets, gloves, smart glasses and virtual environments in their business and innovation process. They promoted their adoption through, e.g. communication channels with customers or presentations in public events. To study the level of a breakthrough as a result of AR/VR adoption, we distinguished and analyzed the cases according to the types of innovation identified in section 2.2, i.e.: (1) Product or (2) Service innovation, if AR/VR resulted in changes in products or services, or with a new product or service commercialized; (3) Process innovation, if new elements have been introduced in manufacturing or service operations; (4) Business model innovation, if the change has extended to the core elements of the company and its business logic (Bucherer et al., 2012; Madrid-Guijarro et al., 2013; Snihur and Wiklund, 2019).

Table 1 presents an overview of the cases selected for this study.

[Table 1 about here]

3.1 Data collection

We employed both primary and secondary sources of data. As primary sources, per each case, semi-structured interviews were conducted with managers and employees being directly

involved in the technology experimentation and thus having a significant understanding of the challenges faced in the digitalization path. Specifically, we performed two interviews per each case, in order to capture different viewpoints about the adoption of AR/VR tools. This allowed to collect data both on the managerial and operational side of technology implementation, as we interviewed the CEOs, innovation or R&D managers, business development managers, and operations managers, followed by one operator in the function interested in the adoption of the AR/VR solution. Besides multiple respondents, there has been also the presence of two investigators in the different interview meetings to enhance the validity and reliability of the collected data (Yin 2013). Due to the COVID-19 pandemic, the interviews were carried out via remote video conferencing software (such as Teams and Skype). The meetings lasted between 45 and 75 minutes and were recorded with the interviewees' consent. The interviewers created a summary of all the interviews and transcribed quotes from each interview. The questionnaire was adapted and translated into Italian from the protocol used (and tested) in a European project aimed at investigating the level of adoption of AR/VR solutions in European SMEs (Jalo et al., 2022), focusing on the areas of investigation related to the innovation process. In particular, the groups of factors affecting the adoption of the considered technologies were adapted from the TOE framework, i.e. technological (e.g., What kind of issues have you faced in integrating AR or VR in your innovation process?), organizational (e.g., What kind of skills were missing to handle AR/VR technologies properly?) and environmental (e.g., Did you need external support to adopt VR/AR?).

The information collected through interviews was then integrated by secondary sources, aiming to triangulation purposes for consistency of findings and mitigation of bias (Yin, 2013). We considered internal documentation provided by respondents and publicly available data on company websites (or other Internet sources) when available. In two cases, data were also

collected during a company visit, with the research team being able to observe the current implementation of AR or VR solutions.

3.2 Data analysis

During the first period of interviews, the researchers performed data collection and analysis in interaction to eventually review and refine the emerging findings. The recorded interviews were first transcribed. Then, researchers created a database for each case consisting of the interview transcripts, field notes, and other secondary data. We analyzed the data following a two-step procedure, including within-case analysis and cross-case analysis. In the within-case analysis, we considered some of the key elements to be investigated on the adoption of emergent technologies in the innovation process from literature (Barczak et al., 2007; Chandra and Kumar, 2018; Ramdani et al., 2021): i) the sources of knowledge for AR/VR adoption, e.g. the existence of internal innovation champions and the customers' demands; and ii) the organizational and technological factors in the uptake of AR/VR technologies, e.g. the innovative climate and the perceived ease-of-use. The results of this phase are presented in the following Section 4. Following the within-case analysis, the pattern-matching and cross-case analysis (Yin, 2013; Eisenhardt and Graebner, 2007) led to identifying the main factors and emerging perspectives on the adoption of AR/VR in the innovation processes of SMEs. Collected data were distinguished in first-order data, corresponding to informants' views, and second-order data, where coding was undertaken using concepts drawn from the innovation literature. Following the analytic technique of pattern-matching, similarities and differences between data incidents and groups of codes were identified (Eisenhardt and Graebner, 2007; Yin, 2013). This analysis allowed us to detect innovation sources and technological and organizational patterns in terms of facilitating and limiting AR- or VR-enabled innovations.

4. Results

This section presents the results from the within-case analysis. After a brief presentation of the company and the type of innovation fostered by AR/VR solutions, factors encountered, and issues emerging in the introduction of the new technologies into innovation processes are described.

4.1 Case A

Company A is an SME working in the manufacturing of process equipment. The company adopted AR technology to support service innovation in providing remote assistance and control to customers worldwide, e.g. during the start-upping phase or machinery maintenance. This represents a service that is sold to the end customer, especially in the post-sale phase, and was previously performed only with the physical presence of the employees of company A. In the new "augmented" service, the customers own a tablet or a smartphone with an integrated app for AR that displays the data on the ongoing problems on machinery. In this way, company A can indicate to its customers how to operate and solve the specific issue by virtually sharing 3D models and documentation for data visualization and collaboration. The main tools adopted are voice-activated viewers of Epson and Google.

Company A is at the forefront of technological innovation in its sector, and the direct competitors haven't adopted AR or VR solutions yet. The company's culture leverages a history of innovation and proactivity to continue operating at the international level because "the big fear was to lag behind everything that went on outside". Therefore, the interviewees argue it is worth working on these technologies, especially in this period of general crisis and restricted travel. According to their knowledge, there is still the need to increase awareness of advantages and issues implied in technological adoption.

Being an SME, company A cannot fund innovative research and development programs on these technologies. Still, they are aware that their employees would need better support to

handle them properly. They mainly searched for technology vendors but didn't consider potential collaborations with other innovation sources, such as universities and research centers to implement AR because they did not know about this opportunity. The president argued: "we had to look into the chaos of Industry 4.0 and AR to look for solutions that were at least adequate for what was our potential needs". Despite this, innovative customers of the steel sector wanted to experiment with the use of these technologies for their machinery, and trials and developments were agreed with them.

For what concerns organizational issues, employees are still facing some problems in using this technology ("It is not easy to move to the new way of working for our employees"). Still, they are supported to be more motivated and able to use it effectively. Even older employees, although not proactively, are adapting to the new way of operating, with low levels of resistance. Internally, the top management has supported the adoption of this technology in one of its core services from the beginning. Externally, the support and the training are provided by the two technology vendors that also provided the hardware and software solutions. One of the external issues highlighted by the interviewee is that proper training is provided only if technological solutions are bought. There is thus the need for more systematic training, also to increase awareness of the implications of AR technologies. Finally, some technical issues have been reported. These are due to the necessary steps to integrate the new technology with company information systems, mainly in terms of automated interfaces among them.

4.2 Case B

Company B is a software development small enterprise that recently innovated its product offering by introducing AR solutions. During the last years, it has started some new product development projects to integrate AR and VR technologies in the offering package to its customers. The interviewee argues indeed that AR has more potential than VR as it allows to have more information, e.g. on processes and procedures. It is easier to be understood by users:

“the AR is much more ‘consumer-friendly’, many users will find themselves, for example, entering a supermarket and framing the counters and seeing the arrows and being told to go from here or there, […] then VR needs a headset, space, and when using these devices, you risk hurting yourself”. In the company’s opinion, the use of VR solutions is thus more linked to training and entertainment purposes. Focusing on possible contents, the 3D models are the most interesting to be used collaboratively for data visualization and predictive maintenance purposes. People can make changes in real-time to a shared model, and have quick access to the information needed at that moment: “for example, a technician looking at a machine with Hololens has the possibility of having reported, there is already written on the machine that next week you have to do a maintenance operation rather than the warranty expires or you have to change it.”

By its nature, the company holds a deep propensity towards innovation and keeps being updated on technologies. For example, when Hololens arrived in the USA, they were among the first Italian companies buying them as developers. Direct competitors (among small companies that develop software solutions) are still not adopting these technologies. The interviewee argues that customers are keener on mobile devices (e.g. Android) and less on AR/VR devices as headsets. There is still scepticism about keeping AR/VR devices on the head or in the hands. This underlines the need to work on the hardware parts and make available to companies more testing options to increase awareness of the perception of discomfort.

As previously underlined, the company shows a clear propensity to innovation. The interviewee reported that “we always try to understand what’s going on […] we hope there will also be a business opportunity”. For example, they often organize internal company contests to bring out new ideas; moreover, business managers explicitly ask younger employees to make proposals for experimenting and testing new technologies. One of the most innovative ideas developed concerns the application of AR in an industrial context for a company producing pieces of

machinery. Last year, they collaborated with the local university to create a prototype that they can use and extend to make demos more targeted to different customers.

The employees are familiar with both AR and VR. They followed courses on Unity and acquired the HTC Vive tools. Other adopted devices are Android tools for AR, Hololens, and Oculus Rift. They are not using these technologies for working (any of the current business processes require this kind of technologies), but they are developing some demos to understand the potentialities of these systems according to their customers' business and demand. Concerning technical issues, the main entrance barriers are for smaller companies among their customers, as there is the need for updated database software and people feeding it, in addition to AR/VR tools. They also underlined that small companies could not afford customized solutions.

4.3 Case C

This company is a start-up operating in the consulting sector for change management and organizational empowerment. They strategically applied VR technology to better support their consulting services, which enabled them to innovate their value proposition. Hence the company implemented Augmented Psychology by integrating the potentiality of VR solutions with the last frontiers of neuroscientific research. VR immersive experiences are used for augmented clinical practice and organizational empowerment. In this second case, protocols and tools are designed to facilitate and accelerate empowerment and change management, thanks to motivating and engaging immersive virtual experiences, managed and elaborated by a trainer during individual or group sessions.

The company provides thus highly-personalized solutions for Virtual Reality content development. Virtual environments are characterized by high visual fidelity, thanks to state-of-the-art 3D graphical engines (Unity, Unreal) and modelling skills. The company adopts holographic projectors for 3D visualizations for training and education purposes. VR is also

used to support collaboration (virtual meetings), particularly during this challenging period due to the COVID 19 pandemic: for this application, they use virtual reality glasses such as Oculus Go and Oculus Quest, which allowed them to exploit a mature technology.

Company C holds a deep propensity towards innovation and is also aware that competitors have benefitted from VR technology even if there is still room for further development in their sector. In particular, “we think that AR will lead to many benefits transversally in a couple of years, but by now VR offers more opportunity for what concerns our needs, even if today we can say that VR reality is much more a niche technology”. The main barriers depend on the market for Augmented Reality: there are only a few products available (Microsoft and Google) and a few costly solutions. Cellular and tablet are low-cost solutions but not proper for their needs: “the headset is what makes the real difference.”

Innovation is mainly led by company team members who have significant experience in designing virtual environments and is also exploited through collaboration with scientific institutions and universities both in Italy and abroad. They started scientific cooperation with the Psychology Department of a leading university to study the immersive effects of VR environments and their application for mental well-being promotion in clinical and organizational settings.

The company management highly supports innovation for what concerns most of their applications. Hence, they can internally develop 3D videos used for VR-based training purposes and test them for the professionals of their community. Employees can all use the technology without problems and do not need any specific support. Due to the particular attitude towards the technology of collaborators, the company does not experiment with difficulties in the acceptance of VR, as they say, to “have more headsets than collaborators”. The company did not experience any specific integration issues: they developed all internally, except for the external support in some particular phases as the dubbing of the immersive videos. Also, for

what concerns the adoption of the technology, collaborators' competencies and skills prevent potential problems.

4.4 Case D

The company is a leading medium-sized firm specialising in structural design services. It has started the adoption of VR ad AR technologies, particularly AR, to support innovation for customer experience. Considering that construction projects are physically ready only some years after their design, the company needs to show its customers the final project in advance. The introduction of AR/VR solutions enhances visualization during the presentation of its projects to the clients from the early stages of the development process. They can collaboratively evaluate the proposal's appropriateness and detect needed modifications in time. In this way, "decisions can be taken on the virtual models, the customer can have different points of view: this is a big potential at a low cost, with AR that allows shortening the time between what we realize and what we sell". They implemented both AR and VR technologies in partnerships with two different technology providers. In collaboration with the first partner, they implemented and now use VR, in particular for visualization, as a substitute for the material architectural model. However, they still do not use it for co-design purposes. With the second partner, they tested the AR to support real estate data management, enabling the virtual visualization of buildings and access to related data. The device used is mainly smartphones and tablets with an integrated AR application. Oculus Go is the specific solution adopted for VR. Company D presents a high propensity to innovate, and it is among the first ones in the sector that have adopted and experimented with this kind of solution. The internal Research Lab drives the development process, established a few years ago and aimed at testing new technologies where partners can collaborate on novel services or products.

Moreover, they were acknowledged on the possible implications of AR/VR for their business by some service providers presenting them with AR/VR solutions for digitalization. Also, the

top management recognizes that AR has a critical technological advantage, even if the market is still not ready for a widespread application in all projects: “We are too in advance for the market, customers say: “ok, see you in 5 years”. Their customers’ low level of readiness represents the main barrier to extending the adoption of AR/VR solutions in all their projects and thus potentially leading to a business model innovation. For this reason, some previous investments to adopt new technologies were not reworded, and they were forced to develop this kind of project internally in the lab. Otherwise, it would be very difficult to pay off the investment in their business. Some competitors are using similar AR/VR applications in pilot cases but not with a systemic approach because the sector is still lagging in developing and applying such solutions.

They collaborate with universities and research centers in some development projects, but not on such technologies because they are not aware of their potential support. The innovation manager argued that “maybe it is silly to say, but we do not even know that research centers or universities have such kind of competencies”. The company needs support in particular for implementing the software infrastructure and the realization of the virtual models; thus, they consolidated the partnerships with a couple of service providers that develop AR/VR solutions as core business. This represents an opportunity also for the service provider to find new applications: for example, one provider mainly developed AR solutions for digital marketing purposes and now is extending its competencies with the development of virtual construction models.

Internally, key personnel in the innovation process are the innovation manager, responsible for the company lab, and the project managers in charge of implementing the digital solutions in some pilot contracts. Even if the company recognizes they are following an “uphill road”, they do not face particular resistance from employees, encountering common problems when adopting a new technology platform. One interviewee highlights that “curiosity towards

colleagues and a competitive attitude can help both internally and with the outside". They do not need specific support for training people because they judge the solutions adopted as self-explaining and user-friendly. Finally, they organize shared events with their customers to show the functioning of these AR- and VR-based applications, and they use them also as opportunities for informal training sessions.

4.5 Case E

This medium-sized company works in the metallic carpentry industry. Company E adopted this technology only for a particular project aimed at identifying innovative approaches for training operators in specific operations (the most hazardous ones as welding) and potentially solving the company's problem of having more qualified operators. The company thus decided to scan the market for VR solutions and got in touch with a start-up that developed a solution integrating VR tools with a welding torch. Specifically, they used a Samsung viewer and external motion sensors; then, the welding torch was incorporated into this immersive environment, being detected by the sensors. The company tested this solution as it was the only one known with a specific application for welding operations. The most significant barrier they faced was the technological content, its efficacy and return from investment. The experience offered by the VR solution was judged not effective for improving operators' skills because, "from a technological point of view, the solution was very interesting, but it did not have those details that are necessary to train a welder". Besides this first pilot project, the company is scanning the market for identifying the best solution to solve the business problem.

The middle management of the company had an essential role as an innovation source: they highlighted the internal need for more specialized welders and the gap in terms of competencies, then scanned the technological solutions judged as most innovative and promising, and decided to test VR with the support of the top management. Conversely, the plants' suppliers and safety measures do not provide input to adopt innovative applications with VR (and AR) technologies.

Company E is aware that some competitors (but not their direct ones) started adopting these technologies in their market but still not exploiting them to their full potential. Only some customers (large companies) have projects dedicated to using these technologies for training operators in systems with high safety requirements.

The company tested the VR solution with some internal welders to evaluate the adoption approach and its impacts. It received support from the external provider in the training phase, but then the operators testing the technology spread the knowledge on their experience to the other employees and collected their feedback. The interviewee argues that "the company and the top management has an attitude to innovation in various areas" and access to highly innovative networks as clusters of companies. The operators involved were enthusiastic about having the opportunity to test the solutions, and then provided objective feedback on the effective potentialities for the company, also considering the sector features, indeed "it was enjoyable for the operators to experience something they had never seen before, beyond the fact that we decided not to continue on this path, it was a very interesting approach". Finally, the company didn't encounter integration issues between the internal information systems and the new solution, as the welding project didn't require any type of data to be transmitted to the application. The provider used standard models of the motion sensors to be codified in the virtual environment.

4.6 Case F

Company F is a leading medium-sized firm in the machinery sector, and it builds customized automatic systems for the assembly of different products, commissioned explicitly by customers from several industries such as automotive, cosmetics, and furniture. Considering the performance, uniqueness of the produced machinery, and a strong culture towards innovation, the company is developing both AR and VR solutions with a long-term perspective. The interest in AR and VR technologies is growing since they saw the first AR applications

from BMW. For what concerns the VR technology, the company developed a prototype of VR solution for training purposes in design, considering that “with the VR I have the opportunity to be immersed in the project: seeing the machine in the virtual is different than seeing it in 3D CAD, which is not three-dimensional”. Otherwise, the AR solution developed is more advanced, and it is adopted for ordinary and extraordinary maintenance and repair, as it allows the interaction between the operator and the machinery. The company is using the complete HTC kit with antennas, viewer, and joystick as regards the devices. They also bought a computer with faster elaboration and graphical capacities and tablets (i-pad) to visualize data with AR.

The company is at the forefront of innovation in its sector, as well as in the adoption of these technologies, indeed “the board starting from the president strongly believes in innovation, and the awareness of this type of technology has grown exponentially”. Therefore, the solid organizational culture towards innovation enables company F to recognize technological innovation opportunities like the one offered by AR and VR technologies. As confirmation, they didn’t find any competitor developing a solution similar to the prototype they are presenting at several industrial fairs. The main barriers they experienced concern the low interest of customers towards these solutions, as they are still bound to more traditional performance requirements for machinery. The company is thus trying to improve their value offer by proposing optional services, such as having real-time monitoring of machinery thanks to machine learning and AR. Still, they have to work closely with the customer to make this additional service something that is needed. The company started the implementation with a selection of technology providers; then, it plans to carry out internal structured projects with specific objectives and scenarios. It is also part of an open innovation network where it collaborates on several projects with universities and research centers; it won European prizes for innovation and is among the founders of a smart regional consortium on mechatronics. The

company invests more than 10% in innovation projects, adding to the quote of investments in innovative solutions developed internally to many projects sold to customers. The top management is highly involved in the design process. It is the first showing an exponential interest in the VR and AR applications and how these solutions can fulfil their needs. From the technical point of view, the integration with information systems required by the AR prototype resulted in just some minor issues.

Concerning organizational issues, company E is aware that their operators do not need high-level skills to use the technology because they demonstrated to learn by doing and using it autonomously: they encountered only a typical 20% of inertia towards new solutions. The company provided a general (basic) course internally on digitalization and Industry 4.0 technologies, only to grow the organization's awareness. Conversely, "the design of AR and VR, and mostly the interpretation of data for virtual environments, require a highly specialized skill, for which we have also invested in training" courses from the technology providers. The company tested just a few solutions and searched for partners only in the industrial environment to implement them faster. In the future, they will pursue investing in VR projects to train their operators and the customer's operators in a completely virtual environment, without the necessity of stopping the machinery during their operational functioning.

5. Discussion

Results from the cross-case analysis show that AR/VR technologies are still not systematically adopted in SMEs' innovation processes. Still, the strong interest and propensity towards innovation represent essential drivers for their strategic application. The key point is that all companies demonstrate an organizational culture that is supportive of knowledge search and innovation: from the one side, the top management highly recognizes the potentialities of AR/VR and promotes their implementation internally; from the other side, they are not

encountering resistance from employees in using them, and adapting to the new ways of operating tasks, possibly indicating a high degree of organizational readiness (Ramdani et al., 2021) for these technologies. Interestingly, the organizational issues, such as the need to raise awareness of the potential value of AR/VR and the perceived need for training, emerged as more relevant than technological issues, such as the integration with company information systems.

SMEs adopted AR or VR solutions (or both only in a few cases) for innovating their product or service offering, a business process or even their business model when integrating these solutions into their value proposition. Table 2 summarizes the results per type of innovation below discussed.

[Table 2 about here]

As a result of AR/VR adoption, specific patterns of SMEs innovation emerged according to the type of innovation pursued (Figure 1).

[Figure 1 about here]

In *product innovation*, the willingness to integrate AR and VR technologies into the offer drives the development and commercialization of new AR/VR-based products. For example, SME B shows an evident willingness to invest in these technologies considering their specific features among I4.0 solutions tested to address customer requirements. Prototyping and testing are critical phases for new product development of AR/VR solutions; thus, collaboration with universities and research centers is essential to properly support employees in realizing cutting-edge product solutions that are still not offered by competitors. Moreover, the involvement of

younger employees in the definition of experiments and tests of new technologies is judged fundamental, also with the organization of internal contests for product improvement. The main issues are mainly related to the need to transfer the added value of AR/VR-based products to be adequately commercialized. To this end, the organization of internal courses and testing sessions with selected customers are fundamental.

In *service innovation*, the drivers of SMEs for adopting AR/VR solutions are the need to "augment" the service and thus the customer experience by visualizing or providing more data on the service outputs, especially if they are delivered with an international scope. By its nature, service innovation by adopting AR/VR solutions is shown to be more effective if customers are also innovative and willing to adopt the technology. The main barrier is indeed the low readiness of the customers in some sectors, and behavioural factors behind the adoption or rejection of technology innovation should be considered (Batat, 2021). Technology vendors are the primary source on which SMEs leverage the architecture implementation, with established partnerships that could also be complemented with an internal dedicated R&D team. Better collaborations between manufacturing SMEs and service providers are key in assisting service performance monitoring (Jardim-Goncalves et al., 2017). Still, the vendor provides support and training for the technology itself. The main difficulties are in the software architecture rather than in the use of the technologies themselves, argued to be user-friendly and easy to use (Ramdani et al., 2021). To overcome possible organizational barriers, training and demonstrative sessions with employees and customers are shown essential to spreading awareness and opportunities for developing these technologies.

When introducing AR/VR solutions for *innovating the process*, SMEs mainly invest in solving real problems in business processes, such as training the workforce for hazardous tasks (Bottani and Vignali, 2019) and increasing operators' qualification in the use of the technologies. Thus, middle management as the operations manager is the leading promoter of adopting these

technologies. A key source of innovation is the presence of internal "champions", i.e. operators testing the solution and then motivating other employees to integrate the technological resources more effectively and spread related advantages (Ibrahim and Obal, 2020; Zabel and Telkmann, 2020). Also, access to external sources of knowledge such as innovative networks and more innovative customers is pivotal to promoting and getting to know new AR/VR solutions in the industry (Snihur & Wiklund, 2019). The technological integration with the company's internal information systems for process management depends on the process and the exchange of data, but It is not judged as an issue.

SMEs that introduce AR/VR for *business model innovation* show an even higher propensity towards innovation, top management commitment (Geissdoerfer et al., 2018) and investments in related projects. Another fundamental antecedent is the strategic requirement of stimulating new customer needs using AR/VR-enabled functionalities while maintaining the uniqueness of their value offer. To sustain business model innovation, a plurality of external innovation sources, from universities and research centers, to innovation networks and technology providers, are proved essential (Snihur & Wiklund, 2019). Sources are involved in different collaborations (also non-technological ones (Radas and Bozic, 2012)), with an engagement that should vary according to the level of internal expertise in AR/VR. Other competitors benefitting from VR applications can also represent an important source of knowledge. Indeed, most interviewed SMEs argue there is a lack of competitive pressure from the market and direct competitors, which is still not considered decisive for introducing AR/VR (Zabel and Telkmann, 2020). Concerning organizational issues, SMEs innovating the business model are aware that better support and more systematic training should enhance more advanced skills for developing software solutions and AR/VR environments more effectively and efficiently. Finally, regarding technological aspects, no need for specific training for using VR/AR or resistance from an employee has been reported probably due to the solid organizational culture

towards innovation characterizing such kinds of SMEs. This result differs from the ones by Schein and Rauschnabel (2021), which identify multiple barriers to the adoption of AR/VR solutions on the worker level.

6. Conclusions

This study explored drivers, innovation sources and organizational issues of AR/VR solutions that are changing and pervading the innovation process of a set of Italian SMEs. Each case proved to have a certain level of adoption of AR or VR solutions with interesting impacts on the innovation that differ according to the degree of complexity and strategic importance (Geissdoerfer et al., 2018). They also show a cultural propensity towards innovation, an important top management commitment, and low resistance to adopting new technologies from employees. These aspects are fundamental due to the higher learning costs and organizational inertia that often occur with the adoption of a radical tool or technology in a process (Ibrahim and Obal, 2020; Zabel and Telkmann, 2020). Conversely, the engagement of external innovation actors and the perceived need for training varies according to the innovation outcome. Indeed, SMEs should look for specific collaboration strategies with the external knowledge sources based on the digital opportunities they are more willing to pursue (Ricci et al., 2021).

6.1 Contributions

This study contributes to the literature on the adoption of AR and VR solutions in companies' development process, especially SMEs, focusing on adoption patterns and involved sources. Firstly, both technological and organizational aspects were studied, considering the importance of organizational issues in the industry but still not reflected in the literature (Jalo et al., 2022; Masood and Egger, 2020). Secondly, this study explored the impact of emergent technologies

in the innovation process along with multiple perspectives. It focused on: i) the type of innovation pursued, distinguishing by product and service innovation, process innovation and business model innovation; ii) the internal and external sources of knowledge for AR/VR adoption; and iii) the organizational and technological factors in the uptake of AR/VR technologies (Barczak et al., 2007; Chandra and Kumar, 2018; Ramdani et al., 2021). Thirdly, we considered a business-to-business market and both manufacturing and service industries, while previous research has mainly focused on the consumers and service value perspective (Zarantonello and Schmitt, 2023).

From a managerial perspective, the results of this study provide critical inputs to innovation, product development and operations managers in factors and sources of innovation to be considered strategically when they plan to adopt AR and VR solutions. Specifically, collaborations with universities and research centers are more structured when innovation is more strategic (as for the business model or new product development). At the same time, partnerships with technology vendors are pivotal for service innovation, and process innovation driven by AR/VR mainly relies on internal "innovation champions" (Snihur & Wiklund, 2019). Drivers and organizational issues analyzed in the case studies contribute to the need for accelerated implementation of AR/VR in industry, with real-world applications in specific areas (Bottani and Vignali, 2019; Palmarini et al., 2018; Wang et al., 2013). In this sense, SMEs already adopting AR/VR tools limited to a certain company area could consider the patterns highlighted in Figure 2 to extend their application, aiming to unleash wider innovation outcomes, e.g. at the product, service or even business model level. The planning and management of the kinds of innovation sources to be involved, and both technological and organizational issues that could affect the innovation process is of critical importance, especially when the delivery of new offerings represent a driver of competitiveness for the SME's business, also considering that SMEs with high digital adoption levels benefit from

increased flexibility and adaptability to both endogenous and exogenous shocks (Skare et al., 2023). The results of the study can guide companies with limited resources for innovation to organize them properly into focused AR/VR-driven innovation patterns, to be aligned with the strategic and long-term investments.

From a societal perspective, the recognition of the value of innovation in companies as well as the adoption of digital technologies such as AR and VR can increase the value of companies products and services and stimulate the competitiveness of enterprises and even countries, enhancing living conditions (Si et al., 2023). A more productive private sector generates tax revenue that can be used for public investment in health, education, and other services. (Skare et al., 2023). Results of the study show that AR and VR represent disruptive technologies unleashing different innovation paths in SMEs, and thus causing a shift in the organization of business processes that – if properly exploited and routinized by company workers – can induce an increase in productivity (Feder, 2018), and even renew the productive capacity of an economy towards sustainable growth (Cirillo et al., 2023). Governments policies should be thus focused on encouraging investment and commitment to AR/VR-driven innovation paths enhancing competitiveness but also human well-being and prosperity towards the so-called Industry 5.0.

6.2 Limitations and future research

This study is part of European research investigating the level of adoption of AR/VR solutions in European SMEs and analyses a set of cases within the Italian context with a qualitative approach, which may result in possible limitations in terms of generalizability of findings. Further research should address a broader sample of companies from different countries and industry sectors, aiming to obtain greater robustness while also considering contextual variables that could affect the type of innovation pursued with AR/VR implementation. Innovation

sources and issues identified according to the different types of innovation could be also tested comparing the SMEs context with the large companies adoption paths. Moreover, even though the majority of interviewees were managers directly involved in the innovation process and deeply aware of the main issues and challenges encountered in the adoption of the new technologies, future studies could involve respondents with the same role to increase the comparability of findings according to product, service, process or business model innovation. In addition, performance indicators – especially in terms of enhanced competitiveness, but also employees' well-being – or even unintended outcomes of AR/VR adoption could be tested.

7. Acknowledgments

All authors declare that they have no conflicts of interest. This research has been partially funded with support from the European Commission. This publication reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein. [Project number: 612618-EPP-1-2019-1-DE-EPPKA2-KA].

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Table 1. Overview of the 6 case studies

Cases	Size	Industry	Technologies adopted	Type of innovation with AR/VR	Level of adoption and importance of AR/VR
Case A	48 employees	Manufacturing process equipment	AR	Service innovation	Long-term and strategic
Case B	21 employees	Software development	AR (VR only tested)	Product innovation	Specific product development projects
Case C	6 employees	Consultancy	VR	Business model innovation	Long-term and strategic
Case D	70 employees	Structural design services	AR and VR	Service innovation	Few projects
Case E	116 employees	Manufacturing metallic carpentry	VR	Process innovation	One project
Case F	73 employees	Manufacturing machinery	AR and VR	Business model innovation	Long-term and strategic

Table 2. Innovation sources, organizational and technological issues in SMEs' AR/VR adoption

Type of innovation (Cases)	**Innovation sources and involvement**	**Organizational and technological issues**
Product innovation (B)	▪ Top management: incentivize younger employees to make proposals for experimenting and testing new technologies ▪ Universities/Research centers: collaboration with the local university to develop prototypes ▪ Competitors: still not adopting these technologies	• Need to increase awareness on AR/VR devices for customers • Training: internal courses and test developments on AR/VR technologies • Organization of internal company contests for new ideas
Service innovation (A and D)	▪ Top management: support and promotion ▪ Internal Research Lab: promotion and testing of innovative solutions ▪ Technology vendor: win-win partnerships ▪ Universities/research centers: not known competencies or opportunities of collaboration ▪ Customers: innovative or low level of readiness	• Low or no resistance from employees • Internal Research Lab • Need to increase awareness on implications on AR/VR • Need for training according to the level of internal expertise in AR/VR • Need of support for software and AR/VR environment development • Shared events and training sessions with customers
Process innovation (E)	▪ Middle management: raise the need and scan the market for solutions ▪ Internal innovation "champions" testing, diffusing and then collecting feedbacks in the organization ▪ Competitors: not direct ones' adopting AR/VR ▪ Innovative (large) customers ▪ Innovation networks: participation	• Need of qualified operators to adopt AR/VR as a routine • Low need for training • Low barriers to technology integration thanks to standardizing models
Business model innovation (C and F)	▪ Top management: support and highly involved in the innovation process ▪ Universities/research centers: stable collaborations and open innovation projects ▪ Technology and service providers: collaboration according to the level of internal expertise in AR/VR ▪ Competitors: benefitted from VR application ▪ Customers: enhanced collaboration (e.g. virtual meetings) ▪ Innovation networks: participation	• High investment in innovation projects • No resistance from employees • No need for specific training for using VR/AR • Need for training for software and AR/VR environment development

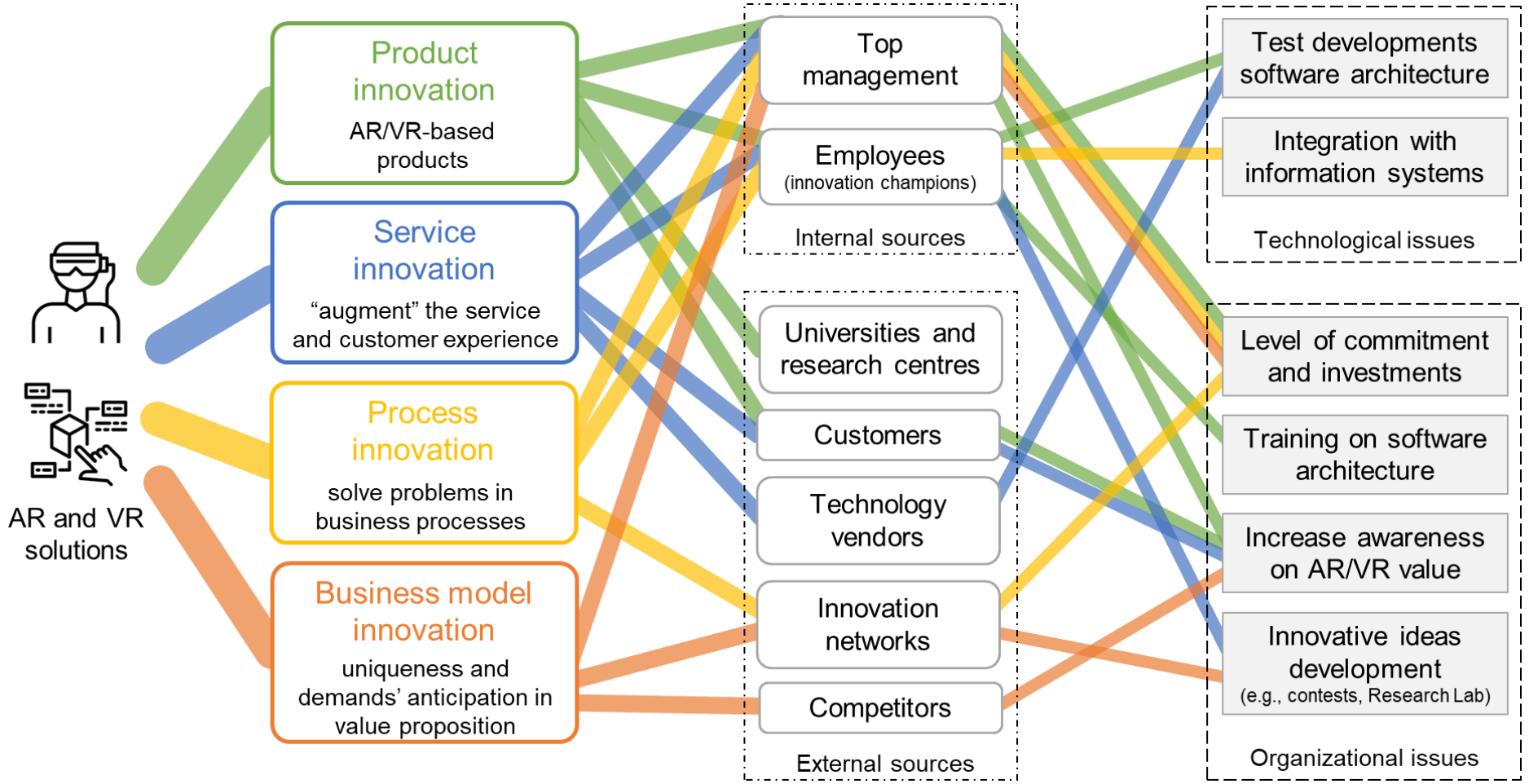

Figure 1. Patterns of innovation in SMEs as a result of AR/VR adoption