This paper was presented at The XXXIII ISPIM Innovation Conference "Innovating in a Digital World", held in Copenhagen, Denmark on 05 June to 08 June 2022.
Event Proceedings: LUT Scientific and Expertise Publications: ISBN 978-952-335-694-8
doi of this publication: 10.53170/HNU

Business usage of XR in Southern Germany

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Abstract: Digital transformation is increasingly reaching companies in our region. Countless products from the VR and AR sectors reached market maturity years ago. Since widespread use does not yet seem to have arrived at a majority of SMEs, we investigated how far the actual acceptance of XR has progressed. We present empirical data on XR adoption among SMUs in our region of interest. The study asserts that a significant number of firms have adopted XR, but also that 60% of surveyed SMEs have not yet applied these technologies. We assert that only a small number of companies show remarkably high levels of XR adoption. Given that XR applications are still not broadly applied, we suggest solutions for a stronger implementation of these technologies.

Keywords: XR; VR; AR; CAVE; SMEs; Surveys; Economic growth

1 Introduction

Since 2019, both Augmented (AR) and Mixed Reality (MR) have disappeared from Gartner's technology radar. This means that the "Plateau of Productivity" for the aforementioned technologies is likely to be reached soon (Gartner, 2019). Countless products from the areas of virtual- (VR) and augmented reality have already reached market maturity years ago. According to the German Media and Entertainment Outlook, the domestic VR sector will post €280 million in sales by 2023 (PwC, 2019).

VR/AR are suitable for occupational safety, in order to avoid dangerous situations through virtual simulation and to train specialist personnel as well and efficiently as possible. In this context, the Corona pandemic in particular has shown that the use of virtual means not only preserves the safety of employees, but also ensures and advances production and development. Especially AR, but also VR applications, are well suited for training measures on complicated machines in production or assembly.

Key VR and AR themes will increasingly extend from the computer and video games industry to live events and video entertainment in the coming years. The term "extended reality" (XR) encompasses the three technology forms VR, AR, and MR. As many tech

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related outlast forecast, production, retail and commerce will be increasingly penetrated by XR in the coming years. In this context, especially the commercialization of AR, both in terms of hardware and apps, is rapidly gaining momentum. XR technology is increasingly becoming a consumer good, escaping the realm of pure research. By around 2025, approx-imately 60 per cent of the global revenue generated will be in the consumer sector. The rest will be in B2B segments (Kind et al., 2019). The market segments of production and trade, including real estate as well as the education and military sectors, hold considerable growth potential for XR technologies.

From the point of view of the innovation drivers in our region, VR and AR applications will shape the way in which football matches or news are watched in the future, even in rural areas, and will guide the means by which medical treatment is carried out, how prod-ucts are presented and purchased, or how machines are built and maintained. It is safe to assume that XR will continue to drive the digitalization of everyday life in the future by massively promoting the integration of social interaction, media use, consumption and en-tertainment in the digital space. In this context, the main drivers for the use and further development of XR, both in terms of hardware and software, are particularly large compa-nies. Small and medium-sized enterprises (SMEs), on the other hand, have not yet ex-ploited their full potential in the use of new technologies. In view of the economic rele-vance of the subject area and the intense competition for technology and knowledge lead-ership, it is a not insignificant challenge for the German innovation system to actually tap the enormous potential of XR, despite its good positioning. For the future promotion of the technologies, it therefore makes sense to support interdisciplinary, application-related re-search in B2B areas in which the companies in the region Danube-Iller-Riss are tradition-ally strong. In recent years, the goal of a densely connected network of leading Universities in the region Danube-Iller-Riss has been to facilitate a sustainable exchange between sci-ence, business and society through innovative transfer formats. Within the framework of the Innovative University Initiative (Innovative Hochschule), the Universities of Biberach and Neu-Ulm, the Technical University Ulm and the University of Ulm, alongside the XR firm TriCAT, have joined forces. Together, they want to create a dynamic innovation sys-tem that will position the Danube-Iller-Riss region among the most competitive and inno-vative areas in Europe in the medium term (InnoSÜD, 2017).

Table 1 Advantages of XR use for SMEs

IMMERSION	AVAILABILITY	NETWORKING	VIRTUALITY	INTERACTIVITY
Digital content is better experienced via immersive 3D-visualization. Thus, an efficient transmission of information takes place that is superior to that of two-dimensional media.	Information and content can be accessed where it is needed at any time.	Large physical distances can be overcome This enables collaboration, knowledge and exchange, teaching or socialization from a distance. XR technologies can be connected to existing digital systems.	Virtual elements can be things that exist in real life, do not exist, do not yet exist or no longer exist. It is therefore possible to walk through a building before breaking ground, to learn how to operate a virtual machine, or to walk through and inspect the digital twin of a real plant. Virtual elements are created only once, after which they can be copied as often as desired. This also means cost efficiency.	Content can be designed interactively and non-linearly, thus promoting vibrant processes.

Source: Esegovic and Plechaty, 2021, p. 11.

The application of XR offers manifold opportunities and advantages for businesses (see Table 1). These include an efficient training of employees in real settings, e.g. machine plants, production halls, operating rooms or virtual buildings and terrains. XR offers a safe working environment, which helps to avoid dangerous situations through virtual simulation. Collaborative work environments can enable individuals to collaborate even over long distances. XR facilitates new services such as digital business models especially for education, art & culture (BVMW, 2021). XR allows remote maintenance with the aid of AR glasses by specialist personnel connected directly to the machine/product. In the realm of planning and design, VR environments enhance visualization in construction and architecture, urban planning or production. Immersive XR technologies can benefit the industry by providing unique costumer experiences, which has led to a revolution in the field of marketing (Rauschnabel et al., 2022). Customers can try out products virtually before buying them, merging the physical with the virtual world. Also, virtual showrooms can be used to present goods and services and virtual configurators can enable the personalization of products. Other areas of XR usage include coaching and training. Virtual training situations can

be created by using VR, AR or MR technology. In medicine, XR technologies offer versatile new possibilities in the therapy and treatment of patients, but also support medical professionals (Eckert et al., 2019).

> "Virtual Reality is computer-based and has better visualization effects for representing manufacturing systems than any other graphical user interface, and this helps users to collect information and decision needs quickly and correctly" (Erenay et al., 2002)

a b c

Figure 1 AR application using a tablet (a); a transportable CAVE system (MR) (b); a next generation VR headset (c); Sources: a: Forbes (2019); b: Barco (2022); c: HTC (2021)

CAVE

The CAVE (Cave Automatic Virtual Environment) is given special attention in this study due to its peculiar nature (see Figure 1b). Unlike other XR technology, the CAVE is a cyber-physical system: Cyber-physical systems are characterized by a linkage of real (physical) objects and processes with information-processing (virtual) objects and processes via open, partly global and at any time interconnected information networks. (VDI, 2013) As the originators of the CAVE put it, it is a "virtual reality interface". Its "abstract design", offers a "room whose walls, celling and floor surround a viewer with projected images. Its design overcomes many of the problems encountered by other virtual reality systems and can be constructed from currently available technology" (Cruz-Neira et al., 1992, p. 65). The advantages of the CAVE include the possibility to immerse into a virtual environment while at the same time having the possibility to sense and see the own body, conversing with other people inside the same cube (mixed reality). Its users are also less prone to cyber- or motion sickness, which can arise when physical, and visual motion signals give the user incompatible or conflicting data. Keeping few objects in a static position irrespective of the user's movement and maintaining high frame rates, which in the CAVE are usually much higher than in the case of VR headsets, can overcome this problem (Saghir, 2018).

Purpose

The Institute for Digital Transformation (IDT) accompanied the scientific supervision of this study at the Neu-Ulm School of Engineering and Technology. This paper's purpose is

to explore empirically small business usage of XR in a key region of Southern Germany. For far over a decade, enterprises in our region have in general been able to actively exploit XR technologies for their respective purposes. However, the actual grade of implementation of crucial technologies, such as XR, has not yet been explored.
We can summarize three broad research questions that have influenced our study:

1. To what extent have small enterprises in our region taken advantage of the XR promises?
2. What type of XR applications do Southern German small businesses exploit?
3. How can SMEs be assisted in implementing XR solutions?

In this article, we present the results of a study on small business XR development (Esegovic and Plechaty, 2021). First, we give a general theoretical framework for small business XR development in this research. Second, we go over the study's methodology. Lastly, before presenting the findings, we consider the broad implications and conclusions that can be drawn from our investigation.

Table 2 Sample distribution by company size and annual turnover (estimates) in the region Danube-Iller-Riss

	€0-1m	€1.1-2m	€2.1-3m	€3.1-5m	€5.1-10m	>10m€	*n*	%
1-9	13	30	9	1	2	0	55	46.6
10-49	2	20	13	6	1	0	42	35.6
50-199	1	2	3	4	3	1	14	11.9
200-499	0	0	0	1	1	2	4	3.4
>500	0	0	0	0	0	3	3	2.5
n	16	52	25	12	7	6	118	100
%	13.6	44	21.2	10.2	5.9	5.1	100	

Source: Esegovic and Plechaty (2021)

Value/originality

The OECD has presented statistics that have proved that North America and East Asian countries are in the lead regarding the build-up of a XR infrastructure (e.g. OECD, 2022). Germany's potential in XR has so far been confirmed by several analyses. Small firms are considered to be underperforming in terms of XR adoption due to a lack of resources and experience. This research investigates small company XR development in a significant European region and adds to a growing body of work aimed at benchmarking XR adoption.

Theoretical framework

SMEs are a vital growth engine in global trade and manufacturing, as well as the backbone of the EU economy. Small firms account for over 90 percent of all businesses in Europe and for approximately 85 percent of all new job openings between 2014 and 2019. The

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majority of these were five years old or younger businesses (AA, 2020). Given the promises that XR development holds for SMEs, and while some XR development literature has been written in recent years, much research remains to be done. In this section, we will review the existing literature on small business XR adoption to provide an overview of empirical studies that have been conducted in the field.

Much of the existing literature on the use of XR among SMEs is based on early and signif-icant studies on XR adoption in the field of immersive system management and application (e.g. Erenay et al., 2002; Macpherson et al., 2005). These studies do in fact provide a solid understanding of the complex and dynamic features of the research field known as small business XR adoption. This in fact, does provide a solid understanding of the complex and dynamic features of this field of study. An important subfield of research focuses on professional XR application in a specific country or region. Recent studies on XR adoption with a geographic focus, for example, include Finland (e.g. Jalo et al., 2020), Germany (e.g. Esegovic and Plechaty 2021; Wendt et al., 2022), China (e.g. Lyu, 2021), the United Kingdom (e.g. Abulrub et al., 2013; Davila Delgado et al., 2020), and, in a cross-national context, Cyprus and Finland (Kosmas et al., 2021). According to a study by IPlytics (2019), Germany leads the way in patenting XR technologies among European nations. Germany is frequently cited as a country with outstanding XR research and a public mindset that is very conducive to the introduction of new technology. Given this, it is surprising that the state of XR adoption among small businesses in Germany is a largely understudied phe-nomenon.

In addition to regional studies, there is research on the entrepreneurial and managerial foundations of XR implementation. Erenay et al. (2002) provide a structural approach that focuses on actual VR implementation in SMEs in general. Ghobakhloo and Ching (2019) employ a methodical approach that focuses on the integration of Information and Digital Technologies (IDT), which includes XR. They study IDT adoption and usage applying a Technology-Organization-Environment (TOE) framework. Certain sectors of the economy that use XR receive special attention. Davila Delgado et al. (2020) identified, categorized, and ranked the most relevant factors limiting and driving XR adoption in the construction industry; they provide an explanation of the main factors limiting and driving XR adoption, which could be used as the basis for developing mitigating actions. Colley et al. (2020) focus on service design, while Abulrub et al. (2013) investigate the adoption of XR for spatial design.

Abulrub et al. (2012), Ghobakhloo and Ching (2019), Tyagi and Vadrevu (2015), and Akpan et al. (2020) are examples of studies that investigate managerial challenges and critical success factors in XR adoption.

Almost all of the reviewed literature indicates a low level of XR adoption among SMEs in any scientific study (see Liagkou and Stylios 2019, p. 451). Following a review of the literature, there is little doubt that the field of research dealing with SME XR adoption is well established in the sense that significant effort has been invested in research into this phenomenon. A review of the topics covered in the field of small business XR adoption reveals significant differences in both methodological approach and conceptual frame-work. Eriksson et al. (2008) classified or structured the field based on the nature of infor-mation technology adoption by dividing the research into approaches based on variance theory or process theory. They argue that the general foci and general logic (diverging the field into variables or discrete outcomes), as well as the amount of time spent in the field, differ between these approaches (i.e. static or longitudinal). The authors rely on Markus

and Robey (1988) who pioneered this systematic approach. Table 3 is the result of a search through the Web of Science database and other sources for key publications over the past two decades. A general critical reflection on this elaboration reveals that process theory and case studies constitute a significant portion of existing studies.

Organizational readiness (e.g., managerial support), external pressure (e.g. demands from business partners), and perceived advantages (performance improvements, cost savings etc.) appear to be the most frequently used variables in driving XR technology adoption among small businesses. In an innovative study by Abulrub et al. (2012) on XR adoption, its acceptance and issues within the management of its implementation, the authors highlighted key issues. The study showed that XR adoption relies heavily on considerations on a strategic level that include Return on Investment (ROI), relative to the risks involved, cost, and HR concerns. When considering the SMEs, the cost of the XR system at hand may pose one of the greatest issues in implementation because of limited SMEs resources. Overall, the findings reveal that external pressure, particularly from business partners, is a major driver of small business XR adoption. We recommend the summary by Jalo et al. (2020) for an excellent examination of XR adoption barriers.

As previously stated, many individuals believe that SMEs are an important growth engine in the European economy. XR adoption has emerged as a strategic issue in small business development, attracting a steady stream of research, despite the fact that much work remains to be done. As shown in Table 3, there appears to be a tendency in the prevalent literature to focus on the pre-adoption phase of XR use, as well as the managerial challenges and critical success factors in XR adoption.

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Table 3 Key issues in research on small business XR adoption

Key issues in studies on SME XR adoption	Literature examples of SME XR adoption
Variance theory and factor studies	
Research analyzing the factors driving XR adoption	Erenay et al. (2002), Ghobakhloo and Ching (2019), Jalo et al. (2020), Davila Delgado et al. (2020)
Research analyzing barriers of XR adoption	Jalo et al. (2020) Wendt et al. (2022), Abulrub et al. (2013), Halonen and Iskanius (2009)
Research aiming to identify categories of XR adopters	Jalo et al. (2020)
Case studies and process theory	
Research investigating stage models of XR adoption	Jalo et al. (2020), Lyu (2021)
Descriptive or exploratory research on XR adoption	Jalo et al. (2020), Macpherson et al. (2005), Ghobakhloo and Ching (2019), Colley et al. (2020), Wendt et al. (2022), Liagkou (2019), Kosmas et al. (2021), Cranmer et al. (2021), Esegovic and Plechaty (2021)
Research focussing on development and support for XR capabilities	Bataw et al. (2014), Esegovic and Plechaty (2021), Büth et al. (2018), Lorenz et al. (2016), Halonen and Iskanius (2009), Jalo et al. (2020) Ullah (2018), Kosmas et al. (2021), Lyu (2021)
Research exploring critical success factors and managerial challenges to XR adoption	Ghobakhloo and Ching (2019), Tyagi and Vadrevu (2015), Akpan et al. (2020), Jalo et al. (2020), Macpherson et al. (2005), Sepasgozar et al. (2021), Liagkou (2019), Abulrub et al. (2013), Lorenz et al. (2016), Ricci et al. (2021), Abulrub et al. (2012), Kosmas et al. (2021), Davila Delgado et al. (2020), Bataw et al. (2014)

Approach/methodology/design

For this research project, we have used a survey approach. In order to investigate the actual use of XR technology among domestic small sized firms, we relied on online engagement with SMEs. Given the fussiness and scientific triteness of phone polls, we decided for an online-based survey. Surveys are one of the most efficient ways to generate data from large numbers of people or enterprises. For the purpose of evaluating the actual use of certain technologies, polling suggests to be the most effective method, given the lack of a large scale spy network at our disposal (See Connelly, 2011).

Target group

The literature differentiates between large, small, and micro businesses (e.g. OECD, 2022). SMEs can be defined in a variety of ways. We used the widely accepted EU Commission definition of SMEs for this study. As a result, SMEs are firms that meet the following criteria:

1. They have less than 50 employees, or
2. they have a maximum annual turnover of €10 million, and
3. they are an independent firm (not a subsidiary) (European Commission, 2020)

This paper illustrates the results from an online survey on South German small businesses. The 273 firms surveyed in this study were mainly independent manufacturers and retailers in the region Danube-Iller-Riss with employees ranging from 2 to 2500 and a yearly turnover not surpassing €300 million. The study began with an online survey, in which participants were asked to respond to a structured set of multiple choice and open questions aimed at determining how small businesses access and use XR. Between December 2020 and August 2021 data was collected using an automated online tool that followed a strict survey protocol to avoid researcher bias. In total, 273 out of the 3232 businesses in our sample agreed to participate in the study, leading to a response rate of 8.45 percent. Conducting the survey, a questionnaire consisting of 21 items was used. The set of questions was successfully pretested in order to avoid any response bias. The participants' response options were organized using five-item Likert scales for questions regarding attitude, including interval or nominal scales for classification questions. The majority of the respondents were CEOs, team leads or general managers (Figure 2). "Others" included project coordinators, COOs, supply chain analysts, strategic production managers etc. If the firm's CEO or owner was unable to participate, as was the case for 63 per cent, another individual in a management (e.g. IT- or marketing manager) or someone in an ownership position (e.g. partner) was able to do so. Any survey participant who was not in a management position of their respective firm, at least highlighted their special role in implementing XR- or related technologies in their respective company. It is worth noting that the framework of this study was originally crafted before the outbreak of the 2020 Corona pandemic. As a result, it is safe to presume that the survey's failure rate regarding turnout correlates with a drop in overall survey participation following the Corona crisis, rather than being caused by the nature of the poll itself. The survey was evaluated at the Institute for Digital Transformation at Neu-Ulm University of Applied Sciences. For purposes of data analysis we used SPSS (Brijesh, 2020).

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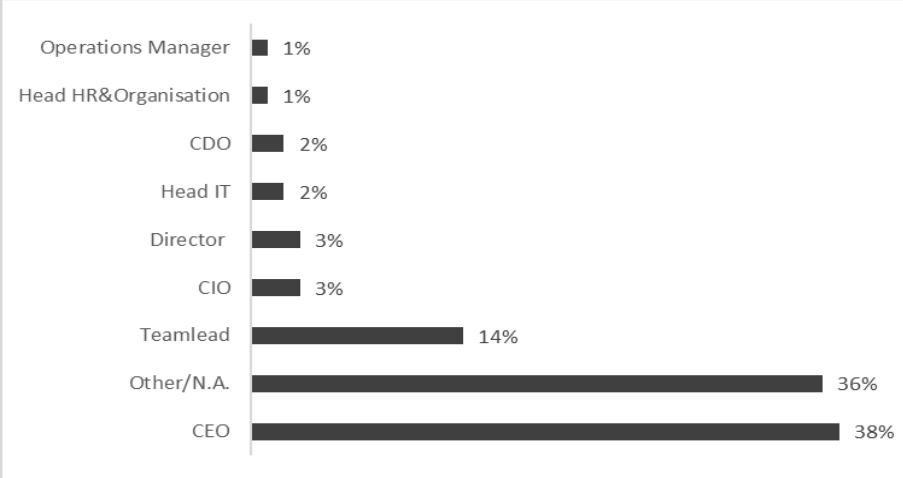

Figure 2 Role of survey participants in their respective company (n = 96).

The interviewees were specialists and managers. For the most part, they helt functions at the (higher) management level. The proportion of business managers / CEOs is proportionally the largest (38 per cent), followed by team leaders (14 per cent). “Others” included shareholders, project managers, and innovation managers (31 per cent).

As outlined in Figure 3, companies are heterogeneous in terms of sectors due to the focus on the Danube-Iller-Riss region. The manufacturing industry predominates with 17 per cent, followed by economic services (13 per cent). The construction industry is represented with 11 per cent. The group of others (30 per cent) includes media design, research, pharmaceuticals, trade, retail, timber trade, and logistics.

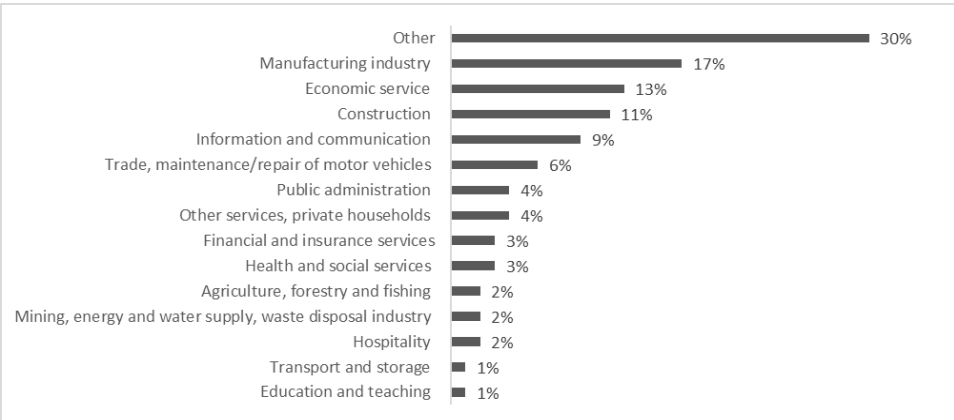

Figure 3 Type of company (n = 105)

Findings

The study presents empirical data on the growth of XR among small enterprises in the Danube-Iller-Riss region. According to our research, a large number of the firms surveyed

had used XR technology, although slightly above half of the investigated SMEs had been using it for five years or more.

> "From previous research in which a distinction has been made between adoption and use, we know that having a technology is not equivalent to actually using it" (Eriksson, 2008, p. 561).

First, we explore the knowledge of survey participants regarding XR technologies. As Figure 4 shows, the level of knowledge in the area of AR is higher than for VR. Only 3 per cent have expert knowledge. Overall, 51 per cent of the survey participants stated that they have good to very good AR knowledge. 17 per cent have no knowledge. In the area of MR, both expertise and lack of knowledge about it are proportionately more prevalent than in the other technologies. 27 per cent say they have no knowledge, with 4 per cent considering themselves MR experts. Overall, ignorance about this technology predominates, which is why over 60per cent have insufficient to no knowledge.

Since the CAVE is considered a typical MR technology, knowledge about it is also weak. Only 2 per cent of the respondents would consider themselves CAVE experts. Nevertheless, over a quarter of the survey participants have moderate to excellent knowledge about this technology (Σ = 24 per cent). However, 42 per cent of the respondents claim to have no knowledge.

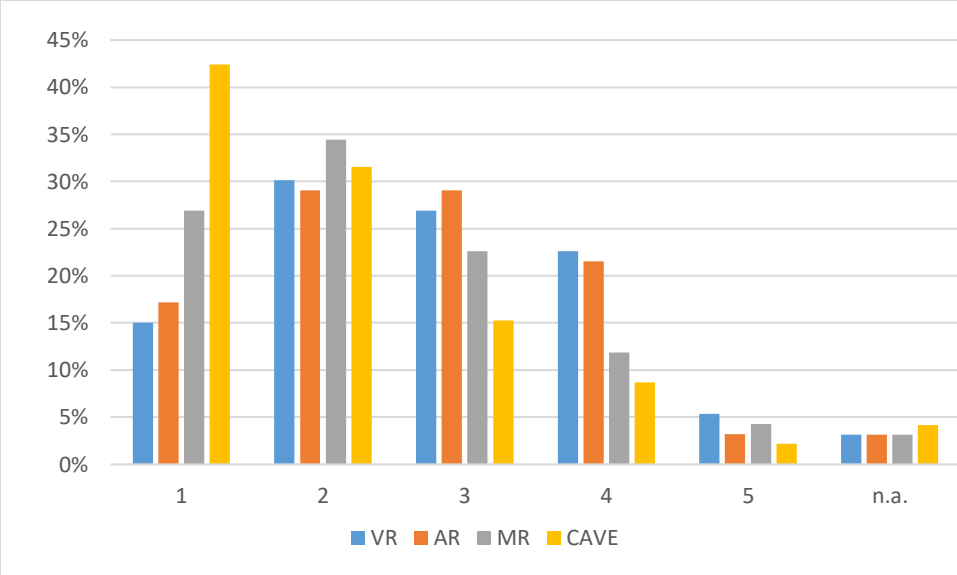

Figure 4 Knowledge of XR-technologies among companies; Ascending scale from 1 to 5 (1 = no knowledge, 5 = expert knowledge); (*n* = 96)

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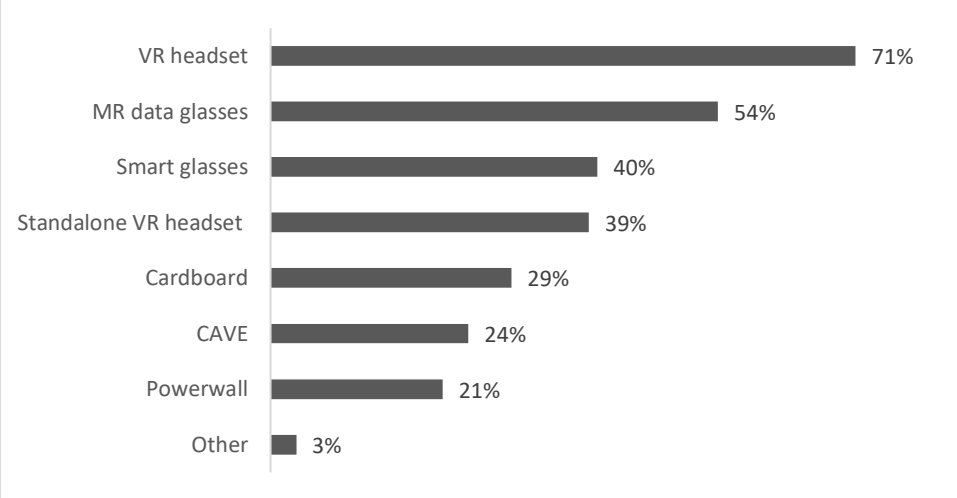

Figure 5 Percentage of known XR devices among companies (*n* = 96)

The most familiar VR/AR application among the survey participants is the classic VR headset. Probably due to the sharp drop in prices and the age of the technology, the VR headset is known to 71 per cent of the company representatives. MR data glasses, on the other hand, are known to far more than half of the respondents (54 per cent). Smart glasses and standalone VR headsets are familiar to 40 per cent and 39 per cent of respondents, respectively. As many as 29 per cent are familiar with the low-cost cardboard system, which is powered by a cell phone. Less familiar are the CAVE (24 per cent) and the related powerwall (21 per cent). 3 per cent said they were familiar with devices other than those mentioned (Other).

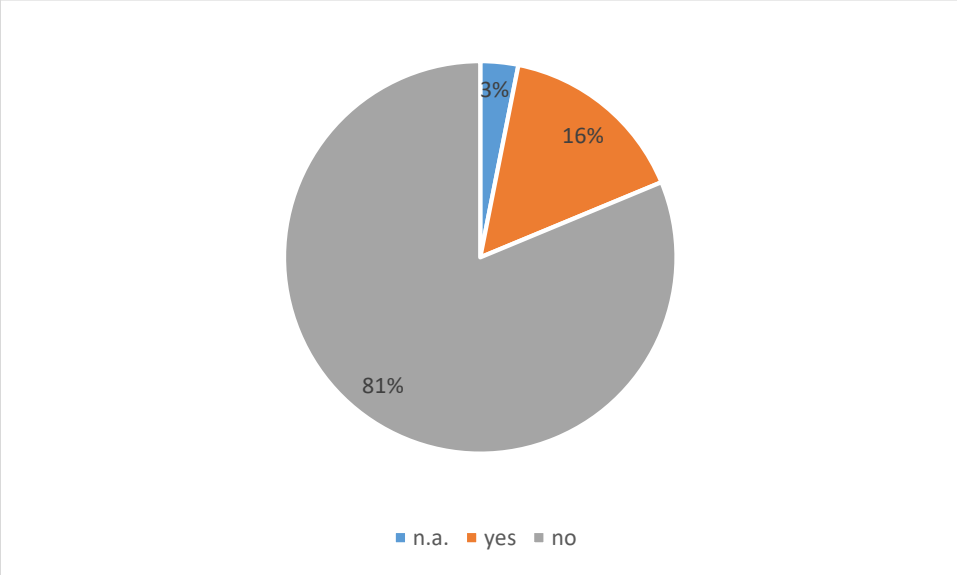

Figure 6 Private use of XR devices among survey participants (*n* = 96)

Over 80 per cent of the company representatives surveyed stated that they did not use an XR device privately. Only 16 per cent professed private XR use (Figure 6). The operational use of XR, on the other hand, shows a different picture. Figure 7 shows that more than 40 per cent of the companies stated that they already use VR technology or will at least do so in the future. 20 per cent of the companies state low use, 8 per cent medium use and 6 per cent account to extensive use. Just as many plan to make greater use of VR in the future. In terms of share, the group of non-users is the most strongly represented with 54 per cent.

The survey confirms the long-held belief that private use of XR technologies and applications matters for business XR adoption by cross-tabulating business- and private use of XR technologies and applications. Furneaux and Rieser (2022), for example, discovered that personal use of technology is linked to individual motivation to acquire status and experience in a study on user motivation in application abandonment. It is also connected to the search for a bond with others, comprehend and grow, which has significant implications for the likelihood of application abandonment or, as we conclude, the potential to stimulate business application. A quite recent example of this is the blockchain technology which has gained considerable business application and interest, although it started off as a personal enterprise (See Nakamoto, 2008).

We find a statistical link between the private use of XR and business use (Pearson χ-squared test = 13.94, $p = 0.003$). Furthermore, the use of XR increases with firm size (linear-by-linear association test = 12.28, $p < 0.001$). We also cross-tabulated industry group and frequency of use of XR technologies and applications when interpreting the survey results. With the exception of a significant pattern indicating a lag in development among firms in agriculture, financial services and other less represented business fields, the cross-tabulation of industries revealed similar levels of adoption across groups.

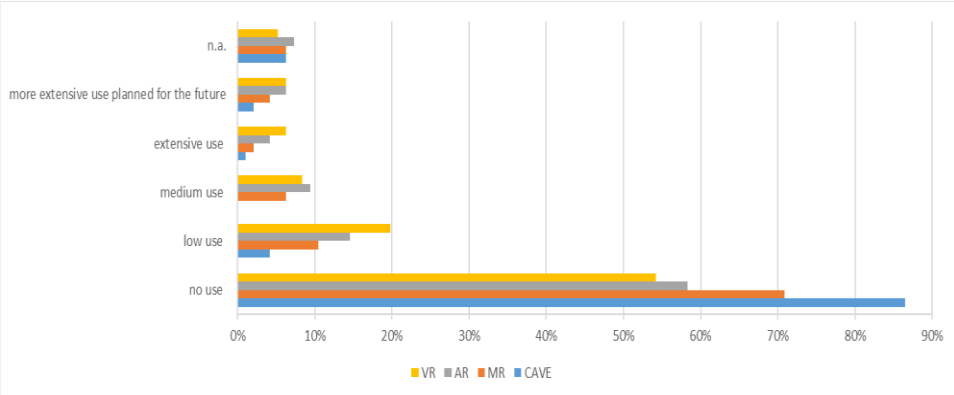

Figure 7 Actual use of XR technologies among businesses (n = 96)

Small businesses in the region, according to our data, have a low level of XR adoption. The survey found that while AR and VR are commonly employed in small businesses, advanced applications are largely underutilized. AR technologies are not used extensively either. MR technologies are used more extensively by 4 per cent of the companies investigated. 71 per cent state they do not use MR at all. VR currently has the largest share. Especially the private use of XR lags behind the commercial one. Only about 16 per cent use an XR device at home. The private use probably has positive effects on the implementation of the technologies in the company. Almost half of the enterprises already use XR, but only

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6 per cent of them use it extensively. Knowledge of XR technologies is highest in the area of VR. However, not much more than 5 per cent of companies trust themselves with expert knowledge in the VR sector. For AR and MR, the figure is even lower. The VR headset has created the highest level of awareness among XR hardware. Niche technologies such as the CAVE or powerwall are so far only familiar to experts. Cross-tabulating the firm size and the frequency of use of XR related technologies, such as VR headsets and AR applications, our survey validates the assumption that private use stimulates business-re-lated XR adoption.

As another key finding, we report considerable interest in a CAVE in the region (Figure 9). Almost ¾ of the respondents show hesitant to strong interest in the active use of this technology. Out of 46 per cent of respondents who claim a vague support for the CAVE, over 95 per cent condition their potential use as follows: 50 per cent of respondents wish more information on the matter, while 64 per cent would like to gain experience with the technology first (n = 52).

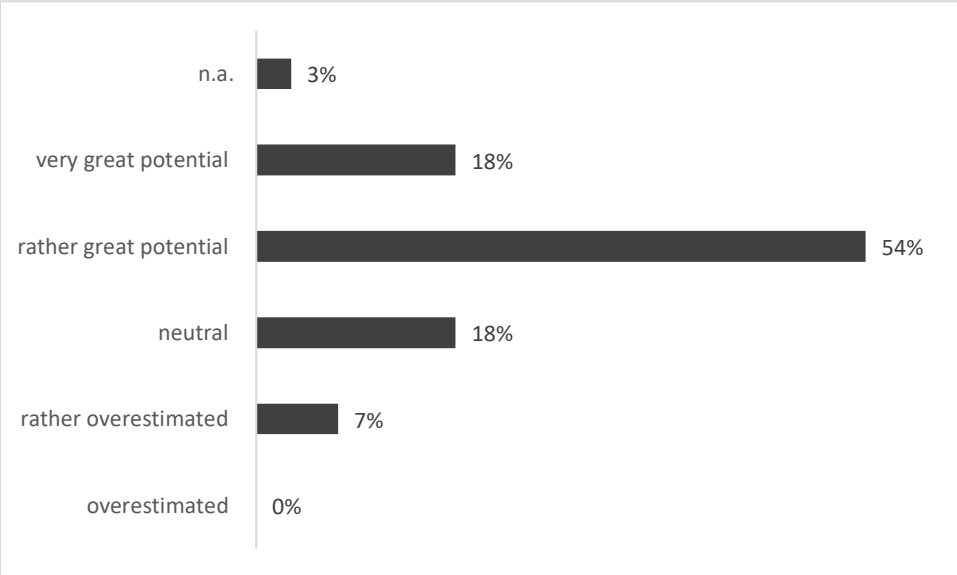

Figure 8 Estimated potential of XR technologies (n = 96)

Smaller businesses are less likely to use XR technologies. Size appears to be an important factor in determining adoption levels. Although the levels of XR adoption are generally low across all groups, and the differences between firms in terms of XR usage are relatively small, firms with less than 25 employees show levels of XR adoption that are below average. We used χ-squared tests to evaluate whether the differences were statistically significant or not. Furthermore, because size class can be thought of as an ordinal variable, we used the linear trend test to see if use of each basic technology changes gradually with increasing size. In terms of VR use, the χ-square test is not significant (Pearson χ-square = 3.76, $p < 0.278$), indicating that there is no conclusive evidence of a link between VR use and size class. AR use, on the other hand, appears to increase with firm size (linear-by-linear association test = 3.01, $p < 0.048$).

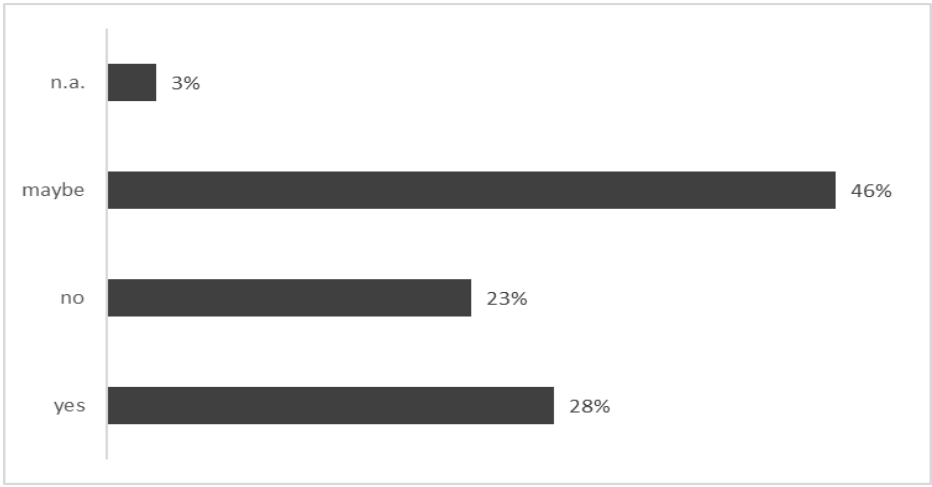

Figure 9 Desire for a CAVE (*n* = 96)

In conclusion, our research shows that SMEs in the Danube-Iller-Riss region have low levels of XR adoption. The study does reveal that a sizable proportion of the firms investigated have not yet adopted XR technologies in their entirety. VR and AR are ranking similar in use, while 54 and 58 per cent of businesses respectively, claim no use of these technologies at all. The numbers for MR are even scantier. 71 per cent do not use MR at all, while merely 2 per cent claim extensive use of such technologies. The CAVE is being used only by 1 per cent use extensively. The CAVE has the lowest share in all categories (low use to more extensive use planned), while the technology leads the category of no use (86 per cent). Our research also appears to support previous studies suggesting that business size is a crucial factor for which small firms lag behind large ones in their intent and decision to adopt XR (e.g. Berman and Pollack, 2020). Nevertheless, there still is evidence to the contrary that smaller businesses do have a competitive advantage implementing XR technologies into their systems (Jalo et al., 2020, p. 28).

The majority of firms see considerable potential in XR (Figure 8). While 54 per cent of enterprises believe in a rather great potential, only 18 per cent report a very great potential in XR use. The fact that 0 per cent of respondents see an overestimation in these technologies highlights the general confidence in XR. The virtual absence of general XR use drives the desire of firms for direction (Figure 10). 50 per cent of respondents report the need for provision of expertise when it comes to this topic. The development of new application areas and the provision of hardware and software is also of great importance to the surveyed businesses (36 and 33 per cent).

This paper was presented at The XXXIII ISPIM Innovation Conference "Innovating in a Digital World", held in Copenhagen, Denmark on 05 June to 08 June 2022.
Event Proceedings: LUT Scientific and Expertise Publications: ISBN 978-952-335-694-8/doi: 10.53170/HNU

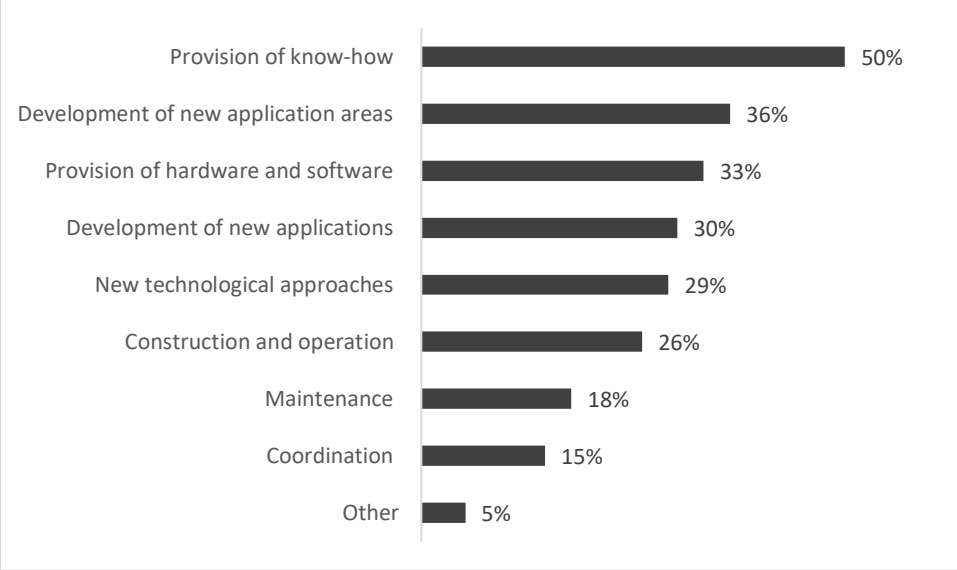

Figure 10 Desired assistance in regard to XR application (*n* = 233)

Conclusion and suggestions for further research

SMEs play an important role in the global economy's growth. Small businesses employ the majority of people in most European countries, and 90 per cent of businesses in Europe are classified as small (European Commission, 2020). Extensive exploitation of XR must evolve within this category of firms in order to achieve broad global diffusion. Only then will XR development begin to have a significant economic impact. As a result, the use of these technologies in small businesses has piqued the interest of academics and practitioners alike. Given the promise that XR development holds for small business managers, and despite the fact that much has been written on the subject in recent years, there is still much work to be done (Abulrub et al., 2012). The goal of this research project was to describe the general state of small business XR development in the Danube-Iller-Riss region. We outlined three research questions:

1. To what extent have small enterprises in our region taken advantage of XR?
2. What type of XR applications do Southern German small businesses exploit?
3. How can SMEs be assisted in implementing XR solutions?

According to the results of our survey, SMEs are exhibiting a trend of low penetration of XR use. Although there are exceptions, more advanced applications are still not widely used. In total over 40 per cent of companies investitagted use XR technologies either on a low, medium or extensive level (with VR ranking highest, $\sum$ = 40.62 per cent). The use of the CAVE, usually constructed as a high-tech virtual environment, is left to merely 7 per cent. These numbers highlight the need for active assistance of SMEs, especially the one

with a small number of employees, when it comes to implementing, maintaining and training in these technologies. Our study revealed that the VR headset has created the highest level of awareness among XR hardware.

Given the obvious need for a CAVE in the region, especially for the cooperation of science and business, the IDT, the HNU, alongside their partners from academia and business, play a key role in the joint creation of places of development, presentation and exchange which need to become accessible to the SMEs in the region. XR will evolve massively in the coming years. Not only will the technology break new, previously unknown ground, but its use will also adapt to the novel needs of market participants. The fact that the individual technologies go hand in hand in the expansion of their use is of particular benefit to XR. For example, the outlook for the expansion of the 5G network and the future assurance of stable and comprehensive network coverage allows for unimagined opportunities. Thus, previously untapped potentials of the technologies described here will be made available to an even wider audience. The communication of user-friendly use cases and guidance for getting started with relevant hardware and software solutions will continue to spur exchange between science and industry in the future (Figure 11).

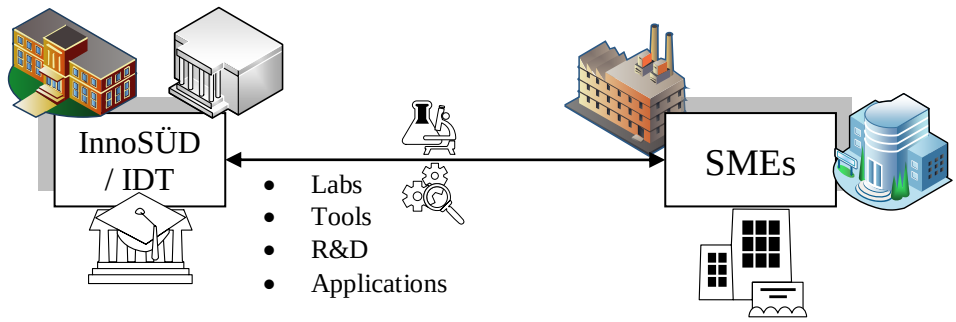

Figure 11 Mutual assistance & interaction between key stakeholders in the region Danube-Iller-Riss

This research study looked into the strategic and user acceptance of innovation, namely XR technology, as well as the difficulties surrounding implementation management. ROI, cost, risk, and HR concerns are all important factors to be addressed on a strategic level. Because of the limited resources available to SMEs, the cost of the system may pose one of the most significant implementation challenges. Large investments in innovation and technology are not considered cost-effective unless they are accompanied by a clear grasp of their worth as evidenced by previous success. Competitive advantage and increasing profit margins may be overlooked if a low-risk strategy of trying a proven recipe is used. As a result, external help might be critical in driving XR adoption among SMEs. A strategic relationship between research institutes and local businesses might help pool the resources needed to better understand the process of innovation and technology integration (Figure 12). Furthermore, the findings revealed the impact of experience and knowledge on factors related to acceptance on an individual level, implying that initial trainings and demonstrations to increase exposure to potential users could help gain greater acceptance (Abulrub et al., 2012). A similar approach could also be used by senior management to gain support at various levels in the organization.

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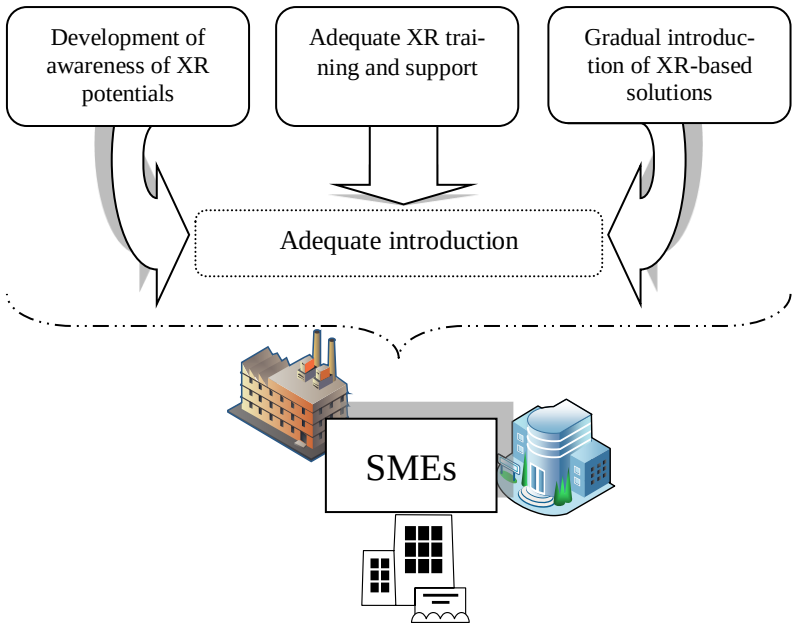

Figure 12 Key elements that can foster an adequate introduction of XR in SMEs**;** Source: Barba-Sánchez et al. (2007), p. 107, adapted by the authors.

This study has helped to develop our understanding of the actual application of XR technologies among South German SMUs for commercial purposes. This area of research has revealed the lack of academic studies on the matter. Although the findings rest upon a rather extensive empirical investigation, a number of obvious shortcomings related to the chosen research approach must be acknowledged: A limitation inherent in the use of self-administered questionnaires in this survey is that it necessitates a line of questions rather straightforward and general in nature. The decision-making process often involves, however, many contextual factors that cannot be expressed in short, written questions. Also "social desirability"-effects occur when respondents are unwilling to admit some of their attitudes or behaviors to an interviewer – be it a person or a machine (Weisberg, 2018).

The threat to predictive validity posed by a possible discrepancy between intention and behavior as a result of a simplified contextual perspective appears especially disruptive in issues relating to technology adoption, where many external factors may influence the final decision, particularly as practitioners learn more about the true benefits, limitations, and costs involved. (Anckar and D'Incau, 2002, p. 59-60)

The findings of this study would encourage large scale future investigations which might yield validated outcomes. Another major limitation of this study was the sample size of businesses. The respondents who were highly apprehensive about XR adoption were less willing to participate in this study. Another limitation of our study is the lack of resources to cover up more firms in our region. The sampling technique used can also be a limitation as convenience sampling can at times lead to sampling bias (Thomas, 2021).

A final, yet important point to be made is that the results of the study are valid only for the region Danube-Iller-Riss, which is characterized by a small, yet for European standards relatively high penetration rate of XR use. More empirical studies should be carried out in

different European and other areas of the globe in order to widen our knowledge of the near future business potential of XR. We would like to conclude this study by suggesting additional research on the basis of our findings.

Notes

1. Using a normal approximation, the *p*-value for the χ-square test for independence between two category variables was calculated. The approximation was considered appropriate when the predicted value under independence was large enough in each cell. In our investigation, there were a few cells with fewer than five instances. As a result, we used the Monte Carlo method for permutation testing (Brijesh, 2020).
2. For these analyses, the Monte Carlo option was used for the permutation tests.

Acknowledgements

The authors wish to thank Professors Dr. D. Schallmo and Dr. K. Lang, as well as Ms. A.-K. Waibel for relevant contributions to this research. We express our gratitude to two anonymous reviewers for their constructive comments on an earlier version of this paper. The project on which this publication is based was funded by the German Federal Ministry of Education and Research and the Federal States as part of the program "Innovative Hochschule" (IHS) under the grant no. 03IHS024C. The responsibility for the content of this publication lies with the authors.

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