A User Evaluation Study of Augmented and Virtual Reality Tools for Training and Knowledge Transfer

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Abstract. Modern augmented and virtual reality (AR/VR) technology open multiple new capabilities in the way people interact, collaborate and deliver or receive information via digital interfaces. Industry workers and operators may especially benefit from such solutions that allow them to get trained, onsite or remotely, using digital copies of the workplace environment. This paper presents the development of AR/VR-based collaborative and telepresence tools, along with a web-based platform for knowledge exchange and interaction, as part of the Ageing@Work project, that enable easy transfer of know-how from experienced (possibly older) to novice workers. The remote collaboration tools facilitate variability in location and working hours, and thus promote age-neutralizing means of participation and cooperation, whereas the knowledge transfer tools support the ageing worker's leadership characteristics within the workplace community, allowing the company or work site to capitalize on her/his experience and expertise gained through the years. The tools were developed in accordance to a user-centred design process and were evaluated by 126 participants in total through online surveys in two pilot sites with regard to core Industry 4.0 processes of mining and machines production, as well as through off-pilot studies. This paper presents analytic outcomes of the assessment of knowledge transfer tools illustrating very positive results on the level of technology acceptance, and the overall potential of the developed solutions to support healthy and productive ageing of workers with enhanced workability.

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1 Introduction

Industry appears increasingly dependent on the knowledge, skills and experience of their older workers [1]. This pushes companies to explore ways to keep older workers employed for a longer period of time and also to support them to maintain their work ability and increase their employability. There is systematic evidence that sustainable job longevity can be associated with positive health outcomes. Work can have a positive effect on physical and mental health and well-being for all workers if working conditions are appropriate [2,3]. For example, keeping an employee integrated in a social environment such as work, can provide health benefits [4], as social interaction helps preventing the loss of cognitive functions [5].

Responding to this need for sustainable job longevity of ageing adult populations, however, is faced with both challenges and opportunities, some of which arise from the changing workplace conditions. Both the shrinkage and ageing of the workforce come at a time where Industry 4.0 is booming, resulting to an ever-increasing impact on the way that contemporary industries, factories as well as office workplaces, operate based on continuous advances in the fields of artificial intelligence, service and collaborative workspaces, etc. Notably, the tasks of future companies operating in this context are anticipated to have an increasing degree of freedom and less structure than before, with the workforce experiencing a change of role. More typical tasks are expected to fall within supervision of the production line and solving of unexpected problems. Clearly, such positions where the employee acts as a problem solver can find major benefits from the experience and skills of older workers. Novel work paradigms, such as those introduced by the gig economy have shown that, once the working arrangements and conditions are flexible enough and controlled by the worker, the worker may prefer to remain at work for longer, even if it is sometimes required to learn how to use a new technology. A core challenge nowadays concerns how this tendency of older workers to remain active at jobs of the gig economy, can as well be migrated to further workplaces, such as industrial ones, allowing workers to indulge similar benefits, while at the same time their skills and experience accumulated over time remain valuable assets to the growth of diverse productive sectors.

Companies have been trying to meet the challenges posed by an ageing workforce by adopting established occupational safety and health practices that promote sustainable working lives. Such practices include life-course approaches to workplace health, workplace health promotion, introducing return-to-work measures, adapting work to the individual, and providing structures for lifelong learning. There are many successful cases that involve at least to a certain extent the use of digital technologies (e.g. GPS-based personal emergency response systems, basic information technology systems); many of these practices, however, although efficient, remain predominantly manual/offline.

In this paper we present and evaluate a series of highly adaptive ICT (Information and Communications Technology) tools, including augmented and virtual reality (AR/VR), developed as part of the Ageing@Work project, that envisions to counteract for crucial issues hindering the ageing workers' workability and well-being by facilitating them to remain active and productive for longer [6–8]. Specifically, we address the problem of lifelong learning and knowledge sharing between older and younger workers, as well as remote collaboration. Results and benefits of such solutions are numerous. More efficient and flexible transfer of knowledge by older experienced workers to younger workers allows to boost inter-generational communication and this gathered knowledge remains in the company's knowledge base, while also a worker's network can be created and maintained. In-time solution of problems is facilitated through real-time guidance and with lower risk, while also decreasing the occurrences of machinery downtime due to absence of guidance and mentoring. Surveillance worker duties enhancement increases the personal perceived security, reduces stress and accidents, and supports the decrease of memory of the ageing workforce. All these benefits may lead to increased workability and productivity.

2 Methodology

The Ageing@Work system provides advanced interfaces, in order to support workers' remote collaboration through telepresence, while workability enhancement is further empowered by advanced VR and AR-based lifelong learning tools. The virtual reality tools provide the necessary framework for more experienced workers to create a VR tutorial and load it into the application. On the other hand, less experienced workers can download a tutorial and get trained at home with a VR headset or at the workplace with an AR headset. In addition, the learning tools can provide training sessions for more experienced workers on new machines that they may need to learn to use. The AR platform aims to help workers in distance training, as well as into remote collaboration. The platform consists of two communication applications intended to be used by a remote supervisor (located, for example, at home) and a worker in the workplace, and uses intuitive digital instructions that enrich the physical environment of the workplace, thus facilitating the execution of tasks. Finally, the knowledge exchange platform is a web interface that provides two-way access to the knowledgebase and supports workers in the manufacturing process, allowing them to interact, collect and share relevant knowledge, ideas, and good practice.

2.1 Remote Collaboration Tools

This tool enables ageing workers to collaborate efficiently in a remote setup, to support functionalities like teleconferencing, to receive and offer realistic descriptions of industrial processes [8]. Moreover, the AR tools could also support lifelong learning by providing captured (recorded) sessions of telepresence meetings during unforeseen issues, complex machine maintenance, and support. These materials can be loaded into the Knowledgebase component and used by workers who are willing to learn new tasks and how to operate/service machines.

A basic set of background services is implemented to allow the AR view to work properly, and those include the sensing of the user's location and orientation, the object (machinery) detection in order to let the system know which machines are involved in the scene, and the image segmentation component which allows the 3D virtual object to be rendered in the correct position in relation to the world 3D coordinates (shopfloor coordinates). The AR view is responsible for synthesizing the view of the user through the AR glasses and includes the graphical user interface, the pushed (by the system) notifications, the projection of the element that the distant user may be pointing at, and finally the sound processing (alarms and the speech synchronization between the distant collaborators). To serve the need of educational content provision, the AR component may also offer the possibility to capture telepresence sessions in 2D videos and to upload those materials to the knowledgebase. This functionality is performed by a lightweight session management subcomponent. This architectural element is also responsible for initialing the telepresence session and for annotating the output 2D video recordings (with metadata like machine ids involved in the study, problems solved, timestamps, worker skills, a description of the physical context, etc.).

The physical view of the AR telepresence infrastructure is presented in Fig. 1. The on-site user (young worker) may raise an issue using the AR telepresence tool and podcast the image (through the camera of a head mounted display or an ordinary smartphone camera) to an experienced user (older worker) asking for advice and support. On the other end, the experienced user can interact through the tablet. The Ageing@Work system operates in the meantime to optimize the outcome of the telepresence tool. Specifically, it retrieves the worker having the appropriate experience and skills to support the raised issue and initiates the telepresence meeting, by loading the 3D models and the scenario to run. Figure 2 shows an application example of the AR tool and how it is used for remote worker collaboration.

2.2 VR and AR Based Lifelong Learning Tools

Lifelong learning tools can help the worker adapt to changes in the working environment through corresponding ICT-empowered training processes. These tools consist of components that support the creation and execution of a tutorial process in virtual environments [7,9]. The software implementation was performed in the Unity3D real time development platform, so the tutorial environment can be encoded in Unity Asset Bundles which are archive files that contain platform-specific assets (such as models, textures, audio clips) that can be loaded by Unity at run time. More precisely, the ageing worker can record the steps required to complete one or more tasks and create a tutorial. The tutorial can then be encoded to JSON format as a list of tutorial step objects, containing necessary data (such as the object unique ID, the type of interaction and human readable content), and shared using the knowledgebase API (application programming

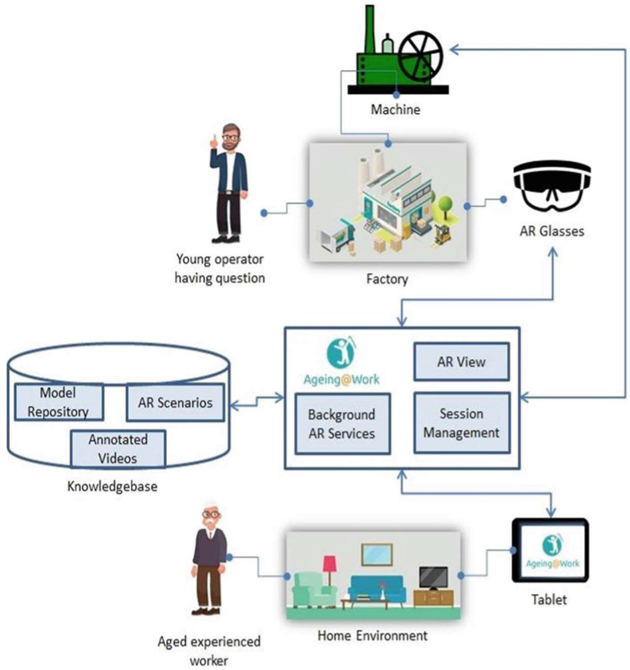

Fig. 1. The physical view of the AR telepresence tool.

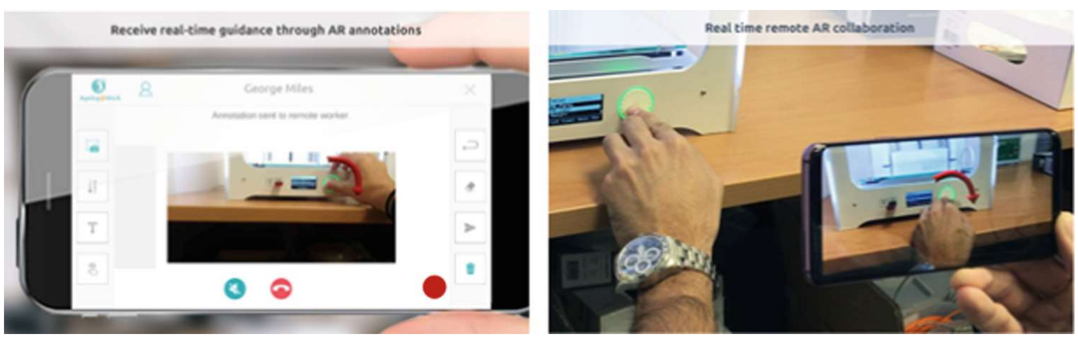

Fig. 2. Application example of AR tool (left) and remote worker collaboration tool (right).

interface). The less experienced worker can connect to the knowledgebase and choose the desired tutorial in order to get trained by following the tutorial steps and the indications recorded by the expert. The system loads from the Asset Bundles files of the 3D environment and sets up the scene in VR (or AR). The tutorial JSON description is decoded and an ordered list of the tutorial steps with the associated voice recordings are created. The user is guided in the training process in the VR environment through indications on the static objects (e.g. buttons) visualized by changing their material properties, or on the dynamic objects (e.g. levers, knobs) by animating ghost objects. A 2D visualization panel is projected in the users' front view in order to guide the trainee through the training process by illustrating the sequence of completed and upcoming steps, along with the performance after each executed task. An example of a user being trained in VR of how to operate a drilling machine is shown in Fig. 3.

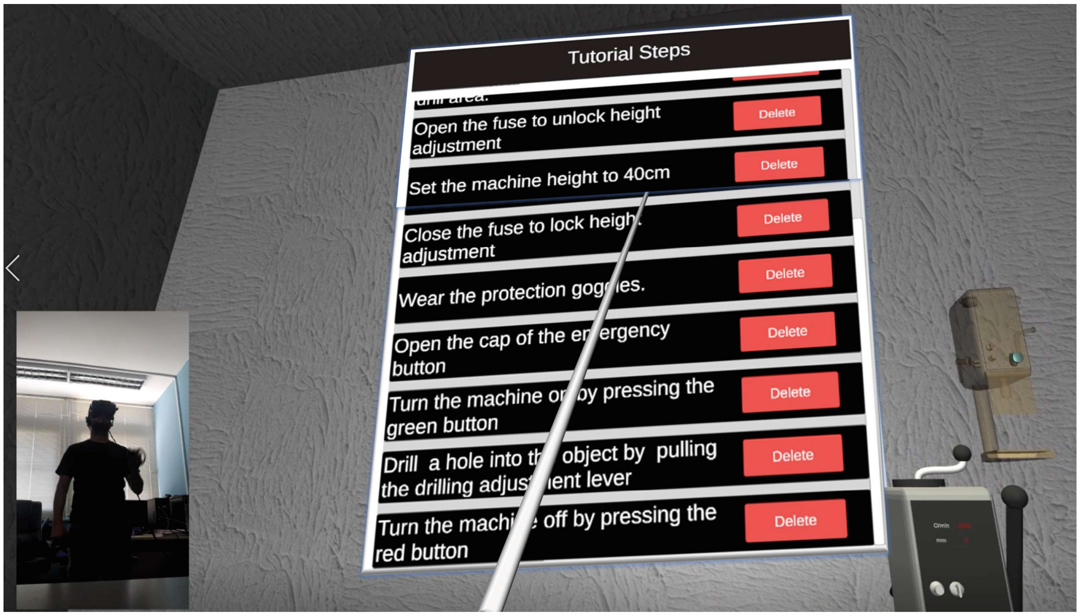

Fig. 3. Illustration of the 2D visualization panel of the VR tutorial creation module.

For the AR version of this tool, the tutorial process can be segmented into discrete steps, automatically or user controlled. Automatic steps' segmentation can be performed by utilizing the background AR services of the AR telepresence tool, such as object detection, location sensing, image segmentation and 3D visual object rendering. At the user-controlled scenario, the tutorials provide visual information to the user about the next steps, but no automatic evaluation is performed, instead the AR telepresence or AR capture is utilized.

2.3 Knowledge Exchange Platform (KEP)

A Knowledge Exchange Platform, in the form of a web-based forum, was implemented to support workers in their interaction and in sharing contextually relevant knowledge and ideas. The KEP enables the creation of user groups to better organize communication and manage the flow of information, workspace and trainings announcements. It communicates through proper routes with the knowledgebase, in order to store and retrieve valuable technical information, training material as well as best practices for both the manufacturing process and workspace procedures. To cater for social aspects, the platform includes social media features, like up/down-voting, options to follow other people and post to other social media. It also aids workers' engagement by rewarding them for contributing. Figure 4 illustrates the main categories and menu items of the KEP, along with a post of a user (question-response) on a job assignment.

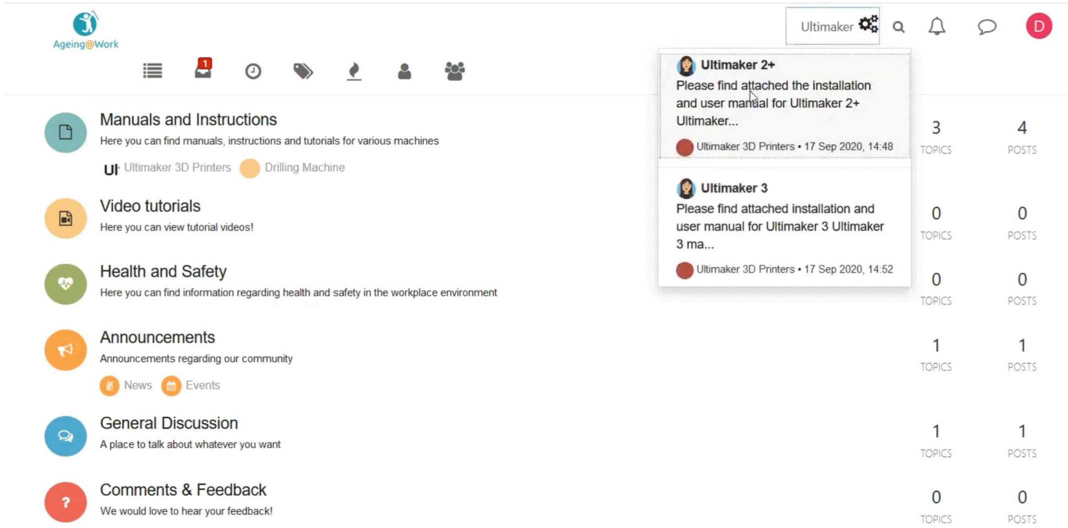

Fig. 4. The main menu of the knowledge exchange platform.

2.4 Evaluation Study

The developed tools were evaluated through online surveys administered through "Google Forms", as it is a simple platform easy to elaborate and complete. Specific sections were included to measure the degree of acceptance regarding the receipt of recommendations by the tool, as well as to measure issues related to privacy and data management. The participants were asked for data on work experience, frequency of use of technology and type of applications used, well-being and satisfaction at work, as well as for the management of personal data. Ethics and privacy issues were considered of high priority. The surveys were translated into local language (one in Spanish and one in German) to be managed by the pilots. In addition, for each of the surveys, videos and images have been included with the demonstration of the tools, to provide to the respondents a greater knowledge of the proposed solution and therefore leading to a more informed response.

To increase the number of respondents and plurality of their profiles, interest groups such as directors or owners of companies, experts in health and safety, lawyers, people dedicated to training or research in mining, etc., have been reached through an additional, *off-pilot*, study. This *off-pilot* study was launched from June to July 2021 and the distributed material had the same content as in the pilot surveys (translated in English).

3 Results

The valuation of the developed tools through online surveys allowed to reach a high number of respondents ($n = 126$) from the *in-pilot* group ($n = 62$), which consisted mainly of extractive industry workers (Asociación Nacional de Empresarios Fabricantes de Áridos – ANEFA) and the *off-pilot* group ($n = 64$)

with workers of diverse profiles and interests. This section presents summarized responses from the workers participating in the surveys. It is important to point out that even though the Ageing@Work solutions are designed for workers between 45 and 65 years old, it was decided to extend the survey to all workers regardless of their age and job, in order to draw conclusions about the future of Ageing@Work solutions and understand if the results obtained can be maintained in the medium and long term.

The profile and responses of each group of participants are presented in the next sections. However, the technology expertise level of the participants (including frequency and type of applications used for everyday life activities) is shown for both groups (pilot and off-pilot) here (in Table 1) in order to provide a better overview of the differences of the two groups and aid in the assessment of responses.

Table 1. Participants experience and use of technology (P: pilot group; OP:Off-pilot group).

Participants experience and frequency in technology use						
Years of experience	**0–5**	**6–10**	**10–15**	**15–20**	**20–25**	**More than 25**
	P: 1.6% OP: 23.4%	P: 3.2% OP: 9.4%	P: 1.6% OP: 21.9%	P: 24.2% OP: 9.4%	P: 27.4% OP: 18.8%	P: 41.9% OP:18.8%
Internet usage	**Never**	**Once a week**	**More than once a week**	**Everyday**		
	P: 0% OP: 0%	P: 0% OP: 0%	P: 4.8% OP: 0%	P: 95.2% OP: 100%		
Augmented Reality devices or tools	**Never**	**Sometimes**	**Usually**			
	P: 75.8% OP: 84.4%	P: 24.2% OP: 18.8%	P: 4.8% OP: 0%			
Virtual Reality devices or tools	**Never**	**Sometimes**	**Usually**			
	P: 58.1% OP: 71.9 %	P:41.9 % OP: 26.6%	P: 4.8% OP: 0%			

3.1 Pilot Study

Participants' Profile. The majority of the participants who have completed the survey were over the age of 45 years (79%). This is due to the fact that the average age of workers in the extractive industry has increased in recent years, because conditions in mining are harsh and unattractive to young professionals. The percentage of male and female respondents was the same. Most participants have had university education (75.8%). The participants' jobs were mobile machinery operator (8.1%), plant operator (1.6%), office worker (54.8%), remote technical assistant (3.2%), maintenance (6.5%), and other (35.5%), The majority of the workers (93.5%) had more than 15 years of work experience. Aspects of work-related well-being are illustrated in Fig. 5.

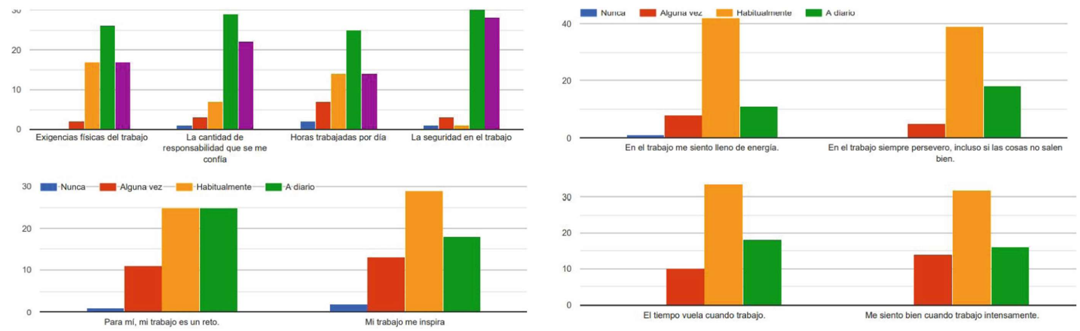

Fig. 5. Statistics on work-related well-being and job satisfaction and job engagement in the pilot group (the corresponding English translation is shown in Fig. 9). Top left: Aspects of the Job position; Top right: Vigor; Bottom left: Dedication; Bottom right: Absorption.

Tools Assessment. Statistics of collected data are presented in the form of percentages of respondents through histograms and bar plots. Results on technology acceptance, including the perceived ease of use and perceived usefulness, as well as on behavioural intention to use and self-efficacy, are shown in Fig. 6 and Fig. 7, respectively. Moreover, responses on data privacy and security are summarized in Fig. 8.

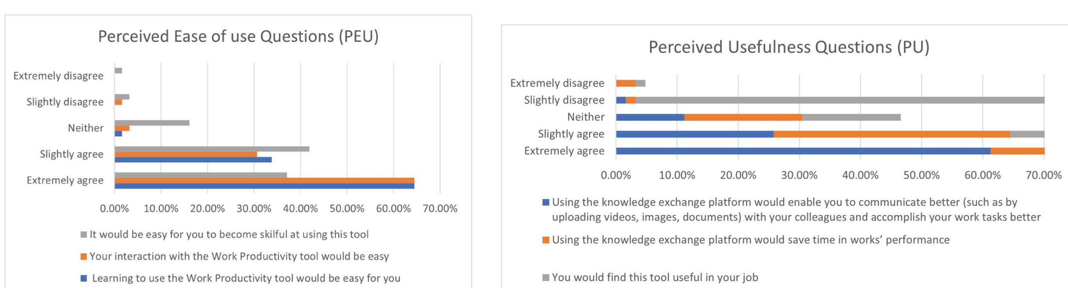

Fig. 6. Statistics on perceived ease of use (left) and on perceived usefulness (right) in the pilot group.

3.2 Off-pilot Study

In addition to Ageing@Work's pilot group, the survey has been circulated to 64 (off-pilot) workers.

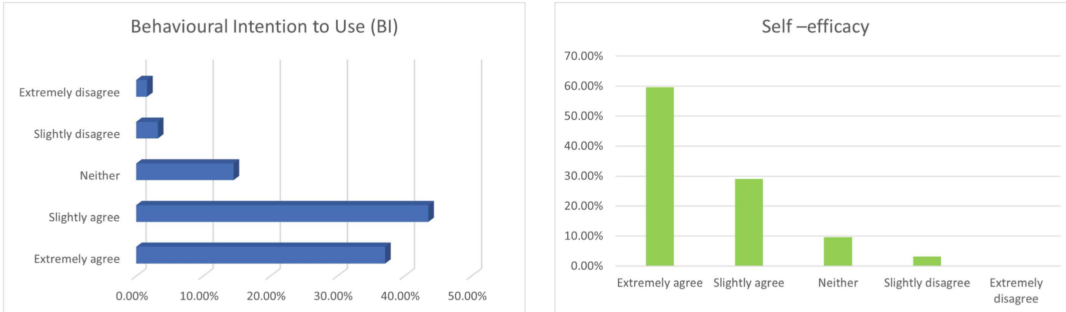

Fig. 7. Statistics on behavioural intention (left) and on self-efficacy (right) in the pilot group.

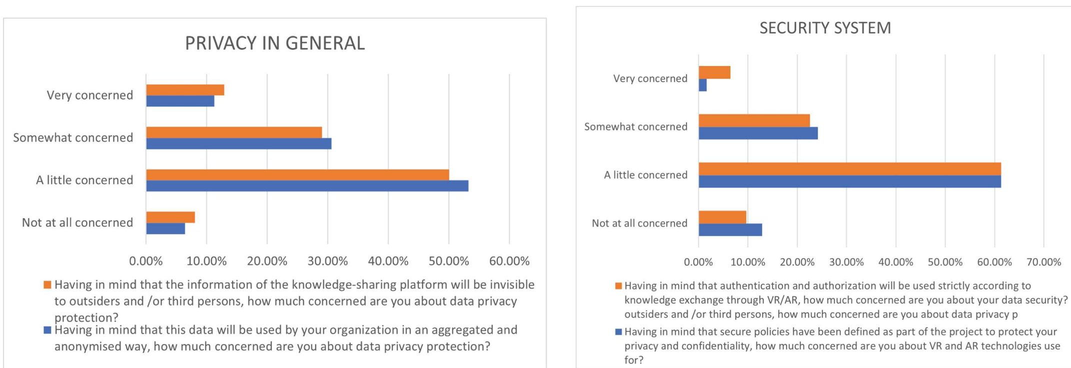

Fig. 8. Results on privacy in general (left) and on the security system (right) in the pilot group.

Participants' Profile. Most of the participants were under the age of 45 years (59.4%) and have a higher education (Masters) degree (50%). The percentage of male and female respondents was quite similar, tilting the balance slightly towards men, with a participation percentage of 54.7%, over 45.3% of female participation. The majority of the participants were office workers (70.3%), but included also remote technical assistants, data or research scientists, public employees, a nurse, and academic positions (faculty members, etc.) with variable years of work experience. Similarly to the pilot group, work-related well-being parameters are shown in Fig. 9.

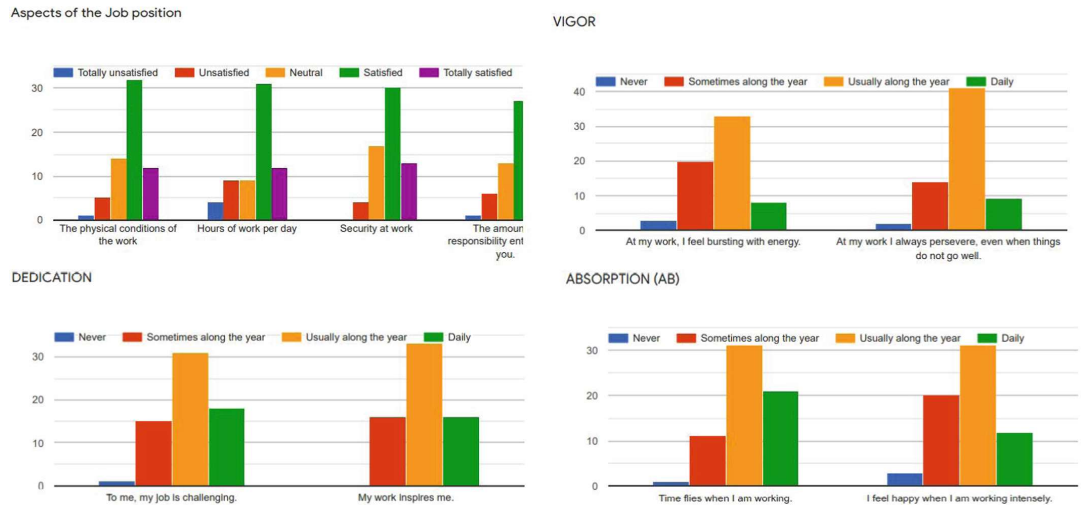

Fig. 9. Statistics on work-related well-being and job satisfaction and job engagement in the off-pilot study. Top left: Aspects of the Job position; Top right: Vigor; Bottom left: Dedication; Bottom right: Absorption

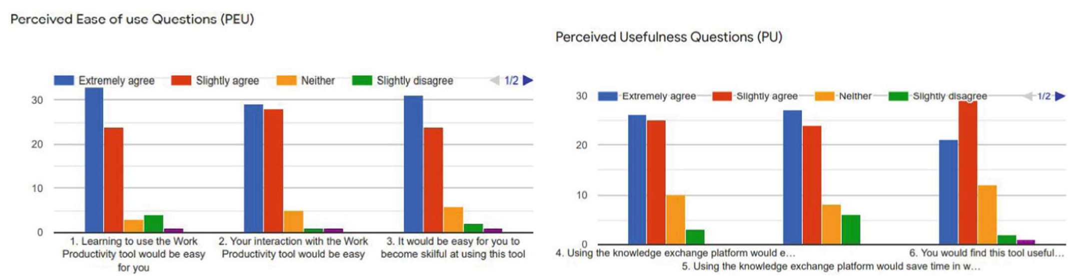

Fig. 10. Statistics on perceived ease of use (left) and usefulness (right) in the off-pilot study.

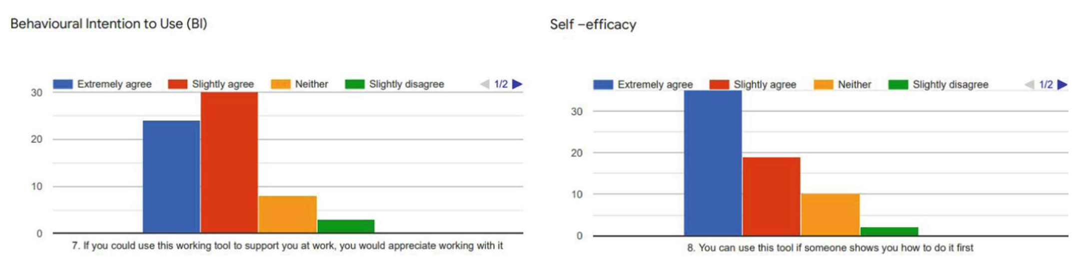

Fig. 11. Statistics on behavioural intention to use (left) and self-efficacy (right) in the off-pilot study.

Tools Assessment. Questions and statistics of responses on technology acceptance are illustrated in Fig. 10 (showing the perceived ease of use and usefulness) and Fig. 11 (summarizing the data on behavioral intention and self-efficacy), while data privacy and security concerns by the off-pilot group are shown in Fig. 12.

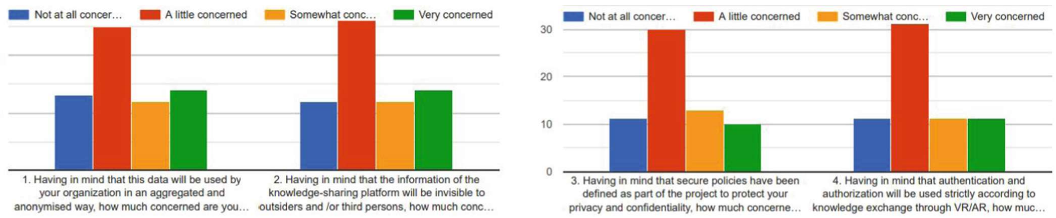

Fig. 12. Results on privacy in general (left) and on the security system (right) in the off-pilot group.

4 Discussion

The aim of this study was to shortly present and evaluate tools that support transferring the long-term experience of older workers to the younger ones. The results on the level of acceptance of the technology are very positive regarding the AR/VR tool and knowledge exchange platform. Regarding the perception of ease of use, the lowest percentage is obtained with respect to the ease of becoming an expert in its use. This reveals a certain reluctance of the users, considering it difficult to use this type of tool. This is expected as, according to the results on frequency of use, most users have never used AR/VR tools. Therefore, it is recommended to keep the tools simple, so that they are easy to be used by the average user, and allow them to focus on the training procedure. Regarding the level of perceived usefulness, the worst result is obtained with regards to considering the tool as a means to save time in carrying out tasks. This may be explained by the fact that some users find it difficult to become an expert in the use of the tools, thus would require more time in the process of familiarization (with the tools) and learning. This highlights again the need to simplify the tools and make them more intuitive. These conclusions are supported by measuring self-efficacy, that shows that about 89% of the respondents in the pilot group extremely or slightly agree that they could use this tool if someone first showed them how to operate it. In addition, when asking the participants of the extractive industry specific questions about the technology, 76–87% consider them attractive and useful in their jobs.

In respect to the off-pilot study, the results on the level of acceptance of the technology are very positive regarding the AR/VR tool and knowledge exchange platform. Regarding the perceived ease of use, 89% of the respondents (extremely or slightly) agree that the tool would be easy to use and that it would be easy to interact with it. In terms of becoming an expert in its use, there are also very positive results, with 86% of the respondents (extremely or slightly) agreeing that it would be easy to become skilled in the use of the tool. These very positive results may be due to a greater knowledge of the group of respondents in how to interact with this type of AR/VR tools. Regarding the perceived usefulness, although the results are less conclusive than the previous ones, the balance continues to be very positive, with the highest number of votes in the category 'Slightly agree' with the statement that the tool would be useful in their job. This may be due to the fact that, since these are questions about the specific effects that the tool can have when used in a daily work context, respondents cannot have a strong opinion when dealing with hypothetical questions. Regarding the intention to use it in the future, 38% of those surveyed extremely agree that they would appreciate adopting the tool, 47% slightly agree and only 15% consider themselves neutral or somewhat in disagreement. We can therefore conclude that the results are positive. Regarding self-efficacy, 84% (extremely or slightly) agree that it is necessary for someone to explain to them in advance how the tool works in order to use it. Regarding the results obtained in the more specific questions about the technology, 84.4% are interested in using these tools, and only 18.7% would prefer to use traditional methods or would not use the tool. We can conclude, therefore, that there is a great acceptance of the technology by the respondents.

About the treatment of private data and security, the majority of the results show little concern by the potential users. While most of the results indicate low concern regarding security and privacy issues, there is a percentage of participants with moderate or high concern about privacy (42%, 41%) and security (26–29%, 34–36%) in the pilot and off-pilot group, respectively. The introduction of guidelines and authentication procedures for data security changed the opinion of the respondents only slightly. Most of them were still concerned about their data, even after introducing such security aspects. It should be mentioned that irrespectively of the participants' perception, security and privacy issues are listed as high priority in the data management process, enforcing strict security measures, and always in compliance with data protection regulations.

5 Conclusions

This paper presented a suite of advanced technological tools that enable workers to interact, gather and share contextually relevant knowledge, ideas and good practices. Through the use of our AR tools, advanced remote collaboration can take place, stimulating good work-related practices, while also facilitating variability in location and working hours, and thus promoting age-neutralizing means of participation and cooperation. The VR-based solution on the other hand, allows to create (or participate in) personal training programs using virtual models of the workplace, avoiding the risks of real working environments. Moreover, the knowledge exchange platform helps workers to easily keep notes of important work aspects, accompanied by images and semantics, and to summarize significant developments that may have taken place upon some absence of the older worker. The former facilitates future easy retrieval of information, regardless working from home or on-site, while the latter serves as a crucial bridge to allow easing the older worker's come-back after some short or long-term absence. Evaluation of the developed tools through online surveys allowed to access diverse professional profiles beyond potential users, such as farm managers, lawyers, engineers, health and safety managers, and has achieved overall a high and representative stakeholders participation. This paper provided an overview of statistics on data collected about work-related well-being, job satisfaction and job engagement, as well as on technology acceptance, functionalities, privacy and security, exposing the potential of the developed tools to support knowledge transfer and workers' engagement in industrial processes.

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