The status of extended reality technology in South Africa's mining industry

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Abstract

The economic upheaval of COVID-19 forced companies to invest in emerging technologies to aid recovery. One such technology is extended reality, which is becoming a mature and innovative tool. Early adopters are seeing significant benefits in learning, training, immersive data visualization, and remote assistance. In South Africa, the mining industry is increasingly interested in using extended reality to optimize and innovate operations. The Minerals Council of South Africa's July 2021 report highlighted the potential of extended reality's to achieve zero-harm production and modernize the industry. However, the extent of extended reality adoption in mining remains unclear due to limited information on its usage. This study addressed this gap by distributing an online survey to assess awareness, knowledge, and current uses of extended reality in South Africa's mining sector. The results indicated that virtual and augmented reality had the highest levels of awareness and usage, primarily for learning and training. Mixed reality, however, had the lowest awareness and knowledge levels. In terms of applications, visualization and remote assistance had the least use cases. These findings highlight that the South African mining industry is deficient in its understanding and use of extended reality technologies. Without better awareness and application, the South African industry risks missing out on the full benefits of extended reality. The study underlines the need for the South African mining industry to improve its outlook on extended reality technologies to fully leverage their potential applications and benefits.

Keywords

extended reality, mixed reality, training, visualization, collaboration, South Africa, mining

Introduction

Governments and businesses across the globe have been forced to accelerate adoption and implementation of new technologies to mitigate the economic upheaval of the COVID-19 pandemic (Hajj et al., 2020).

One technology set to innovate businesses across the globe is augmented reality (AR), which is part of a larger class of emerging technologies referred to as extended reality (XR) technologies. XR technologies either blend the virtual and real world, or vice versa (Marr, n.d.). XR technologies include virtual reality (VR) and mixed reality (MR). These reality-extension tools are transforming into mature technologies at the forefront of innovation. This is supported by Gartner's most-recent technology report, which forecast that multi-experience or immersive platforms would be deployed in at least one-third of all businesses by 2021 (Dilmegani, 2022). Moreover, the technology scouting report of Minerals Council South Africa (MINCOSA) (2021), which explored technology-driven training solutions to support the South African mining industry to achieve zero-harm production and assist with modernization of the industry, placed XR technologies at the forefront of these efforts.

What is the significance of extended reality technology?

The appeal of XR technologies in this data-driven era is that businesses that embrace data are those that will succeed. XR technologies enable this by putting valuable information in a context that allows users to get better results. This represents a significant change in how businesses and individuals interact with data (Engholm, 2020): instead of struggling through spreadsheets to analyze and understand their data, businesses could get a more accurate understanding by using XR technologies, such as smart glasses, to assess the data through immersive data visualization, which will assist them in making better and more informed decisions (Engholm, 2020). XR technologies make this possible by giving users the opportunity to absorb and decipher vast amounts of information through immersive, three-dimensional (3D) experiences, which enable on-the-spot solutions and continuous, dynamic training environments (Engholm, 2020). Moreover, XR tools have the ability to connect individuals, regardless of their physical location, for engineering tasks that require communication of spatial data, such as in-design and prototyping and for troubleshooting and repair, through immersive remote collaboration and remote assistance (Rabaudo et al., 2020).

Industrial applications of XR technologies can be categorized as learning and training, immersive data visualization, and remote assistance or collaboration. Their added benefit is that all the subtypes (VR, AR, and MR) are capable of performing each of the aforementioned applications. Figure 1 provides a schematic summary of the XR technologies and their supported applications.

There are several users of XR technologies, particularly AR, in the manufacturing industry that are incorporating these into their processes to optimize their business and achieving significant gains. Table I summarizes how three early adopters are utilizing AR technologies, as well as the gains from adopting and implementing XR solutions within their processes. All XR technologies are capable of supporting all industrial applications, so it is possible to achieve similar gains utilizing either VR or MR, provided the specific XR technology is suitable for a particular field and its intended use.

Motivations for the manufacturing industry's drive towards developing XR technology solutions are the persistent rises in costs of equipment, product assembly, and workforce training. This is further compounded by technological innovation, which is driving even higher demands for a more skilled labour force due to the growing complexity of manufacturing equipment. These conditions create new challenges for manufacturing companies to find ground-breaking solutions, such as those provided by XR technologies, which save time, lower costs, and guarantee that their more-generalist workforce has the know-how to efficiently do their jobs (Montgomerie, 2019).

Globally, the mining industry is experiencing similar issues as well as mining-specific issues, such as depleting reserves, increasing geological complexity, decreasing ore grades, and price volatility (Viktoriia et al., 2019). In response, mining companies across the globe are collaborating with experts and service providers of immersive technologies to develop XR solutions to optimize their operational processes and improve profit margins. Findings of a literature survey concerning the use of XR technologies in the global mining industry revealed that some of the initial research goes back over 20 years. Much initial research focused on use of VR technology for learning and training (Bise, 1997; Denby et al., 1998; Schofield et al., 1995; Zhang et al., 1999). The mining industry in South Africa took notice of XR technologies during this period because there were similar publications concerning use of VR technologies for personnel training (Squelch, 2001).

Through advances in XR technologies in the past decade, the global mining industry has furthered integration of XR technologies within their organizational processes. This is seen in research regarding the adoption and implementation of technologies such as AR and MR, and concerning applications of XR technologies besides learning and training. For example, Belyi and Nikitenko (2018) did research in Russia concerning the application of HMT-1, which is an AR device that allows employees to gain access to documents and communicate with other employees to assist with dispatch control in underground mining. In Chile, Gonzalez et al. (2016) published their findings on an immersive 3D geological and mining data visualization tool, known as Mixed Reality Exploration Environment (Miree). However, based on the available academic and informal publications, there appear to be no comparable

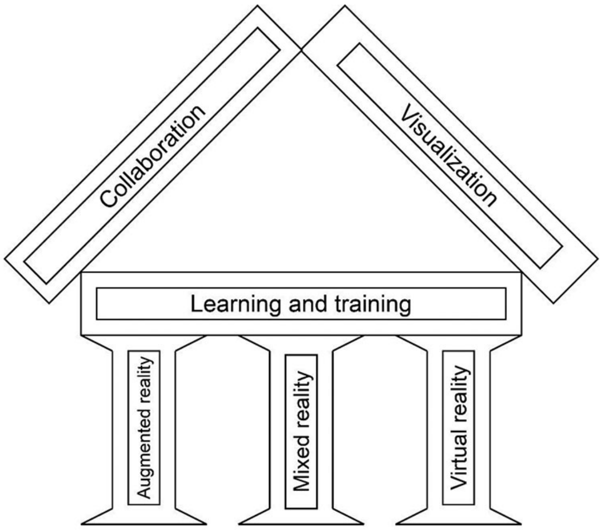

Figure 1—Extended reality technologies and their supported applications

Table I

Initial users of extended reality technologies for industrial applications (adapted from Montgomerie, 2019)

Company	Lockheed Martin	Unilever	Prince Castle
Industrial sector	Aeronautical engineering	Consumer products manufacturer	Foodservice equipment manufacturer
XR technology	AR	AR	AR
Use category	Visualization, training	Collaboration (remote assistance)	Collaboration (remote assistance)
Purpose	Superimpose digital data and assembly instructions onto components	Connect employees on factory floor with experts for machine repairs	Connect general contractor with Prince Castle experts for troubleshooting and repair
Results	35%–50% decrease in overall technician time; 90%–99% decrease in time to interpret drawings and instructions; 85% decrease in overall time for training.	50% decrease in overall machine downtime; 1700% return on initial investment.	100% success rate in diagnosis on initial visit; 50% decrease in service trips; 50%–80% decrease in labour cost.

efforts in South Africa's mining industry with regards to the advancement of XR technologies. This lack of available literature served as motivation for this research project, which was to provide insight into the state of XR technologies in South Africa's mining industry, with particular interest regarding the levels of awareness and knowledge, and existing applications of XR technologies in the industry. To comprehend the methodology and results of this paper, it is important to understand XR technology, with particular reference to the capabilities and properties of the different technologies: VR, AR, and MR.

What is extended reality technology?

XR is a relatively new term that covers all immersive technologies that extend the reality of the real world (Lokesha et al., 2020). The concept originates from the reality–virtuality (RV) continuum proposed by Milgram and Kishino (1994), which explains the transition between the real world on one end of the continuum and completely digital or virtual environment (VE) on the other end. Figure 2 shows a graphical adaptation of this continuum.

From a technology perspective, XR is a more modern term used to describe the RV continuum. XR encompasses VR, AR, and MR, as well as other future realities that could be created as immersive technologies (XR4ALL, n.d.). XR covers the entire spectrum of real and virtual environments and the technologies associated with each environment.

Virtual reality

VR represents an artificial computer environment, which allows users to explore a realism that differs from the physical environment. It typically uses head-mounted displays (HMD), such as HTC Vive™, to create realistic sensations, such as sound and visuals, to create an artificial reality that is similar to the actual physical environment. Users who wear an HMD enter a simulated digital experience and are under the illusion of the VE. A VE is a digital world in which a user's actions are tracked and their surroundings are rendered, or digitally composed, and presented to the senses in accordance with the movements made by the user (Lokesha et al., 2020).

Augmented reality

AR is a system that enhances the real world with virtual objects that seem to co-exist in the same space as the actual physical environment (Azuma et al., 2001). Moreover, according to Azuma (1997), an AR system is characterized by two or more properties that interact in real time, as well as alignment and blending of actual and digital objects in 3D. Although virtual elements are seamlessly projected, in contrast to VR, AR does not produce a new synthetic reality that replaces the actual physical environment; instead, it overlays supplementary virtual data onto the actual physical surroundings/objects (Carmigniani et al., 2011; Tang et al., 2003). Simply put, AR adds additional information to the user's perspective, thereby enhancing their perception of their surroundings by providing contextual information by overlaying digital objects in the actual physical environment. However, these objects do not interact with the physical environment: the interaction with the digital objects occurs on the devices themselves, with inputs from the user (Nee et al., 2012).

Mixed reality

The MR environment combines real and virtual environments in such a way that a window is created between them. As a result, a physical object interacts with a virtual object to perform practical scenarios for the user. There are three key characteristics of any MR system: (i) combining of real-world and virtual objects; (ii) interacting in real time; and (iii) mapping between a virtual object and physical object to create interactions between them. MR systems are created to give their users the sense that the digital objects are in the same space as the physical objects. For coexistence to be possible, the digital objects have to be accurately placed in the actual physical environment and aligned with the physical objects in real time (Rokhsaritalemi et al., 2020). MR includes systems where either virtual elements or those in the physical reality are prevalent; within this range, AR contains more physical elements than virtual elements (Rokhsaritalemi et al., 2020).

A more simplistic or intuitive interpretation of XR, the RV continuum, and the different XR technologies is provided by Figure 3. In summary, real-to-virtual environments may be understood as a spectrum, where AR or VR are specific regions within the general area of MR. AR combines the physical environment with the digital environment, while VR enables users to control and navigate their movements in a VE, which could simulate an actual physical environment (Zeng and Richardson, 2016). As such, AR and VR may be seen as technologies that produce varying levels of MR and allow users to experience a sense of immersion in a mock environment where physical and digital objects co-exist (Di Serio et al., 2013).

Methodology

Two tools were applied to determine the status of XR technologies in the South African mining industry. The first was a literature survey regarding XR technologies; the second was the distribution of an online survey questionnaire concerning XR technologies to the South African mining industry, with assistance from the Association of Mine Managers of South Africa (AMMSA) through access to their extensive membership database.

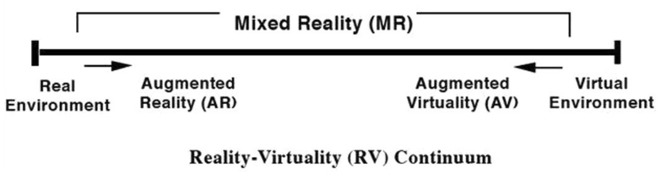

Figure 2 —Reality–virtuality continuum (Milgram and Kishino, 1994)

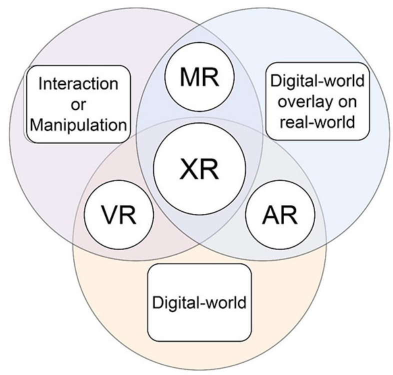

Figure 3—What is extended reality technology? (Adapted from StraitsResearch, 2020)

Literature survey

The purpose of the literature survey was to get a clear comprehension of XR technologies with regards to their properties and capabilities. These findings were the precedent for determining the status of XR technologies in the South African mining industry with regards to assessing the levels of awareness, knowledge, and how XR technologies are used in mining. As such, the findings of the literature survey formed the basis of the development of the online survey questionnaire and aided in analysis of the respondents' descriptions of XR, VR, AR, and MR.

Online survey questionnaire

The objective of the online survey questionnaire was to determine the status of XR technologies in the South African mining industry using the following questions:

➤ Do you know about XR/VR/AR/MR?
➤ What is your understanding of XR/VR/AR/MR?
➤ Does your company utilize any XR technologies?
➤ How are XR technologies being used at your company?

The responses to and analysis of these questions provided both quantitative and qualitative results for this study.

Results

The invitation to participate in the study was sent via email to AMMSA's entire membership database, but recipients were not obligated to participate, so responses to the online survey questionnaire represent a convenience sample: only those invitees who were interested in filling out the online survey questionnaire are included in the results. This means that the results may not be fully representative, but nevertheless provide insight to the research question. The responses to the online survey questionnaire formed the basis of discussion of the results of the study and provide insight to the status of XR technologies in the South African mining industry.

Status of extended reality technologies in South Africa's mining industry

There were 50 respondents to the online survey questionnaire, all of whom were stakeholders in the mining industry: 87% of the sample group comprised individuals with more than eight years' experience. These participants serve in different capacities in the industry, as illustrated in Figure 4.

Contextual analyses of the responses focused on identifying the following quantitative and qualitative aspects regarding XR technologies in the South African mining industry:

➤ Awareness of XR technologies (VR, AR, and MR);
➤ Knowledge of XR technologies (VR, AR, and MR);
➤ Application of XR technologies in their respective organizations.

Awareness of extended reality technologies

The responses revealed that awareness levels of XR, VR, AR, and MR were 30%, 70%, 44%, and 22%, respectively. Figure 5 summarizes these results. Levels of awareness surrounding XR and MR were lowest. Possible reasons are that these are relatively new terms and technologies compared with VR and AR, which are more mature technologies with several high-level industrial applications, some of which are used in the mining industry.

Knowledge of extended reality technologies

Additionally, from the responses shown in Figure 5, those who said that they were aware of VR, AR, or MR were asked to provide their own description of the respective XR technology or technologies. This was to gain insight into whether personnel in the mining industry had a functional understanding of the different XR technologies. Qualitative analysis – particularly grounded theory (Glaser et al., 1968) – was used to assess their description(s), i.e., their knowledge of XR technologies.

The criteria for assessing these respondent descriptions were the findings of the literature survey. The discretion and disposition of the researcher was core to assessing these descriptions and how closely they fitted the literature definitions of VR, AR, and MR, with particular focus on the keywords and concepts regarding the properties and capabilities of each of the technologies. A ranking system was then used to evaluate the responses as either showing advanced, proficient, approaching, or novice understanding of these concepts.

The descriptions categorized as advanced understanding possessed comprehensive discussions of the key properties and capabilities of the XR technology. The proficient and approaching understanding categories were for those responses that discussed either properties or capabilities of the XR technology, but not both. Responses in the novice category were those with incomplete statements and did not exhibit any distinguishable comprehension

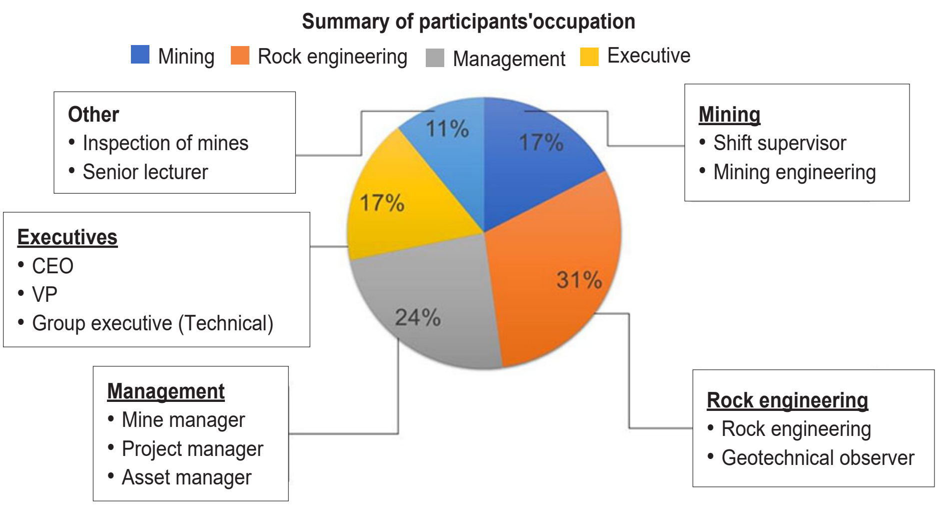

Figure 4—Occupations of survey participants

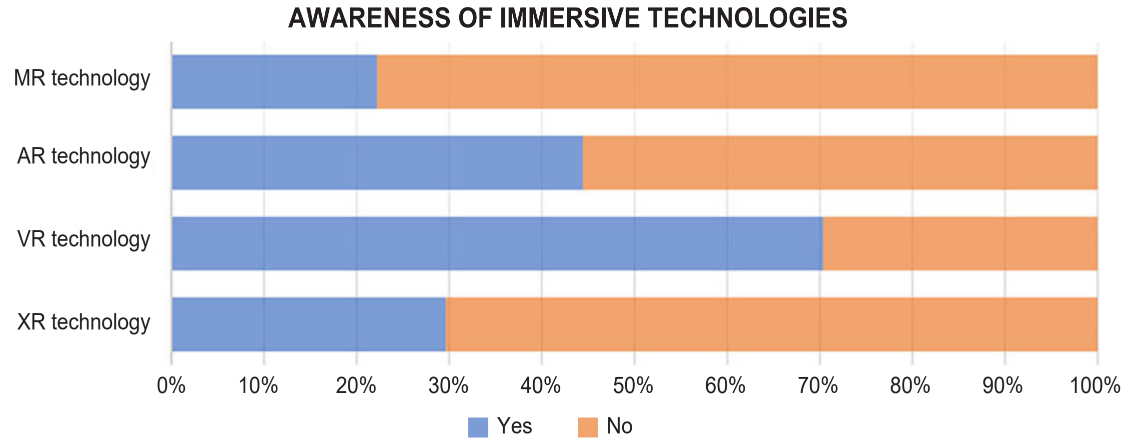

Figure 5—Awareness of immersive technologies

of the properties and/or capabilities of the XR technology being described. Figure 6 provides a graphical summary of the ranking system and classification criteria.

Status of extended reality technologies in South Africa's mining industry – virtual reality

Figure 7 provides a statistical summary of classification of the respondents' descriptions of VR. Approximately 35% of respondents were categorized as advanced, with comprehensive descriptions of VR that closely corresponded with the literature definition concerning how VR places a user inside a simulation or artificial environment where the space consists only of digital elements or objects. In contrast, 23% and 25% of the responses were considered proficient and approaching understanding, respectively. The main reasons for these classifications were that these responses discussed how VR places a user in a simulation or artificial environment, but did not mention that the environment within the simulation only consists of virtual or digital objects.

Status of extended reality technologies in South Africa's mining industry – augmented reality

Figure 8 summarizes the corresponding results for descriptions of AR. Here, 24% of the responses were in the advanced category. These responses discussed how AR is the overlay of digital objects or elements over the real world to enhance the user's view of the real world (i.e., provide additional context to real-world situations). The responses classified as proficient and approaching understanding (32% and 36%, respectively) mentioned how AR comprises overlay of digital objects over the physical environment, but did not discuss that the purpose of this overlay is to enhance the view of real world. Some responses discussed how AR enhances the real-world view, but did not mention that this is done through superimposing digital objects onto real objects or the real world.

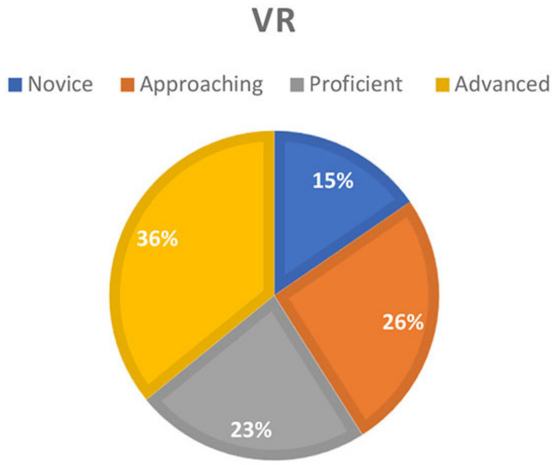

Figure 7—Summary of classification of virtual reality descriptions from responses to the online survey questionnaire

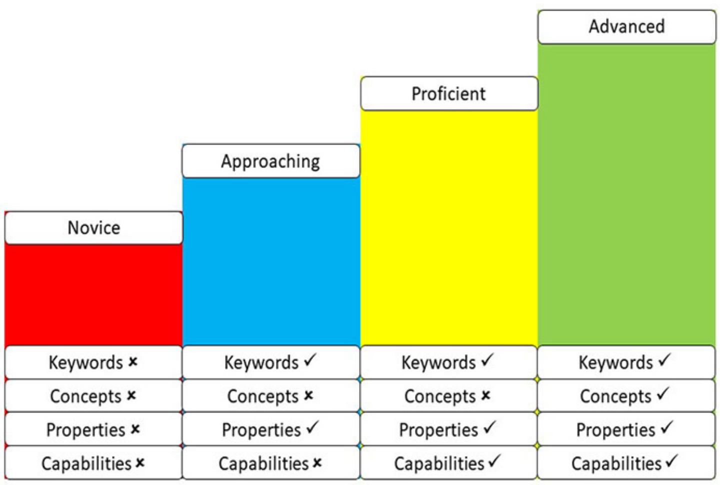

Figure 6—Criteria for response ranking system

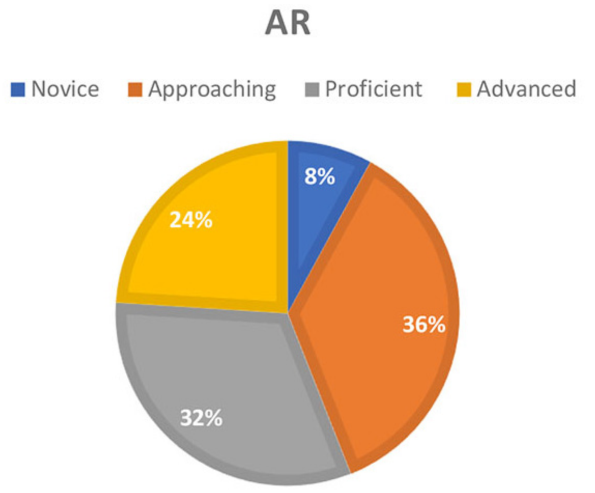

Figure 8—Summary of classification of augmented reality descriptions from responses to online survey questionnaire

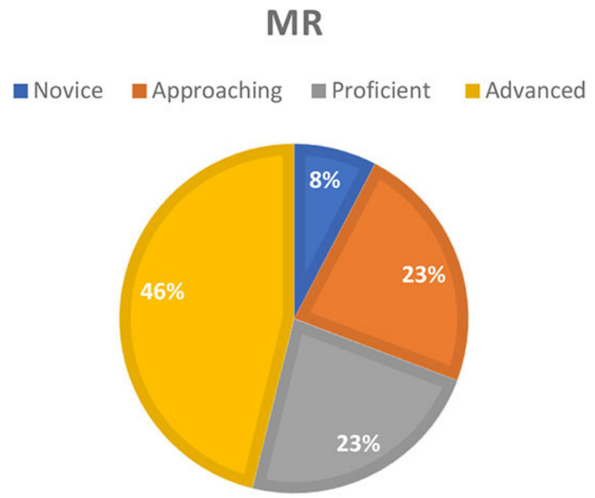

Figure 9—Summary of classification of mixed reality descriptions from responses to online survey questionnaire

Status of extended reality technologies in South Africa's mining industry – mixed reality

Figure 9 summarizes classification of the responses regarding the definition of MR. Here, 46% of responses were categorized as advanced. Approximately 23% and 23% of the responses were considered proficient and approaching proficiency, respectively, in that they were correct in indicating that MR involves merging of real and virtual environments, but there was no mention of how MR creates a space for interaction of real and virtual objects within this environment.

Status of extended reality technologies in South Africa's mining industry – other findings

A more interesting analysis comprised assessing how appropriate the responses were for the particular XR technology being described. Some responses were ambiguous, in that the singular discussion described a range of immersive or XR technologies. The 50 participants of the online survey questionnaire produced 77 descriptions of VR, AR, and MR. Of these, 23 responses were considered unclear, and were more a descriptor of generic XR technology, rather than of a specific XR technology subtype. These 23 responses constituted 29% of the descriptions. This means there is a significant contingent in the South African mining industry who are aware of different XR technologies, but are unclear in their comprehension of the respective properties and capabilities.

The significance of these latter responses is that, as much as South Africa's mining industry may want to adopt and implement XR technologies, it is more important that there is clarity regarding the desired product or outcome of the XR solution. The importance of this is that if the mining industry approaches service providers of such technologies with unclear directives of the required product – particularly with regards to the properties and capabilities, then there may be a lot of dissatisfaction with the delivered product when the XR solution does not perform its intended function. A knock-on effect would be disenchantment surrounding XR technologies and less appreciation of their potential applications for the mining industry. Therefore, it is important that the South African mining industry improves its comprehension of the properties and capabilities of the different XR technologies, so as to have a clearer directive of what it wants to achieve with such solutions. This will ensure that the correct technology – VR, AR, or MR – is chosen for the specific application for which it will be deployed.

Existing applications of immersive technologies in South Africa's mining industry

Figure 10 summarizes responses to the online survey questionnaire regarding existing applications of XR technologies in the South African mining industry. The results show that affirmative responses to the use of XR technologies for productivity, training, visualization, and collaboration were 7%, 33%, 19%, and 4%, respectively. Learning and training appear to be the largest use for XR technologies. This result corresponds with discussions from MINCOSA's technology scouting report (Minerals Council South Africa, 2021).

Assessment of validity of the responses regarding the use of XR technologies for productivity, visualization, and collaboration proved difficult, in the absence of details of the specific hardware and software used by respondents at their respective mining operations/companies. In retrospect, this was a flaw in the compilation of the online survey questionnaire with regards to assessing existing applications of XR technologies in the South African mining industry.

Conclusions

An online survey questionnaire to assess the status and understanding of XR technologies in the South African mining industry was undertaken. Analyses of the 50 responses received revealed the following:

- ➤ VR and AR have the highest levels of awareness owing to maturity of these technologies and several high-level applications in the industry.
- ➤ XR and MR have the lowest levels of awareness because these are recent developments in the domain of immersive technologies.
- ➤ It is concerning that the levels of awareness of AR, MR, and XR are less than 50%, because this means that large portions of immersive technologies remain unexplored by the South African mining industry.
- ➤ The South African mining industry has inadequate understanding of the properties and capabilities of the different technologies, which represents a problem with regards to their adoption and implementation.
- ➤ The South African mining is primarily considering VR for learning and training. This corresponds with MINCOSA's

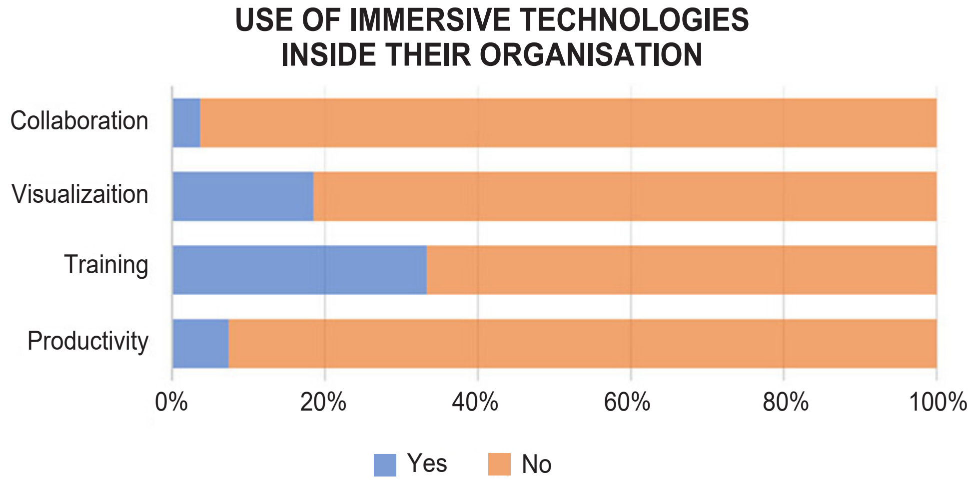

Figure 10—Use of immersive technologies within respondents' organizations

technology scouting report, which provided an outlook on XR technologies for the industry. This narrow view shows that more must be done to expand the visibility of XR technologies in the mining industry.

➤ By improving levels of awareness of the different XR technologies and knowledge of their respective properties and capabilities, the South African mining industry could further its scope of applications beyond that of learning and training with VR.

➤ A more holistic approach will assist in utilizing XR technologies to realize zero-harm production and assist with modernization of the South African mining industry.

Recommendations

From the discussions and conclusions provided above, the recommendations from this research paper are as follows:

➤ More effort should be applied to informing the South African mining industry about XR technologies and their benefits to ensure that the industry has a more proficient comprehension of their properties and capabilities. This should lead to improvements in the development of XR solutions for the industry and ensure that the correct solutions are developed. In turn, this will improve the level of adoption and implementation of XR technologies by the South African mining industry.

➤ More investment into research and development of XR technology solutions beyond the scope of VR for learning and training purposes is required. This will assist the mining industry to provide real-time solutions to improve optimization strategies and profit margins.

Suggestions for further studies

Based on the discussions emanating from this study, recommendations for further work are as follows:

➤ Identification of suitable XR technology applications from other industries (besides VR for learning and training) that could be easy to pilot for a process in the mining cycle, and assess the impact thereof;

➤ Create a report that informs the mining industry about XR technologies to improve understanding and dispatch current misconceptions of immersive technologies, as apparent from the results of the online questionnaire.

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