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Application of an Industry-inspired Mock Mine as a Pragmatic Platform in Support of future Skills Development for the South African Underground Hardrock Mining Industry

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Abstract

The South African Mining Industry directly employs more than 450 000 people, and has consistently seen a significant reduction in Total Capital to Labour ratio expenditure over the past few years. This reduction means that more focus is being placed on retaining the services of the mining labour force, even in the advent of digital transformation in mining, driven by the core technologies of the Fourth Industrial Revolution. Most underground hard-rock mining companies have adopted some form of automation where possible, however the nature of the orebodies and infrastructure constraints favour conventional and human-centred mechanised mining methods over completely automated production environments. The skillset of the workforce is therefore crucial in maintaining high production levels with zero harm, whilst planning for technology and operational changes brought about by continuous improvement initiatives in these environments. A challenge exists when balancing the insight and efficiencies brought about by introduction of new technologies, with the generally low-level of skillset of much of the labour force. An appropriate strategy for skills development is therefore crucial to ensure that the workforce is suitably trained to capitalise on the offerings that new interventions bring about.

A simulated mining environment has been developed, herein referred to as the Simulacrum, to bridge the gap between students, the department, and industry stakeholders. This mock-mine includes replicas of multiple sections in an underground mine, including a haulage, crosscut, refuge bay, stope and virtual blast wall. The platform was designed to be modular, for capacity to represent the workings of multiple commodity environments such as gold and platinum. The use of cyber-physical tools such as VR and AR experiences added to the modularity and allowed the users to gain an enhanced experience of what it would be like to be in a mine, when combining visual, tactile, acoustic and olfactory stimulations. The added advantage of easy access makes the platform ideally suited to serve as a testbed to support proof of concept research for industry partners. This approach supported the pedagogy of connectivism, wherein students were taught to use digital tools, as well as adopting the use of digital tools to facilitate the transfer of knowledge. In doing so, barriers of literacy levels, language differences and inexperience with mining technologies were addressed.

1. Introduction

The South African Mining industry consists of four major mining sectors namely Coal, Gold, Platinum and Diamonds. Smaller sectors include operations to mine Titanium, Copper, Chrome and other lesser minerals according to the Minerals Council of South Africa (MCSA) [1] . The industry was reported to have employed 458,954 people in 2021 with a contribution of approximately R480.9 Billion South African Rands (~US$26.8 Bn) to the country's GDP in that same year [2]. The production output of any operation is heavily reliant on the ability of the mine management to effectively monitor and control the utilisation of their workforce, equipment and financial resources. Most operations in the country are supported by a dedicated and skilled workforce to maintain production outputs, placing a great responsibility on the skills development platforms implemented to generate a skills pipeline for current and future needs. The lack of education among workers is an important barrier to productivity due to low literacy rates; a low skill base, a lack of understanding of business principles, and a lack of understanding of how workers fit into a productive workplace, or why productivity is important as argued by Roussos [3] and Neingo and Tholana [4]. Recent trends have shown a decline in capital to labour ratio (Figure 1 [5]) across the industry, which indicates that mining companies are spending more money on retaining their labour force rather than CAPEX to achieve their target production rates.

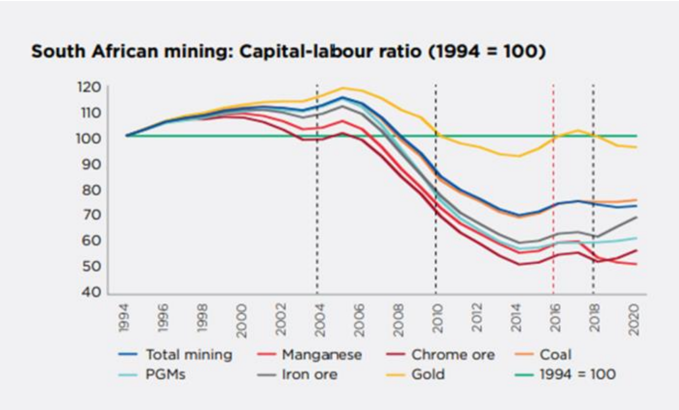

Figure 1: Trends in Capital to Labour Ratio for the South African Mining Industry [5]

The Fourth Industrial Revolution has brought about many opportunities for the mining industry in South Africa. In some cases, the technologies of the 4IR have already been implemented in different sections within most operations. The implementation of these technologies is however limited in most mines due to challenges associated with infrastructure, skills and cost. Most mines have already been established to operate conventionally with fixed infrastructure until the life of mine is reached. This makes any drastic changes to the infrastructure to accommodate certain interventions quite challenging. The skills required to keep up with the rate of potential interventions brought about by the 4IR is also challenging to manage due to the fact that the South African workforce consists mainly of elementary and semi-skilled workers [6], further exacerbated by the low-literacy levels amongst youth. A platform to develop a skills pipeline for adoption of digital technologies in mining is needed. The more realistic that platform is, the more effective the training is envisaged to be. A training platform to simulate mining operations underground was established as a result, with the following objectives:

- Serve as a realistic mining environment to support skills development and research.
- Bridge the gap between students, the department, and industry stakeholders.
- Accommodate skills development for multiple mining environments.
- Support development of currently needed and future skills for the mining industry for multiple levels of students.

- Demonstrate the latest technologies applicable to the mining industry.
- Serve to train on cutting edge technologies relevant to the mining industry, as well as use cutting-edge technologies to support training for the mining industry.

The use of Extended Reality (XR) in training and research enabled the use of the platform to be modular, scalable, upgradeable and reconfigurable. These attributes contributed to the agility and flexibility of the platform for multiple training types to different levels of students. The added advantage of easy access makes the platform ideally suited to serve as a testbed to support proof of concept research for industry partners. This approach supported the pedagogy of connectivism, wherein students were taught to use digital tools, as well as adopting the use of digital tools to facilitate the transfer of knowledge. In doing so, barriers of literacy levels, language differences and inexperience with mining technologies were addressed. Sibanye-Stillwater were the major sponsors of the platform and a facility to replicate an underground mining environment was decided upon due to the facilities available at the University.

2. Skills Considerations for Modern Mining

2.1 Trends in the Mining Industry

The level of automation in mining ranges from fully automated mining operations such as the Kibali Mine in Congo [7], to conventionally operated mining operations which are very deep as some gold mines in South Africa. Barnewold and Lottermoserthe (2020) [8] presented a heat map which indicated the adoption and usage of different common digital technologies across the mining value chain. These technologies included advanced process control, artificial intelligence, automation, big data, data analytics, ERP, machine learning, mine nerve centre, mobile devices, predictive analytics, real-time data, robotics, simulation, social media and VR mine training. The intention of the map was to highlight a number of key digital technologies that could reduce costs, improve business productivity and efficiency, and transform mining practices across the entire value chain. Automation, was depicted to be most widely adopted in the industry, having the highest application across the value chain (specifically in haulage and concentration operations) followed by the generation of real-time data. Barnewold and Lottermoserthe (2020) [8] also highlighted that currently, most mining industry professionals do not have the skills and knowledge to understand and use the new digital technologies that were presented. Specialist skillsets need to be brought into mining operations in order to gain the leverage associated with digital transformation.

PWC and the MCSA performed a study of the South African mining industry, by surveying a number of experts from the local industry in 2021 [9]. The results from this survey is shown in Figure 2, which captures the general view on the impact of digital transformation on both the mining companies and their workforce over the next five years. The mining labour force is currently dominated by low and semi-skilled workers in terms of numbers. There will have to be a shift to have more skilled and less unskilled employees when considering digital transformation at an operational level. Benefits of digital transformation are expected to include more productivity per operation and per employee, decreased production costs, higher workforce costs (due to more skills in the workforce), and a safer operating environment. These drastic impacts further support the need for a training platform that is able to supply a pipeline of skills for the mining industry on demand.

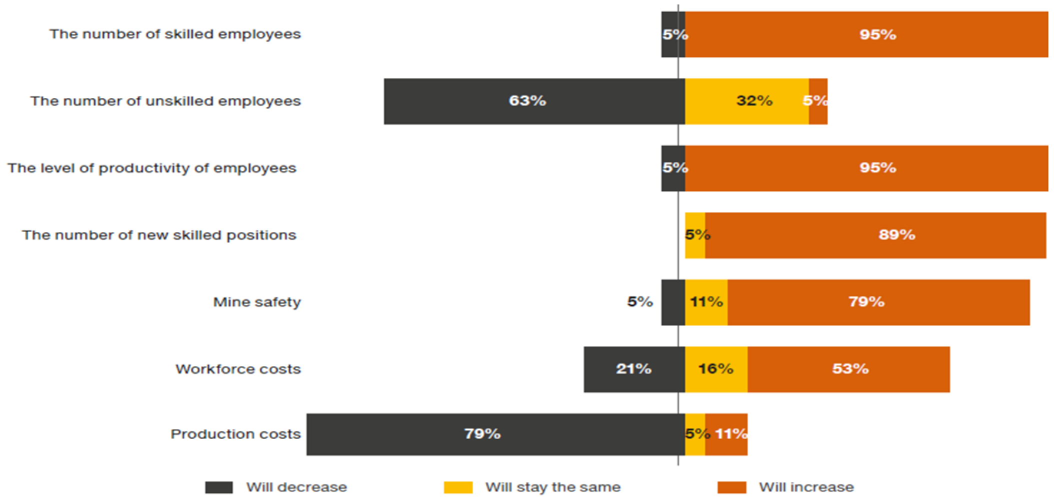

Figure 2: Impact of digital transformation on mining companies and their workforce over the next five years [9]

The trends described above indicate that digital transformation in mining operations is inevitable in order to maintain the sustainability of the industry. In South Africa specifically, the implementation of digital strategies needs to accommodate the low literacy levels and skillset of the majority of the workforce. Introduction of new technologies such as the world's first Hydrogen-powered Haul Truck require upskilling and reskilling of the existing workforce. Job loss has to be kept at a minimum in this environment as the country is experiencing its highest ever unemployment rate. It is therefore crucial that systems which enable low-skilled labour to conduct skilled work are needed. More importantly, the systems used to generate the skills to operate these systems must facilitate On-The-Job (OTJ) training, in a flexible and agile manner in order to meet the variances of needs arising from different levels of technology competency, language barriers, age and general skills. Following these findings, it was decided to pursue the use of XR and cyber-physical systems to enable the development of a modular, agile, flexible and customisable training platform for the mining industry.

2.2 Overview of XR

XR comprises of Mixed Reality (MR), Augmented Reality (AR) and Virtual Reality (VR). Virtual Reality can be defined as a computer-simulated experience that replaces the user's perception of the real world with a virtual world. With this virtual world being entirely created out of three-dimensional graphics and the user (placed within it) is able to interact with this world to some degree. This intervention is intended to "trick" a user's sense of presence and perception into believing that they are in a different environment according to Doolani et el (2020) [10]. AR on the other hand features computer-generated graphics overlaid on top of the real world. AR aims to bring digital information to either a user's immediate surroundings or their indirect view of the real-world, this could be enabled through devices that feature integrated cameras or by use of projectors according to Carmigniani & Fuhrt (2011) [11] . MR is viewed to represent the merging of real-world elements within virtual worlds. These 3 models fall into a blanket term known as extended reality, yet each has their own specific means of engagement [10].

VR is heavily reliant on computer-based technology which incorporates specialized input and output devices to allow the user to interact and experience these virtual environments. These devices usually include an HMD (Head Mounted Display) accompanied by a physical component to which one would interact with in order to impact or navigate the digital world and thus provides a link between the physical feeling of touch and the actions or impact within the virtual world. VR packages tend to include navigational tools, such as handheld controllers that feature wearable items like motion capture gloves which can provide accurate finger placement of the user inside virtual space. Commercially available virtual reality devices (some, if not all) tend to include a form of haptic feedback enabled within them. Haptic feedback relates to force being applied against the user's sense of touch (this can include sensations such as rumblings, vibrations or stiffness intentionally created to provide a sense of feedback to the user based on their actions within a virtual world) and can exist in any of the devices identified above.

2.3 Review of XR Teaching and Learning methods applied within mining

According to Brown and Poulton (2018) [12], the gamification of complex mine safety training, through turning intricate (yet crucial) information into digestible and entertaining activities directly results in better knowledge retention and skill development of users, when compared to past training techniques. In their thesis, van Wyk [13], argued that the more immersive an experience is, the more one can understand the "rules of engagement" of that particular space, by working within those conditions without any associated risks. In fact, these virtual spaces may even go so far as to encourage risk taking in order to see, learn from and better prepare for the resulting consequences.

The benefits of these systems include the repetitiveness of training within a safe environment as well as training for a plethora of different situations from within a single area. Benefits also stretch out to production as vehicles do not have to be set aside for training purposes but rather can function per normal within the mining cycle, essentially not halting productivity of the mining environment. Given the right equipment, virtual reality can offer a high degree of realism and interactivity within virtual environments. Mining for instance can be seen as a welcomed environment for this type of training, as real mining environments are too hazardous (from both a safety, production and a financial perspective) for novice workers according to Mendes (2022) [14].

The physical structure of the Simulacrum may never change however, digital interventions can be implemented to cater for the specific needs of the department at any time. This adds to the modular design of the mine as the digital world can enhance specific teaching and learning solutions with little to no impact on the Simulacrum's physical structure. For students, the purpose of these digital tools was to bridge the gap in terms of their visualization and interaction with various mining devices, activities and processes. These have included drilling, blasting, haulage as well as various other independent low-cost applications that are constructed around and used with the Simulacrum.

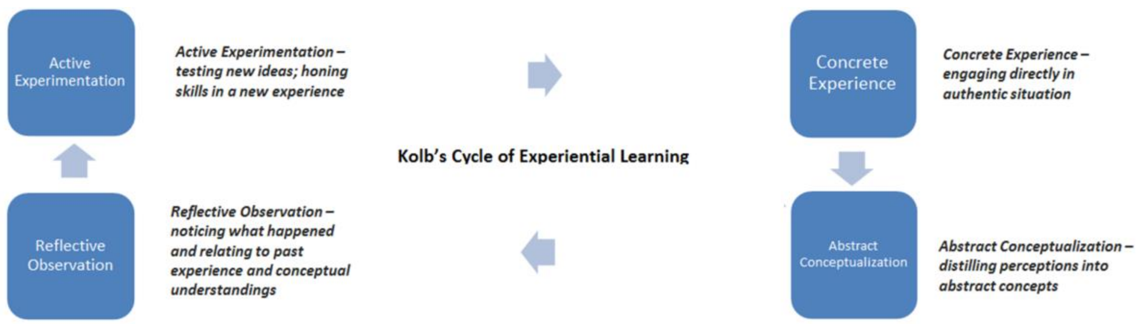

Figure 3: Kolb's cycle of experiential learning [15]

For educators, these tools provide insight into the direction of the industry from a technological standpoint, as well as an opportunity for growth and development of an educator's own teaching methodologies. One of the chief benefits of any digital learning platform is the ability of having real time feedback. This is usually based on the impact of the user's actions within virtual space. Much like the elements outlined in Kolb's Cycle of Experiential Learning (Figure 3 [15]), the presence of both the mine and these digital tools allows for an authentic experience as it provides an opportunity to relate the physical experiences within the Simulacrum to their conceptual understanding (here it seeks to provide a link between the "textbook" theoretical knowledge ascertained and its physical application). The presence of both the mine and the digital tools allows for a reflectiveness within the student. In that they can reflect upon the teachings from a theoretical perspective and apply that to various instances and use cases within the Simulacrum. As the mine and its subsequent digital interventions allow for an experience in which students can repeatedly come back to, as this enables active student participation and observation through experimentation. The following examples demonstrate the application of XR tools developed for education in the mining industry:

- **ThoroughTec Simulation's CYBERMINE:** is designed to fully replicate a mining vehicle's cabin which virtually simulates the operation of real-world, heavy-duty mining machinery. These simulations are based on OEMs (original equipment manufacturers) specifications and are designed to be direct replications of these real-world vehicles [14]. This simulation places the user at the centre of a physical cabin which is populated with a comprehensive recreation of the vehicle's controls, matching the functions of the physical mining vehicle. This enables the trainee's skillset to be easily transferable onto the simulation's real-world counterpart [14]. The exterior environment is a virtually simulated 3D environment displayed using physical panels.

- **The Boiler Room AR Sandvik Health Monitoring Kit:** is an augmented reality application for a Sandvik double boom drill rig [16]. The application uses a mobile device's built-in camera to show the inner workings of the various mechanisms within the Sandvik machine. It allows users to see the various different components of the machine, their locations and a description of the function/s of each component [16].

- **Mining Evacuation Training Simulator (METS)**: provides a simulated VR training environment (enabled through the use of Vive VR devices) in which to practice proper evacuation procedures and build communication skills for use during adverse underground conditions [17]. The software initiates an emergency within the mine at the start of the procedure. Cooperation through communication is then needed between two users in safely navigating the underground VR environment for evacuation [17].

3. Development of the Simulacrum

3.1 Simulacrum overview

The functioning of the Simulacrum is primarily to bridge the operations of the university department, students of mining and mine surveying, and industry as well as other external stakeholders. The platform is intended to support on-demand skills development for the local mining industry as well as support research that will be impactful to the industry where possible. In doing so, students get to obtain training on a platform that includes technologies and strategies for real-world industry pain points, industry suppliers are able to demonstrate and test their latest solutions, bursary or scholarships become more accessible to students. Figure 4 highlights the overview and purpose of the Simulacrum platform.

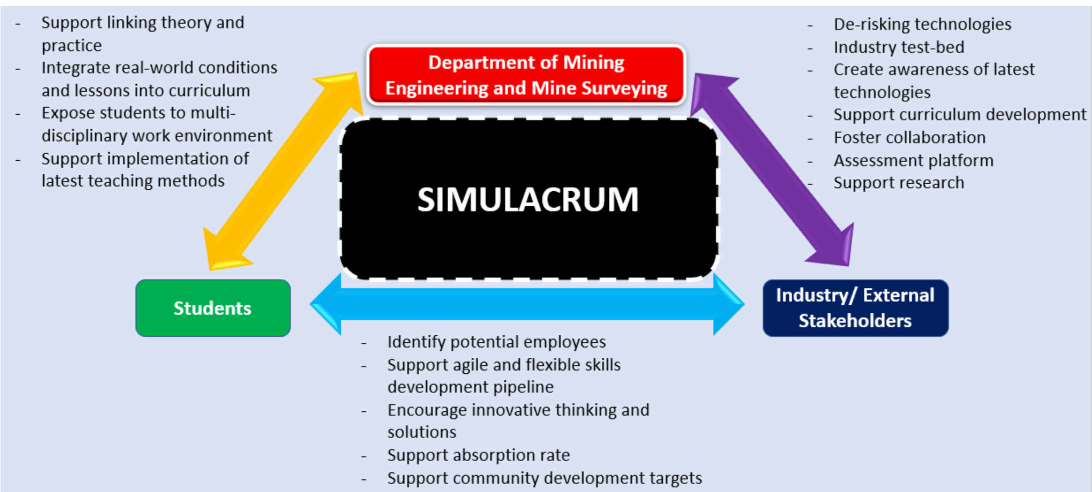

Figure 4: Overview of purpose of Simulacrum

The Simulacrum was built to have the following attributes:

- Modular design: A modular design of the components in the platform allowed for reconfigurable, scalable, upgradeable, and customisable training stations.
- Combined implementation of physical, cyber-physical and virtual components: These were specifically combined to create a realistic representation of a working mining environment with respect to look, feel, smell, touch and sound.
- Easy integration into university curriculum: The platform will be used for supplementing the degree curriculum in addition to supporting training for external stakeholders.
- Industry interfacing: to include mining equipment and practices that will be seen directly in industry on leaving the facility
- Easy access: To support efficient and cost-effective de-risking of technologies and on-the-job training.
- 4IR ready: to support training on digital transformation in mining.

These above attributes contributed to the overall systems layout of the Simulacrum as shown in Figure 5.

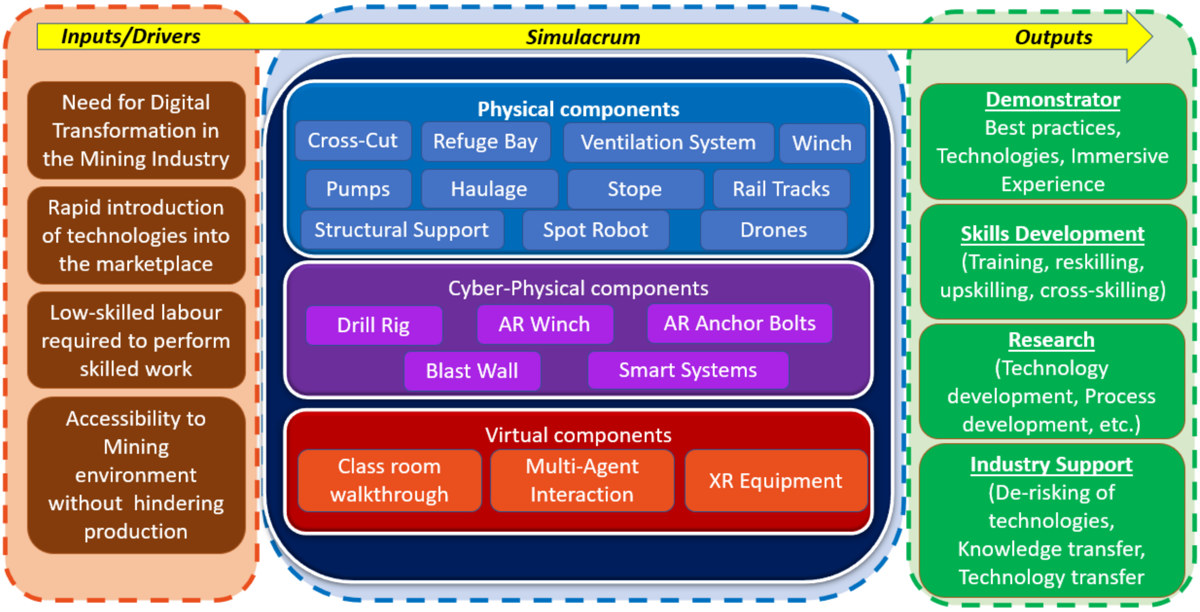

Figure 5: Systems layout of the Simulacrum

3.2 Physical Layout

The Simulacrum was developed to represent an underground hard-rock mining environment. The physical layout included a vertical shaft, haulage, crosscut, stope with wooden supports, industrial winch and scraper, refuge bay, rock support with anchor bolts, and waiting area (shown in Figure 6). These components combined to replicate the layout of an underground mine with respect to look and feel, smell (as the mine houses local fountains and is always damp), and the ventilation and pumping system added to the sound disturbances often experienced in a mining environment. The risk factor in this type of environment is significantly less than on a real operation due to lack of moving heavy equipment, and stable ground conditions. This makes the platform much safer to train and research in. The accessibility of this platform is one of the key advantages, since it can be accessed via a staircase as opposed to having to wait hours for a cage in a real-world operation.

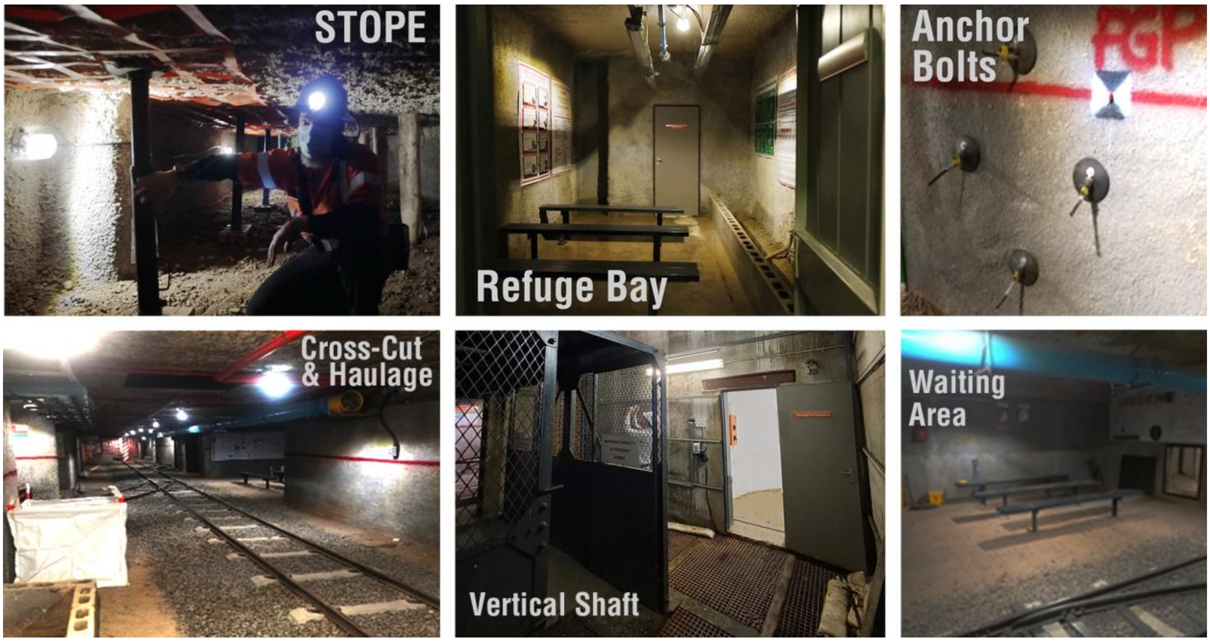

Figure 6: Physical components of the Simulacrum

3.3 Virtual and Cyber-Physical Components of the Simulacrum

3.3.1 VR Scraper Winch

The Simulacrum features a physical mining winch area (Figure 7). Comprising of the industrial winch, the steal cabling, and gully scraper. However, the usage of these components would be too dangerous to be physically demonstrated here. This is due to the difficulty in ensuring that the components do not malfunction during operation and lead to injury of the operator. Therefore, a virtual solution, as seen in Figure 7, was required in which to showcase the operation of the winch and display its function to a wide audience, within the current setup. Developed internally, the purpose of this VR intervention was to take an otherwise static piece of underground equipment and provide a platform in which the department can safely visualize and demonstrate its functionality.

Figure 7: Physical winch area and VR winch simulation

These physical components exist in the real world with students capable of inspecting (digitally and physically) the different winch elements, gauging each element's size and physical feel. The corresponding digital intervention provides the link in showing how this specific piece of equipment functions and operates. This digital tool is employed using an Oculus (now known as Meta) quest HMD. The HMD itself is wireless. Within the HMD, software was created to allow students to engage with each leaver on the winch and visualize its operation in 3D virtual space. The simulation features a digital replication of the physical winch environment. The simulation uses the HMD's hand tracking technology. The HMD detects the position and orientation of the user's hands and configures itself to the movement of each finger. Once detected, the software replicates the exact hand movement of the user within this virtual simulated environment. As the virtual winch area is hosted on a server, an accompanying mobile application allows for mobile users to view the VR winch operator's actions in virtual space. This is accomplished via internet connection through the mobile platform.

3.3.2 VR Drill Rig

The Simulacrum features a virtual reality drill rig, created and implemented by a South African virtual reality company known as STS3D. The rig itself is based on a Sandvik double boom drill rig (Model DD321) [18]. The drill rig's design was to teach and assess operators in regards to correct drilling methods [18]. Internal use allows students to visualize and interact with the machine's various functionality, drilling methods and components as well as learn how the operation (or mis-operation) of said machine directly correlates to problems encountered when inappropriately used. Furthermore, it provides a risk-free environment in which to learn, experiment and operate the rig. The use case of this simulated experience is simple, the more one interacts with something the easier problem solving can occur when issues arise. This is in large part due to the student's previous interactions (active hands-on experience) coupled with, or informed by, a theoretical framework (knowledge brought from classwork and applied under realistic conditions).The rig's operation is tied to two consoles (Figure 8) located within the designated drill rig area of the Simulacrum. The consoles feature various levers, switches, dials and buttons that, when interacted with in the physical world, provide the user the corresponding mechanical functionality of the drill rig, in the virtual world. The rig is displayed through a Vive Pro HMD which provides a 360-degree 3D underground drilling experience. It also features a leap motion attached, which tracks the user's hand movement inside virtual space.

Figure 8: VR Drill Rig internal virtual environment and external setup/ operation

Built into the software are two core modes, assessment and arcade. The simulation allows the user to practice various drilling methods and allows for the triggering of various hazardous scenarios. Practices such as crosscuts, incline and decline drilling patterns as well as drill alignment to the marked area are all featured within the simulation. It also features a helpful UI panel in which the user's active inputs are visually relayed back to them. Components of the rig adhere to real world physics properties therefore, providing a faithful representation of the rig's reaction with the geological environment underground [18]. As such, misuse of this machine results in visible structural damage to the component/s in real time. The drill rig's placement within the Simulacrum was purposefully set in order to provide a layered user experience. The sense of feeling the crunching sound of the earth below them when they move, the moisture in the air due to the humidity as well as the smell of dust all coincide to create this vivid underground drilling experience.

3.3.3 VR Blast Wall

This experience (developed by STS3D) is located opposite the VR drill rig and is featured within its own designated area of the mine. The simulation is enabled through a Vive Pro headset connected to a PC which runs the VR software. There are base stations (Vive infrared cameras) attached to the adjacent walls which track the user's position in virtual space via a sensor attached to a helmet. As shown in Figure 9, the face of this digital tunnel is projected onto a screen, in front of the user, at which point they can physically interact with it by touching the screen with the controller. The software allows the user to mark the face of a development or a stope, set up charges for blasting as well as time the blasting sequence. A Vive Pro controller acts as both a spray paint can and a cursor to place charges or set the blast sequence. The user can make use of the Vive Pro HMD or the projector screen as a display.

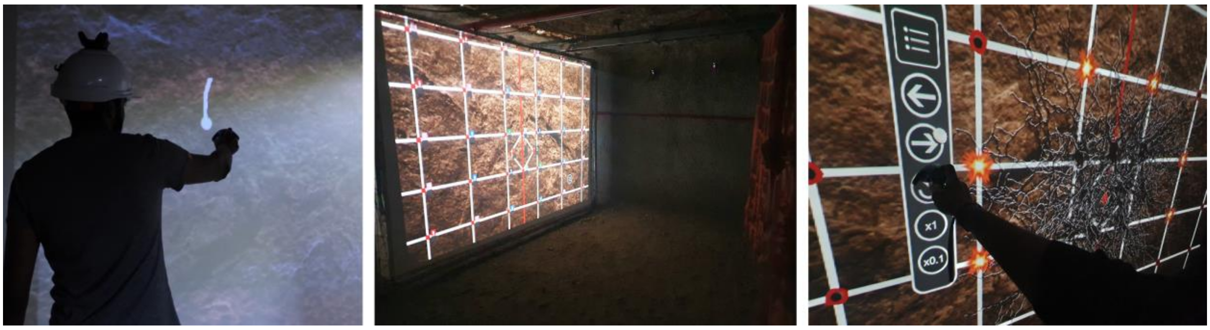

Figure 9: VR Blast Wall internal virtual environment and external setup/ operation

The Blast Wall's presence within the Simulacrum was to encourage a heightened VR experience (increased level of immersion) much like the drill rig. The audio feedback via the speakers behind the screen adds a further dimension as the vibrations and blaring sound of the blast echo through the tunnel. The benefits of this tool as a device for teaching is that students can repeatedly mark and blast in a safe environment. For educators, the ability to demonstrate various marking patterns and procedures allows for a more in-depth learning experience as they can show students the results of correct blasting methods and the inefficiencies related to missing a blast or blasting incorrectly.

4. Application of the Simulacrum Platform

4.1 Application to Skills Development

4.1.1 Relevance to Mining Engineering

The following summarises the relevance of the Simulacrum to skills development for mining engineers:

- Puff-Puff test: Test in which the effectiveness of the ventilation system is assessed through visual inspection of the time taken for a puff of smoke to move between two designated points.
- Ventilation design: Used to support design projects for mining engineers in order to optimise the ventilation system in an underground mine. This is particularly useful when considering that many operations in South Africa are undergoing a change from diesel to electric equipment which affects temperatures, diesel particulate matter and operating efficiencies.
- Drill-rig training: Used for training on multiple types of equipment found underground such as Drills, LHDs, Support equipment etc.
- Blast-wall training: Training on the blasting process with respect to blast hole patterns and sequenced timing of the explosives. This can contribute to students obtaining their blasting ticket in the working environment.
- Scraper and winch operation: Training on setting up and operating a winch underground. This is useful for identifying and relaying best practices across various mine types.
- Safety training for rescue chamber: Used for safety training with respect to inspection.

- Setting up and inspection of support packs in-stope: This is crucial for setting up support in the working area in which heavy machinery may not have access, typically in conventional or hybrid mining.

4.1.2 Relevance to Mine Surveying

The mine simulation provides Mine Surveying students with a realistic recreation of a mine to learn and develop skills in underground specific mine surveying applications, including:

- Visual representation of common excavation dimensions and structures to be encountered in a mining environment.
- Establishing three-dimensional survey control in the hanging wall and sidewall of the excavations
- Laser scanning of the tunnel, shaft, geology and stope simulation for the purpose of mapping and forensic surveying. Laser scanning is done using terrestrial, aerial and robotic quadruped (Boston Dynamics' Spot) platforms.
- Post graduate studies in creating virtual reality visualization of various mining layouts from laser scanning point clouds.
- Establishing shaft sinking survey control in the vertical shaft.
- Mapping geology and mine sampling simulation in the geology section where standard platinum and gold reef geology combined with faults and dykes have been created. These exposures are to be linked to virtual boreholes in order to create a virtual extension of the ore bodies for resource estimation.
- Marking-up of excavations using survey controls and aligning these markups with survey designs and layouts.

4.2 Technology Development: Low-Cost, broad applications

Here the function of these items is very much related to low cost in terms of integration time, useability, widespread availability as well as development cost. A simplified version of an AR Drill Alignment experience exists within the Simulacrum (Figure 10). This mobile version allows any user to download the app to their phone in order to view drill alignment within a rock face. This model provides a basis for further augmented reality experiences to be implemented into the mine. Such as an opportunity for students and lecturers to contribute meaningfully towards this shared learning environment by allowing tangible digital information from any real world setting to be brought into the mock mine. This can be done via low cost data capture such as photogrammetry which is then used to create 3D meshes of these real world items and have them be hosted at various display points.

Multiple digital twins have been created from various different data sets of the Simulacrum. The benefit is having a digital model of the real-world representation, which can be manipulated and used in various ways. The implementation of this digital twin allows for a real-time monitoring system of the physical mine. As the Simulacrum features WIFI throughout, real-time presence of any individual can be captured through a mobile application acting as individual trackers throughout the mine. Going one step further, capability was added that allows multiple users to share the virtual Simulacrum at the same time. This intervention is now seen as low cost as any tools or objects that need to be digitally imported within the virtual mine can be done in a timely manner, then manipulated and visualized.

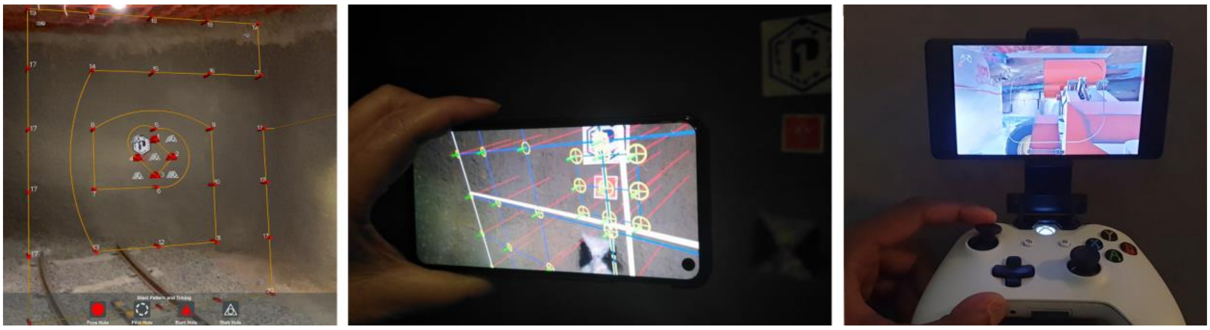

Figure 10: Simple AR Drill Alignment experience and virtual LHD simulation inside Simulacrum digital twin

The digital twin also allows for interventions where the mine is being placed into the hands of anyone with a mobile phone. Furthermore, lecturers can contribute towards their own classes or research by simplifying complex machinery and process into more streamlined, user-friendly solutions such as the use of commercial gaming devices. As shown in Figure 10, an Xbox controller is used to manipulate an LHD within the digital twin of the Simulacrum. This intervention can serve as a steppingstone for students by starting out on a gaming controller and gradually moving towards a fully functioning virtual rig which simulates the real-world counterpart identically. This provides an opportunity for students' knowledge to progress with the complexity of the equipment.

4.3 Support of Research and industry collaboration

4.3.1 Boston Dynamics Spot and Leica Integration

The Simulacrum was also used to support Research and Industry collaborations. It enabled University postgraduates to conduct their research without having to frequently visit mine sites, and served to integrate the application of industry solutions with research being done at the University. An example of this was an MSc project which focussed on 3D laser scanning and photogrammetry applied to accident and fatality data capture (Figure 11). The project involved implementing a LiDAR scanner onto a mobile robotic platform (Spot built by Boston Dynamics), to facilitate autonomous inspection of a simulated fatality on a mine (avoiding the need to send humans into a dangerous environment).

A test day was set in which representatives from Leica and the University collaborated to assess whether or not the set of technologies from different suppliers could be integrated to conduct an inspection. Initially Spot's on-board camera was used to survey the scene, then was attached with a Leica RTC 360 3D laser scanner, which was replaced with Leica's ARC

BLK connected to Spot CORE (Figure 11). The haulage, crosscut and stope in the Simulacrum provided the necessary environmental conditions with respect to ground conditions, spatial constraints, various lighting conditions and humidity that would be experienced in a real mining environment. The outcome from the assessment was that the robot could be retrofitted with 3rd party commercial systems to autonomously navigate and inspect dangerous underground environments. This exercise involved the training of students to setup and operate the robot, integrated with obtaining readings from commercial hardware. They had to also process the data obtained to make decisions on the safety conditions of the environment. In doing so, the Simulacrum provided the means to facilitate skills and knowledge transfer from Leica to the students as well as serve as a demonstration platform for Leica to representatives from mining companies, who were also present.

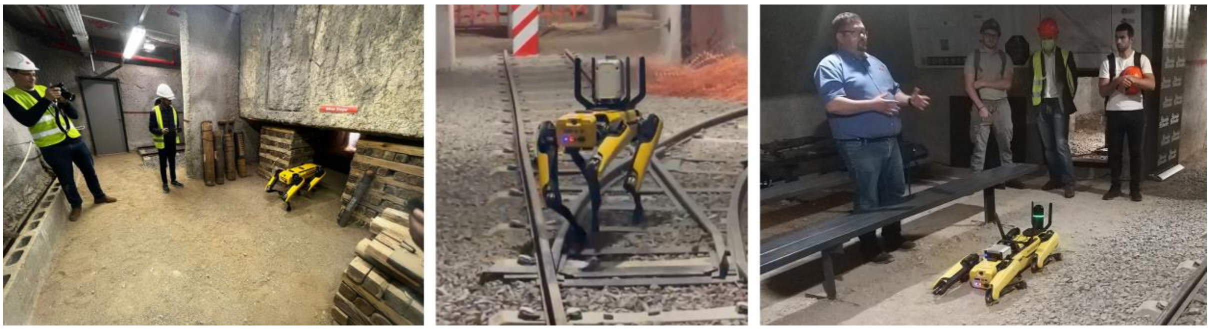

Figure 11: Use of the Spot robot integrated with Leica hardware to conduct underground inspections

4.3.2 Application of Inspection Drones

A similar application of the Simulacrum was performed in application to the operation of drones in underground mining environments. The focus of this exercise was to demonstrate and assess the inspection and visual data capturing capabilities of different UAV platforms. The drones featured a rugged exterior design with some having built-in lidar scanners and robust lighting for low light conditions, all of which needed to be showcased to prospective clients. As seen in Figure 12, the Simulacrum provided such conditions as Flyability’s Elios 2 and Elios 3, OPTRON’s AI controlled ExynAero and Flybotix’s Asio drone were all exhibited within the mine. In the case of OPTRON, operation within the Simulacrum helped them identify issues in regards to the drone’s clearance within the mine’s physical parameters. This discovery provided an opportunity for further functionality to be enabled that would allow the drone to initiate its take-off sequence within these constraints. Flyability and Flybotix’s drones feature a dust omitting lighting technology in which robust directional light is used to illuminate and omit dust particles from the drones’ camera [19], [20]. This mitigates impairment of the operator’s view. As the Simulacrum is a recreation of an underground mining environment, the extensive sand swept up by the drones’ propulsion was not a hindrance but a rather welcomed condition for this technology to be actively demoed, in real-time.

Figure 12: Application of the drones at various points in the mine

4.3.3 ProductONE's Drill Pattern Mark-UP AR Experience

ProductONE is a South African company that provides digital solutions to the local market whilst collaborating with international partners. The intention of this AR experience was to show that the process of underground mining and drilling mark-up could be modernized and improved. ProductOne's application features a range of different augmented mark-up tools that focus on face marking, enhancing operator training and establishing modern channels of real-time communication [21]. It provides further functionality to show the blast process, visualize the drill rod alignment within the actual physical rock face and show various mining infrastructure that is to be placed once blasting occurs. ProductONE's use of the Simulacrum was to test the accuracy of the application's implementation into an underground mining environment. The presence of these tools assist in directing internal University research, by demonstrating what exists in development as well as providing context towards future improvements in efficiency in modern mining techniques. More so as a tool for internal education purposes, it allows students a platform to visualize the underground drilling and blasting cycle in 3D space, before it even begins. The project was part of an initiative run by the Mandela Mining Precinct, supported by the Department of Science and Innovation and the Mineral's Council of South Africa.

4.4 Effectiveness of the Simulacrum

The primary purpose of the Simulacrum was to serve as a platform to enable technical demonstration, skills development, research and industry support for the mining industry in South Africa. It is difficult to quantitatively assess the effectiveness of the platform, however the following qualitative outputs were observed:

- The platform was demonstrated to mining engineering and mining surveying students from first year to third year level of the BEngTech Degree offered at the University. Students in the first year found the platform to be most useful in that it was their first exposure to a mining-related environment. Some students felt nervous, having to walk across the rail tracks with only their safety lights on their helmets. It was also observed that they were surprised by the weight of the rescue packs that they were required to wear whilst in the environment. The students in their second and third year of study had already been to a limited number of mine visits and were familiar with, but very surprised at the detail of the simulated environment. These students drew the most value from the AR and VR tools. In particular, they did not have prior experience with operating mining equipment nor the blasting process. They found it to be extremely useful in linking these concepts to real-world applications. The lecturers had also expressed their endorsement of the platform as it helped them to physically present use-cases from their industry experiences.

- The Simulacrum was also effective in facilitating demonstration of technologies from multiple suppliers and providing a common case study for the integrated application across vendors. An example of this was the integration of the Leica ARC on the SPOT robot dog which was aimed at assisting a proto-team in their search and rescue applications.
- A number of demonstrations were held at the Simulacrum, with executives from different mining companies present. These demonstrations presented a unique opportunity where the executives could relate the applications to the specific requirements of the mine-sites for which they were respectively responsible. Opportunities for applications on relevant mine-sites were then discussed and are currently undergoing trials. This could potentially lead to more research and funding opportunities for the Simulacrum stakeholders.

5. Conclusion

The South African Mining Industry is under pressure to undergo drastic changes with respect to digital transformation. There are a number of barriers to implementing these changes including infrastructure constraints, CAPEX availability, and lack of appropriate skills to function in a digitally transformed mine. The Simulacrum was developed as a platform to support skills development, research, industry collaboration and demonstration of relevant practices and technologies. Its design accommodates for various skill levels, simulated operation of various equipment in multiple mining environments and can accommodate multiple users simultaneously in virtual walk-throughs. These cyber-physical interventions are relatively new and are constantly being updated to maintain relevance. The Simulacrum was also designed to bridge the gaps between industry, the department and students associated with the UJ. It can therefore serve as a platform to support the development of currently needed and future skills for the mining industry in South Africa, with the focus on enabling low-skilled labour to engage with high level technologies.

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