A generic central information environment framework for mining operations - a plausible alternative

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Mines generate significant amounts of data, and this data must be converted into information that can be analysed to aid in decision making. Failure to acquire complete and accurate data timeously affects the entire mining value chain and possibly causes loss of opportunity for value creation. A general assessment showed that mines, in particular conventional mines, fail to adequately collect and convert data into useful and timeous information. Therefore, this paper explores the digital twin architecture as an alternative avenue in collecting and integrating data from various underground inter-related activities. This paper focuses on the entry level transformational technology that can be used by an underground mechanised mine to collect, store, and use data to improve processes and decision making. Furthermore, a functional software prototype has been developed to demonstrate how the envisaged digital transformation can be implemented in a mining environment.

INTRODUCTION

The mining industry has been conservative in its adoption of digital technologies. However, it is undergoing transformation towards the adoption of digital technologies to improve mining processes along the mining value chain. This process is generally referred to as digital transformation and is characterised by digital mining employing technologies such as automation, machine learning, a digitally enabled workforce, system integration and digital twin. Information generated, collected, and processed by these technologies through various enabling software interfaces is of the magnitude that requires data science capability to enable real-time value-adding decision making; all with the primary objectives of maximising value, promoting health and safety, and saving the planet (Odendaal, 2019). The upside of digital transformation is that under current technologies the quality of decisions made on the mines can be improved by approximately 20% to 30% (Deloitte, 2018). However, challenges that a mine might face with digital transformation are lack of competencies, goal ambiguity, technological constraints, and external constraints (Dragičević, and Bošnjak, 2019).

Successful digital transformation of the workplace is dependent on the mindset of the workforce, that is, the workforce must embrace new technologies and accept that changes brought about by digital transformation are associated with new and sometimes completely different work routines (Bulbulia, 2019). However, the entrance of Generation Y (millennials) in mining industry in the not distant future will eliminate the challenges related to adoption of digital technologies, as this generation is familiar with the usage of digital technology in their daily life compared to the older, more traditional mine workers. Figure 1 shows a typical mine value chain and transformational digital technologies that can be implemented along the value chain.

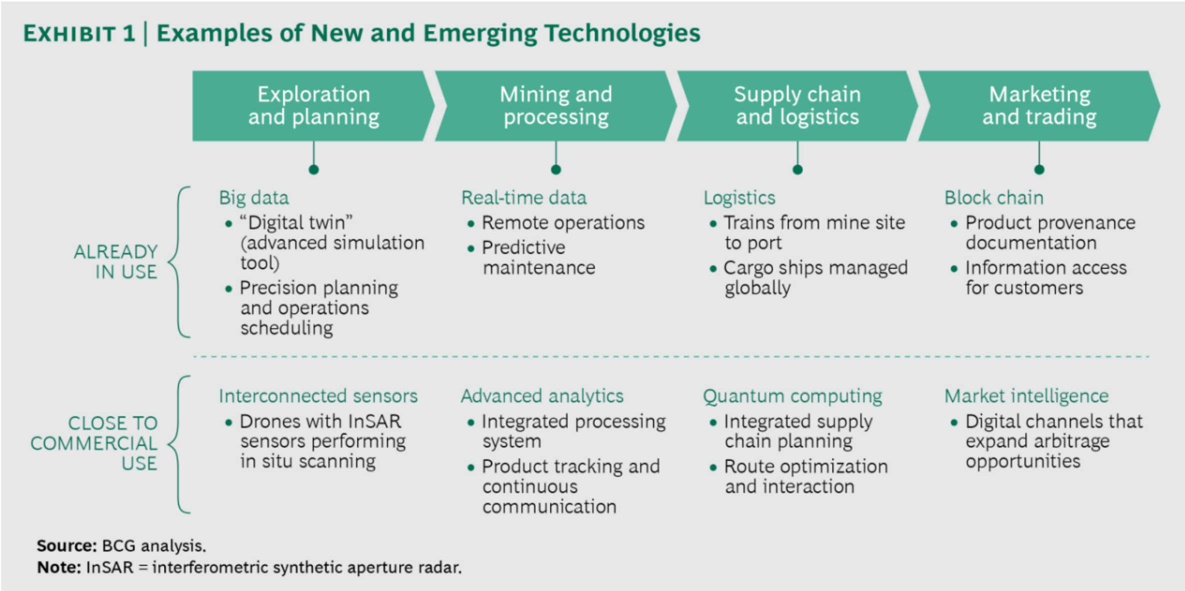

Figure 1. Existing and probable digital technologies along the mine value chain (Tauber, et al., 2018).

The rate of digital transformation is not uniform in the mining industry, with some mines using some of the technologies indicated in Figure 1, while others are still locked in non-digital technologies. As it can be seen in Figure 1, there are various digital technologies that are in the process of being commercialised for use in the mining industry. The difference in the rate of adoption of digital technologies gives rise to a digital divide, with mines that are categorised as conventional mines generally lagging behind mines categorised as modern, while digital mines are ahead of the pack.

In this era for mines to remain competitive, they must embrace the digital culture where data is ordered in real-time such that decisions can be made timeously (Australian Mining, 2019). Figure 1 indicates that big data analysis, real-time monitoring and tracking, logistics, and blockchain technologies are already being used in the mining industry to varying degrees. It should be stated that the mining industry is benefitting from the lessons learnt in other industries such as manufacturing, oil, and gas where digital technologies have been applied with greater success (Deloitte, 2019).

According to Ernst & Young (2021), inadequate investment in digital technologies and innovation was considered as one of the top business risks for mining in 2021. It was observed that mines that have adopted automation and remote operation centres' technologies have fared better than those lagging behind in adoption during the COVID-19 restrictions. In this respect, it is not surprising that mining companies are planning to invest more in data mining, cloud computing, operations intelligence, and digital asset management, among others in the coming five years. This investment is aimed at ensuring that mines gain a better understanding of their operations and improve process efficiencies along the mine value chain. However, with digital technologies there is always the presence of cybersecurity risk which must be mitigated, as in any other industry (Accenture, 2016; Ernst & Young, 2018a).

DIGITAL MINING

A digital mine can be described as a mine where integrated digital technologies akin to technologies mentioned in Figure 1 are used to plan, manage, monitor, and report on all business aspects along the mine value chain. For existing mines to attain this state, they will have to embark on digital transformation. Stolterman and Fors (2004) cited in Dragičević and Bošnjak (2019, p. 73) defined digital transformation as a "business model driven by the changes associated with the application of digital technology in all aspects of human society". Mining exists within society; therefore, digital transformation is a strategically chosen business model to transform conventional and modern mines into digital mines.

Klein and Walsh (2017) identified five key features in operational processes of digital mines as automation and remote operation, real-time data capture, digital twins (particularly digitised data of geology, engineering, and assets), drones, and wearables. In this paper, the focus is on digital twin technology as one of the processes to digitise mining operations.

Digital twin

The concept and hence the definition of the digital twin technology has evolved over the years from twin entities in two different spaces, that is the laboratory space and the real world, to a now increasingly accepted definition involving twin physical and cyber entities. The digital twin emerged around early 2000s as a concept proposed by Michael Grieves and is one of the emerging technologies enabled by the fourth industrial revolution (4IR) (Fuller *et al.*, 2020; Son *et al.*, 2022). Fuller *et al.*, (2020) described the digital twin as a technology that integrates the digital and physical worlds effortlessly, enabled by 4IR related technologies such as data analytics and the internet of things. Fundamentally, a digital twin architecture, as shown in Figure 2, consists of a physical space, cyber-space, and communication interface that allows for flow of information between the two spaces. In addition, there must be provision for data authentication, security, and information visualisation (Botín-Sanabria *et al.*, 2022; Son *et al.*, 2022).

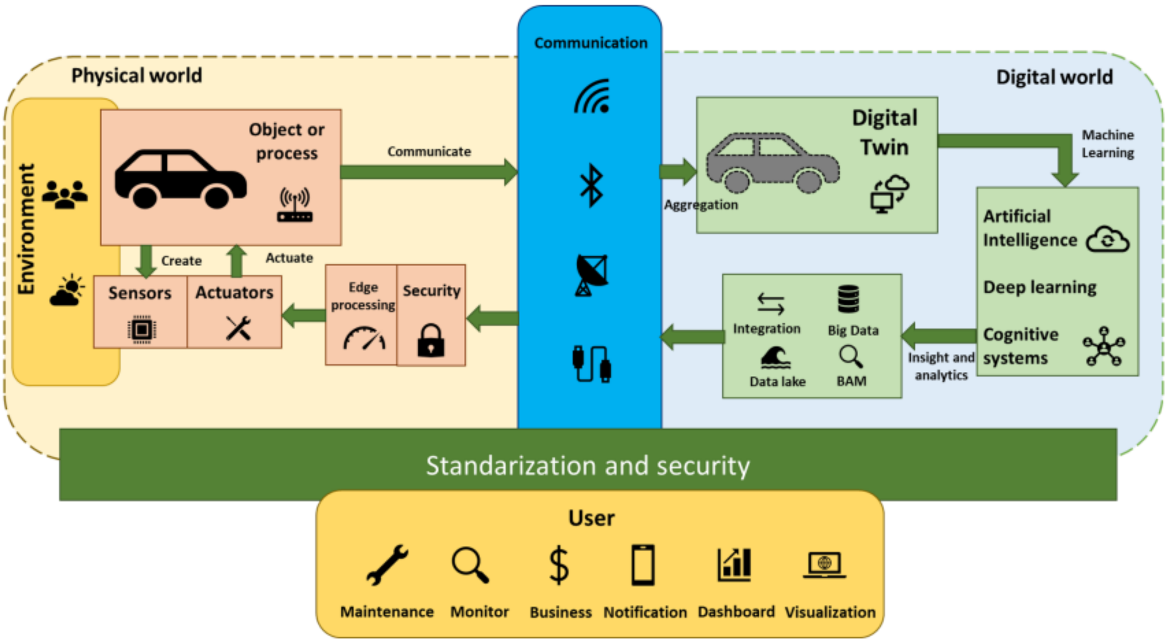

Figure 2. The digital twin technology architecture (Botín-Sanabria et al., 2022).

Fuller *et al.*, (2020) and Botín-Sanabria *et al.*, 2022 described the digital twin as having three integration levels: namely digital model, digital shadow, and digital twin. In the digital model integration, data flows unidirectionally from the physical twin to the cyber twin. The physical twin and cyber twin are not automatically linked, meaning that there is a high level of human intervention with respect to information input and flow. In the digital shadow integration, data flows unidirectionally from the physical twin to the cyber twin; however, the link between the twins is automatic, with very little human intervention. In the digital twin integration, the data flows bi-directionally between the physical twin and the cyber twin with automatic data linkages and very little human intervention. It can be said that the digital twin integration is a highly automated and technological advance mode which allows changes in the cyber twin to effect changes in the physical twin and vice versa.

While the benefits of the digital twin model integration and by extension, the digital mine, are obvious and attractive, it is however difficult for some conventional and modern mines to achieve this state due to several constraints such as sunk capital; entrenched working routines and culture; mindset of management and/or workforce which in most cases is not in sync with executive mindset, and fear of the unknown to some extent. To this effect, Ernst & Young (2018b) proposed a pragmatic transformation pathway of adopting a structured wave approach.

This approach entails starting with groundwork in preparation for the first wave. The groundwork entails formulation of a business strategy, organisational assessment, change management, and investment in fundamental infrastructure and essential technology. The first wave entails optimising current business processes, and, where opportunity exists, modernise processes through automation for example. The first wave is not necessarily transformational, but it is undertaken with a view to transforming the mine in subsequent waves. The second wave is transformational in the sense that digital technologies are used to remodel processes and culture. While there is an integration along the mine value chain, the emphasis is still on achieving best practices in various activities and nodes that make up the mine value chain. The third wave is focused on disrupting the business model where digital technologies are used to disrupt how inputs are sourced, acquired, and processed, and how outputs are sent to the markets. This disruption extends to all factors of production with the view of maximising value, promoting health and safety, and being environmentally sensitive (Ernst & Young, 2018b).

This paper is centred on technology at digital model level during the first wave. The focus is on the entry level 'transformational' technology that can be used by an underground mechanised mine to collect, store, and use data to improve processes and decision making through what we call a central information environment for mining (CIEM).

Central information environment for mining

The CIEM is a data repository space which can be hosted on-site, off-site or in the cloud. As envisaged in this paper, it can be used in the first wave transformation to usher a non-digital mine into a digital mode. This can be illustrated through a CIEM database where all departments in the mine are required to log their daily information in the CIEM. The CIEM database is compatible with devices such as cellular phones, personal computers, etc. The information in the CIEM can be viewed by all cleared employees but can only be logged by the responsible persons. There are various departments at an operating mine such as mining (e.g., development and production), rock engineering, geology, mine planning, mineral resource management, engineering, health and safety, survey, and security.

These mining departments work together to carry out different tasks to ensure that the mining operation yields the maximum economic value from the mineral deposit. Therefore, it is important that the sharing of information in a mining operation is simplified and optimised, hence the adaptation of the CIEM is vital for mining operations. The CIEM operation is illustrated by using the mining department as an example. It is important to note that the data collected by mining operations vary from mine to mine.

Figure 3 shows the landing page of the CIEM where the user can select the appropriate department to access and/or capture information. Furthermore, background about the mining operation can be recorded under the 'About' tab. An illustration of one of the departments is shown in Figure 4 where a mining department was selected.

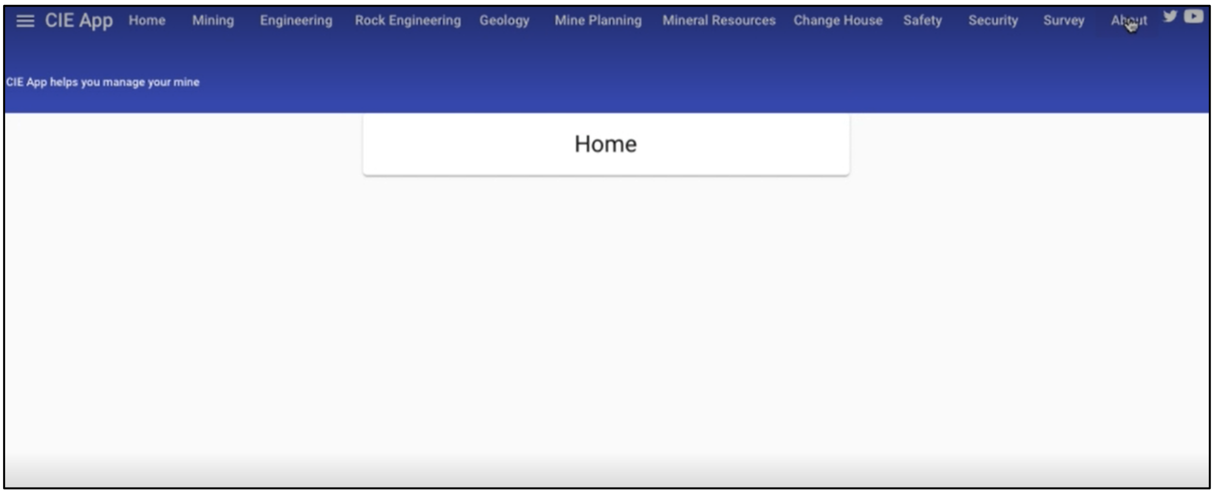

Figure 3. Central information environment landing page.

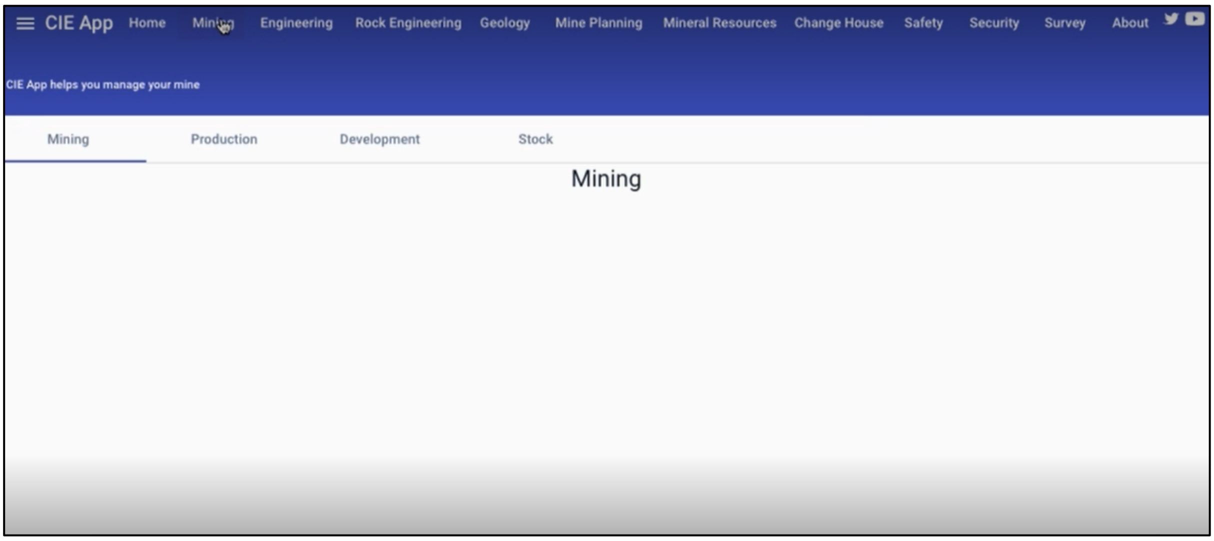

Figure 4. Selection of a mining department.

Under the 'Mining' tab, the user can select to view or update information about production, development and/or stock inventory. For illustration purposes, production was selected, the user is then required to choose a section of interest as shown in Figure 5. Once a section has been selected, there are various options that are displayed such as stope reports, construction, equipment, production report, purchase and costs, and tip and section conveyor.

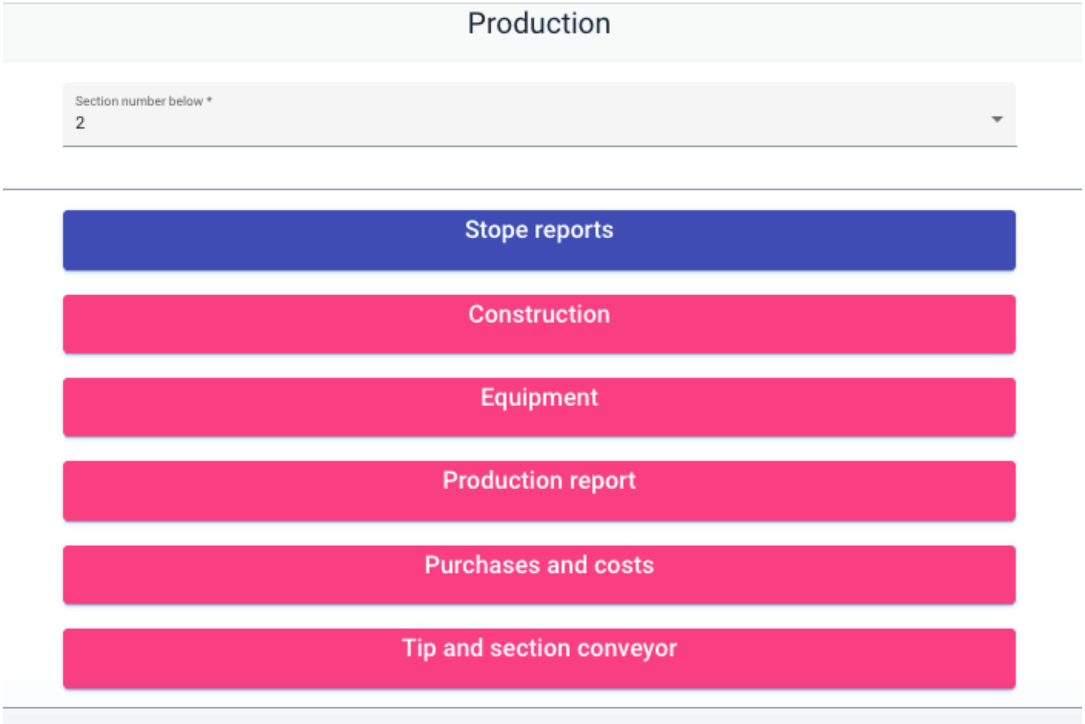

Figure 5. Selection of the area of interest.

Figure 6 shows the various choices the user can access and/or update for a specific section once the 'Stope reports' option has been selected. Figure 7 presents the section specific information that needs to be recorded by the miner when the 'Miner's logbook' option is selected. Under the Miner's logbook tab, the various information needs to be captured such as blasting, drilling, mucking, support, and crew complement. The miner can also access section-specific instructions from the shift supervisor and mine overseer through the 'Reports' tab.

Figure 6. Stope reports for a section.

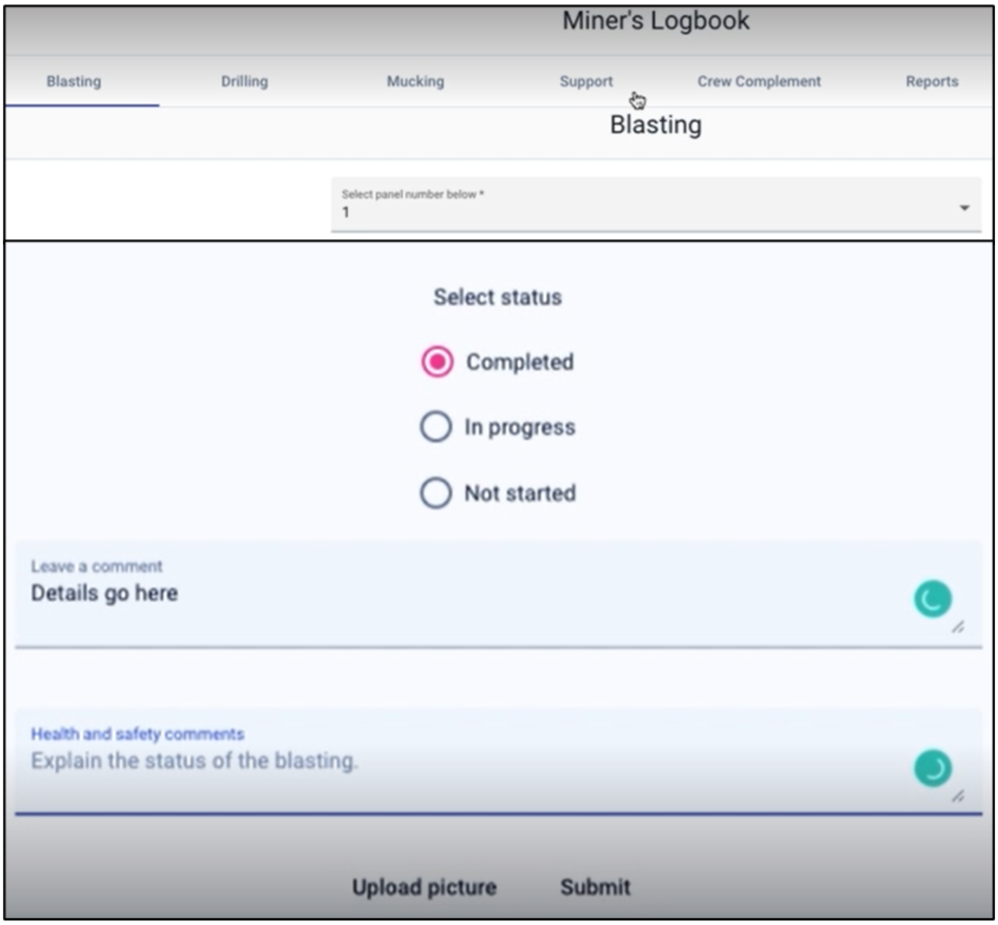

Figure 7. Miner's logbook.

Figure 7 shows that the miner can update the status of each panel in the section. Furthermore, the mine is expected to provide general operational comments about each panel under the 'Leave a comment' box. The miner is also required to provide the health and safety status of the panel and can upload pictures to provide a visual of the working area to aid in decision making for the next crew and/or the line management. Once all the information related to the panel has been captured, the miner must click on the 'Submit' tab. Once the information has been submitted, the miner is unable to make changes. This inability to edit ensures the integrity of the data.

Figures 3 to 7 illustrate a generic CIEM for a mining operation. However, different mining operations have different structures and types of data to be captured. Therefore, this generic CIEM can be adapted to be mine-specific.

CIEM development approach

The automation of the CIEM followed an Agile software development methodology. This methodology covers many software engineering techniques and is premised on the idea of ensuring the timely development and delivery of software products. In this paper, rapid prototyping and iterative development were used because they are the main aspects of the Agile methodology.

In addition, a client server-based architecture was used for the implementation of the CIEM. Therefore, the CIEM software requires server(s) from which users on diverse platforms can access the application. Different technologies are used in the implementation of the server and client/user components. In our case, Python and PostgreSQL were used for coding and database development on the server side. While on the client side the single page architecture was used for web, desktop, and mobile user platforms.

This software application design approach was selected to ensure that the following principles are adhered to:

- Data integrity: no unauthorised users can make changes to data once captured.
- Ease of use: the application can be accessed on multiple devices and has an intuitive user interface.
- Scalability: the application can support as many users as necessary with minor adjustments.
- Customisation: the application can be easily adopted to suit the mine's needs.

CONCLUSIONS

In the 4IR era, it is imperative for mines to integrate relevant technologies into their business processes to maximise, among others, goals of financial and value benefits, health and safety along the mine value chain and social and environmental harmony. While digital integration is relatively easier to achieve in newly designed and developed mines, it is challenging and complex to achieve in old mines that do not have adequate infrastructure to support digital technologies.

This paper proposed the use of CIEM as an entry point towards digital transformation for mines that were not designed with digital technology in mind, at least not on the scale witnessed under 4IR. The CIEM is a data repository space that can enable conventional mines to rapidly achieve digital model mode in some of their mining activities. This was demonstrated by developing a CIEM software using a hypothetical mechanised narrow reef mine as a case study. The software was developed using the Agile methodology with client server-based architecture such that it can be accessed by users on different platforms. Furthermore, the CIEM was developed with the principles of data integrity, ease of use, scalability, and customisation.

REFERENCES

Accenture, 2016. Digital Mining. [Online] Available at: https://www.accenture.com/_acnmedia/pdf-26/accenture-resources-digital-mining.pdf
[Accessed 29 July 2019].

Australian Mining, 2019. Future of mining - digital transformation as a journey. [Online] Available at: https://www.australianmining.com.au/news/future-of-mining-digital-transformation-as-a-journey/
[Accessed 29 July 2019].

Botín-Sanabria, D.M., Mihaita, A.-S., Peimbert-García, R.E., Ramírez-Moreno, M.A., Ramírez-Mendoza, R.A., Lozoya-Santos, J.d.J., 2022. Digital Twin Technology Challenges and Applications: A Comprehensive Review. *Remote Sensing*, 14(6), 1335, pp. 1-25.

Bulbulia, T., 2019. Mining industry on the cusp of digital transformation. [Online] Available at: https://m.miningweekly.com/article/mining-industry-on-the-cusp-of-digital-transformation-2019-09-13/rep_id:3861
[Accessed 18 October 2019].

Deloitte, 2018. Intelligent Mining Delivering Real Value. [Online] Available at: https://www2.deloitte.com/content/dam/Deloitte/cn/Documents/energy-resources/deloitte-cn-eri-intelligent-mining-en-180910.pdf [Accessed 25 July 2019].

Deloitte, 2019. Deloitte Global mining report explores key trends in 2019. [Online] Available at: https://www2.deloitte.com/cn/en/pages/about-deloitte/articles/pr-deloitte-tracking-the-trends-2019-future-of-mining.html [Accessed 20 June 2019].

Dragičević, Z. and Bošnjak, S., 2019. Digital transformation in the mining enterprise: The empirical study. *Mining and Metallurgy Engineering Bor*, No. 1-2, pp. 73-90. doi:10.5937/mmeb1902073D

Ernst & Young, 2018a. Is riding the digital wave key to wiping out your competition? [Online] Available at: https://www.ey.com/Publication/vwLUAssets/ey-digital-mining-the-next-wave-of-transformation/$File/ey-digital-mining-the-next-wave-of-transformation.pdf [Accessed 18 October 2019].

Ernst & Young, 2018b. Digital mining: the next wave of business transformation [Online] Available at: https://assets.ey.com/content/dam/ey-sites/ey-com/en_gl/topics/mining-metals/digital-mining-the-next-wave-of-transformation.pdf. [Accessed 14 May 2022].

Ernst & Young, 2021. Top 10 business risks and opportunities for mining and metals in 2022. [Online] Available at: https://assets.ey.com/content/dam/ey-sites/ey-com/en_gl/topics/mining-metals/ey-final-business-risks-and-opportunities-in-2022.pdf [Accessed 11 May 2021]

Fuller, A., Fan, Z., Day, C. and Barlow, C., 2020. Digital Twin: Enabling Technologies, Challenges and Open Research. *IEEE Access*, Vol. 8, pp. 108952-108971. DIO: 10.1109/ACCESS.2020.2998358

Klein, P. and Walsh, S., 2017. The digital mine: What does it mean for you? Deloitte Touche Tohmatsu. Available at https://www2.deloitte.com/content/dam/Deloitte/au/Documents/energy-resources/deloitte-au-er-digital-mine-030817.pdf. [Accessed 14 May 2022]

Odendaal, N., 2019. SA mining adopting, driving 4IR as its transformation journey continues. [Online] Available at: https://www.engineeringnews.co.za/article/sa-mining-adopting-driving-4ir-as-its-transformation-journey-continues-2019-06-21 [Accessed 18 October 2019].

Son, Y.H., Kim, G., Kim, H.C., Jun, C., and Noh, S.D., 2022. Past, present, and future research of digital twin for smart manufacturing, *Journal of Computational Design and Engineering*, Vol 9, No. 1, pp. 1–23. https://doi.org/10.1093/jcde/qwab067

Tauber, M., Bender, J. P. and Steinberg, A. S., 2018. The New Technology Frontier in Mining. [Online] Available at: https://www.bcg.com/publications/2018/new-technology-frontier-mining.aspx [Accessed 18 October 2019].

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