Sociotechnical perspectives of digital technologies in sustainable mining

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Abstract

This paper adopts an interpretive case study approach to understand the role of digital technologies in addressing seemingly contradictory sustainability goals in mining. The sociotechnical model of information systems was used as a framework to guide the analysis of twenty-five in-depth interviews with globally dispersed digital technology experts working collaboratively at an industry-leading hi-tech mining solutions company. The sociotechnical-led thematic analysis findings highlight the trade-offs experts face in balancing narrow technological imperatives and economic outcomes with broader sustainability goals. The analysis moves beyond the technological and economic to a harmonious perspective of social, human, environmental, and technological interactions. A visual thematic map is presented to aid practitioners in designing and optimally implementing digital technologies to simultaneously address the United Nations Sustainable Development Goals while prioritising business sustainability. We conclude by drawing from the proposed sociotechnical perspectives approach for digital sustainability to provide scholars with possible pathways for future responsible information systems research.

Keywords: Case study, Digital mining, Digital sustainability, Sociotechnical, Sustainable development goals, Thematic analysis.

1 Introduction

Recently, scholars have called for Information Systems (IS) researchers to address the need for society to transition to a more sustainable approach to sociotechnical IS (Nishant et al., 2020; Pan and Zhang, 2020). Together with these calls, an increasing amount of responsible IS researchers' studies have urged for IS to contribute to the practice of sustainability and innovate new approaches for academia, policymakers, and industry-based practitioners to contribute to sustainable development (Nishant et al. 2020; Khuntia et al. 2018; Seidel et al., 2017). Digital technologies present both an opportunity and a challenge to the United Nations (UN) Global Sustainable Development Goals (SDGs) (United Nations, 2023).

This opportunity and challenge highlight the predicament of balancing narrowly focused business objectives against the need for social and environmental sustainability for IS leaders and practitioners (Carberry et al., 2019; Linkov et al., 2018; UN, 2023; Winter et al., 2011). In recent discussions, responsible IS research scholars focusing on broader societal benefits continue to address digital technologies' growing ethical, moral, legal, and environmental challenges (Davison et al., 2019; Kotlarsky et al., 2023; Pan & Zhang, 2020; McCarthy et al., 2020). We contribute to this debate by studying an essential contextual space – the role of digitalisation on sustainability in the mining industry (Chiasson & Davidson, 2005).

Digital technologies can support and transform mining activities, from prospecting, exploration, construction, operation, maintenance, expansion, abandonment, and decommissioning to repurposing and remediation (Haddaway et al., 2019). Recent studies carried out by Barnewold and Lottermoser (2020) and Young and Rogers (2019) confirm that various digital technologies currently used in mining practices are revolutionising the industry in several ways. For instance, implementing automation technologies, such as autonomous haul trucks and remote-operated drilling rigs, are being used to enhance operational efficiency while reducing worker safety hazards, data analytics and big data are being used to analyse geological data for better site exploration, predict equipment failures, and optimize operational parameters, the Internet of Things (IoT) is transforming mine operations through real-time monitoring of equipment and environmental conditions, artificial intelligence (AI) and machine learning algorithms are being employed to interpret vast datasets for pattern recognition in mineral exploration and for predictive maintenance, remote operations and control systems are enabling the management of mining equipment and operations from a distance, which is particularly beneficial in hazardous or remote locations, 3D modelling and simulation tools are providing accurate visualizations of mining operations for improved planning and risk management, environmental monitoring technologies are playing a crucial role in assessing the impact of mining activities and ensuring compliance with environmental regulations (Barnewold & Lottermoser, 2020). Additionally, blockchain technology is enhancing supply chain transparency and traceability (Young & Rogers, 2019). Last but not least, the adoption of wearable technology for worker safety is enabling real-time health monitoring and environmental awareness for on-site employees. These technological advancements are optimising mining processes and contributing to a shift towards safer, more environmentally conscious, and sustainable mining practices (Young & Rogers, 2019).

Building upon the aforementioned applications of digital technologies in the mining industry, we define digital mining as the comprehensive integration and use of digital technologies to transform mining operations. This definition aligns with Young and Rogers (2019), who emphasise the transformative impact of digital solutions on traditional mining practices. The concept of digital mining represents a paradigm shift in how mining operations are conducted, marking a move from traditional, labour-intensive methods towards a more technology-driven, automated, and data-centric approach (Barnewold & Lottermoser, 2020). The shift to digital mining is not merely about the adoption of new technologies. It is also about a fundamental change in mining philosophy that embraces a holistic approach where efficiency, safety, and environmental sustainability are not seen as separate objectives but as interconnected facets of a modern mining operation (Aznar-Sánchez et al., 2018).

While there have been marked improvements in social and environmental sustainability, the mining industry is still plagued by negative environmental impacts such as deforestation, erosion, contamination of water resources, increased noise levels, dust and emissions (Haddaway et al., 2019). Mining also has a negative social impact on public health, living standards, the human rights of indigenous peoples and local communities, and land conflict (Moran et al., 2014). With the rapid adoption of digital technologies throughout the mining value chain, the mining industry increasingly relies on digital technology to support business goals (Sganzerla et al., 2016). However, digitalisation can yield positive and negative social and environmental impacts – it can alleviate or exacerbate the abovementioned social and ecological concerns. The concept of sustainability, like development, can guide future research and offer contributions that can help make a better world (Walsham, 2012; Qureshi, 2015). We agree with this important, future-oriented conceptualisation of sustainability and the pivotal role of IS in addressing and shaping new social and environmental concerns (Pan et al., 2022; Melville, 2010). According to the World Commission on Environment and Development (WCED) (1987, p. 43), sustainability can be defined as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs.” Similarly, Morelli (2011) defines sustainability as ensuring that resource needs do not negatively impact ecosystems. Gladwin et al. (1995) view sustainable development as an inclusive and equitable process to achieve human development goals. Meanwhile, Hart and Milstein (2003) view sustainable enterprises as contributing simultaneously to the triple bottom line (people, planet and profit) that addresses economic, social, and environmental benefits.

Although IS research has promoted sustainable development goals in research streams, such as green IS and IT for development (Davison et al., 2019; Roohy Gohar & Indulska, 2020), existing research perspectives have not explicitly applied a sociotechnical perspective to frame their conceptualisation of digital sustainability (Sarker et al., 2019; Gholami et al., 2016). Scholars have found that IS studies tend to focus either on a critique of technology appropriations to achieve the organisation’s narrow instrumental goals or promote the organisation’s broader social responsibility and humanistic goals (Kotlarsky et al., 2023; Watson et al., 2010). While the IS literature tends to treat the social and technological aspects of digital sustainability separately, we agree with those scholars who argue that it is crucial to explicitly consider the interplay of both elements in designing sustainable information systems (Petrini & Pozzebon, 2009; Seidel et al., 2013). Following the reasoning of Sarker et al. (2019), a sociotechnical perspective of digital sustainability privileges neither technology nor human activities in shaping sustainability practices but seeks to account for the interplay between social and technological systems. Therefore, a sociotechnical perspective offers a way of considering the interrelationships and interactions between IS and the human and nonhuman actors as part of a larger ecosystem (Kotlarsky et al., 2023; Watson et al., 2010) rather than overemphasising the IT artefact or focusing exclusively on the social responsibility of organisations (Cooper & Molla, 2017; Tim et al., 2021).

In doing so, we substitute the anthropocentric and engineering-centric term of ‘optimisation’ that tends to dominate current sociotechnical perspectives with the systems and ecological concept of ‘harmony’ to emphasise the importance of the experiences of humans and their interactions among human communities, the inseparable interrelationship of humans and nature and the respect, regeneration and balance with the natural environment (Meadows & Randers, 2012; Steffen et al., 2015; United Nations, 2023). Whereas optimisation focuses on efficiency and effectiveness within specific parameters, harmonisation seeks a balanced and integrated approach that considers a wider range of factors, including long-term sustainability and diverse stakeholder needs (Steffen et al., 2015; Washington, 2018). After all, a so-called optimised digital mining solution risks producing a discordant effect on the overall system. Therefore, the core research question guiding our investigation in this paper is:

How can an expanded sociotechnical perspective enrich our understanding of the role of digital technologies in sustainable mining?

In this paper, we apply a sociotechnical perspective supported by a social constructivist epistemology to examine the plurality and complexity of digital sustainability perspectives in the mining context. We have done this to provide a better understanding of how digital mining experts understand and experience the role of digital technologies in sustainable mining practice. Digital mining technologies appear to offer promising innovations for sustainable mining (Gorman & Dzombak, 2018). The research objective is to understand to what extent a group of digital mining experts at an industry-leading hi-tech mining solutions company hold contradictory and consistent perspectives about the role of digital technologies in sustainable mining. The key contribution of this paper is a visual thematic map that improves upon the extant understanding of digital sustainability by providing a more holistic analysis of the social and technical challenges facing current digital mining practices. In addition, this paper addresses two weaknesses in the extant literature: First, exploring the role of digital technologies in the context of sustainable mining is scarce and second, there have been calls for IS research to conceptualise information systems phenomena as a 'harmonious' interaction between the social and technological sub-systems (Sarker et al., 2019; Seidel et al., 2013). We propose an expanded sociotechnical perspectives framework to guide our analysis about current understandings of the role of digital technologies in sustainable mining.

As the world is becoming increasingly more complex and faces enormous social and environmental risks, emphasising economic imperatives alone has become inadequate in evaluating IT's contribution to organisational objectives (Chen et al., 2009). Porter and Kramer's (2006) assertion that firms need to address the triple bottom line of 'people, planet, and profit' also implies that IT is pivotal in the firm's broader value-creation process (Hertel, et al., 2013). Saldanha et al. (2022) support these points of view and further stress the necessity of firms to balance economic and sustainability imperatives better to improve complementary organisation objectives.

Therefore, this research aims to explore the various ways experts at a hi-tech mining solutions company firm make sense of the social and technical dimensions of digital technologies for sustainable mining. Drawing on the sociotechnical perspective (Sarker et al., 2019), we develop diverse themes about employees' views about the role of digital technologies in sustainable mining. These themes reflect the different perspectives on digital sustainability and hence contribute to the academic discourse on the effects of the new generation digital technologies on broader sustainability goals to a multi-facetted understanding that can guide future studies of digital sustainability, but also help practitioners to better support more sustainable use of these technologies.

This study assumes that sensitising concepts from a sociotechnical perspective framework can enhance and enrich the understanding of digital sustainability themes in mining and other sustainable informatics domains.

2 Literature Review and Theoretical Background

2.1 Related Digitalisation and Sustainability Studies

In broad terms, digital sustainability refers to an organisation's broad strategy for achieving sustainability with technologies (Wut et al., 2021). Another earlier definition of digital sustainability outside the IS literature refers to the specific use of technology to support an organisation's environmental, social, and economic sustainability goals (Bradley, 2007). This definition emphasises the appropriate use of technology infrastructure and tools to support digital sustainability practices. Moreover, while some definitions of digital sustainability focus on how organisations actively engage in activities that support sustainable development goals by leveraging technology for generating, managing, and disseminating electronic data (George et al., 2020), other definitions focus on the lifecycle of digital artifacts within their ecosystem (Stuermer et al., 2017).

In a more recent and comprehensive literature review, Kotlarsky et al. (2023) found that there are two primary IS research streams on digital sustainability. The first stream concentrates on the intrinsic sustainability of information systems themselves, encompassing the design, development, and lifecycle management of digital technologies to ensure they are environmentally friendly and resource-efficient (Cooper & Molla, 2017). This includes creating energy-efficient hardware, eco-friendly manufacturing processes, software for energy optimisation, sustainable data centres, and extended product lifecycles with effective end-of-life management.

In contrast, the second stream is centred around using digital technologies as tools to achieve broader sustainability goals in various organisational or societal contexts (Tim et al., 2021). This involves using digital solutions like smart energy management systems, big data analytics for environmental monitoring, digital supply chain management for resource efficiency, telecommuting technologies to reduce travel emissions, and Geographic Information Systems (GIS) for conservation efforts (Naumann et al., 2011; Watson et al., 2010). The key focus here is on applying digital tools to enhance environmental sustainability across different domains rather than on the sustainability of digital technologies themselves (Kotlarsky et al., 2023). In IS research, the distinction between green IT and green IS mirrors these broad delineations within the field of digital sustainability (Watson et al., 2010). For instance, green IT primarily concentrates on the sustainability of digital technologies themselves, while green IS emphasises leveraging technology for broader sustainability goals. Moreover, green IT is inward-looking, focusing on the sustainability of IT components. In contrast, green IS is outward-looking, emphasising the role of IT in advancing sustainability across a broader spectrum of organisational and societal activities (Tim et al., 2021).

Drawing from the abovementioned review, Kotlarsky et al. (2023, p. 938) define digital sustainability as “the development and deployment of digital resources and artifacts toward improving the environment, society, and economic welfare.” While our research resonates with this definition in how we explore the use of digital technologies in the mining sector, it also offers a unique dimension reflective of our specific context. For our study, we define digital sustainability as harmonising the interplay between the social and technological subsystems within the broader concept of integrating technological advancements with social and ecological dynamics to achieve sustainable outcomes. This perspective aligns with the sociotechnical view, which posits that effective and sustainable solutions emerge from the synergistic interaction between technology and the social elements of an organisation (Petrini & Pozzebon, 2009). This holistic approach recognises that the sustainability of digital initiatives in an organisation is not solely a technical challenge but also a social one (Tim et al., 2021).

According to Binder and Wade (2024), despite the transformative potential of digital technologies, the application of digital technologies directed at enhancing environmental sustainability may, in certain instances, lead to improved or, conversely, potentially compromised organisational performance. Similarly, our use of the term 'harmonise' as opposed to 'optimise' in conventional sociotechnical perspectives reflects the recent understanding that in complex sociotechnical systems, especially in sectors like mining, unintended consequences often emerge from attempts at optimisation (Watson et al., 2010). Unlike an optimisation approach that primarily aims to maximise efficiency and effectiveness within a system, a harmonisation-oriented perspective seeks to integrate and balance the interplay of social and technical elements to achieve cohesive and sustainable outcomes (Steffen et al., 2015). This approach recognises that achieving a perfect optimisation of individual components in complex environments may not lead to the overall best outcome. Instead, harmonising efforts focus on aligning and synchronising various elements to work cohesively towards shared goals (Porter & Kramer, 2006). This perspective is particularly critical in the mining industry, where the interconnectedness of environmental, social, and technological factors demands a comprehensive and holistic approach to ensure sustainable and responsible operations (Whitmore, 2006).

Digital sustainability can also refer to organisational activities working towards achieving the UN SDGs for future generations by leveraging information technologies and electronic data (United Nations, 2023). IS scholars have argued that contemporary digital technologies such as artificial intelligence (AI), big data, and distributed ledgers can promote sustainable economic growth and development (Nishant et al., 2020; Pan & Zhang, 2020). A review by Schoormann et al. (2021) found that AI contributes to health (SDG 3), education (SDG 4), sustainable farming (SDG 2), energy management (SDG 7), animal protection (SDG 15), working conditions (SDG 8), smart infrastructures and innovation (SDG 9), and inclusive political systems (SDG 10). Butler (2011) argued that IS can also ensure compliance with regulatory constraints brought about by a sustainability focus. Meanwhile, Seidel et al. (2013) found that IS affordances can enable environmentally sustainable work practices. However, some scholars contend that current theories, concepts and artefacts fall short of addressing IS sustainability challenges (Baskerville et al., 2016; Elliot, 2011; Watson et al., 2010).

Despite the potential of digital technologies to enable sustainable decisions and work practices, they can also increase the gap between the beneficiaries of the digital economy and those it disadvantages – e.g., the victims of massive job losses (Bessen, 2019). The term 'digital divide' has been used by IS scholars to articulate the inherent inequalities in the digital economy. After all, planned IS affordances, prone to creating unintended effects, do not necessarily translate into actual or optimal affordances. Addressing sustainability challenges requires a transdisciplinary approach to align the deployment of digital technologies with sustainability imperatives (Elliot, 2011; Malhotra et al., 2013; Pan & Zhang, 2020; Stillman et al., 2020). Sustainability initiatives need to consider economic, ecological, legal, political and cultural perspectives. For instance, Piotrowicz and Cuthbertson (2009) identified the need for IS evaluation research to pay attention to sustainability by going beyond economic factors, calling for the inclusion of social and environmental factors.

As alluded to, the sustainability concept is complex and multifaceted and reflects the perspectives and interests of multiple stakeholders. Traditional management approaches continue to assume that economic sustainability is at odds with social and environmental sustainability despite the obvious interdependence (Ghoshal, 2005; Porter & Kramer, 2011). IS scholars have called for improving the current conceptualisation of sustainable IS to guide sustainability research (Baskerville et al., 2016; Malhotra et al., 2013). We contend that a more holistic research framework is needed to explore and demonstrate the interdependent nature of sustainability, contributing to the design and adoption of more responsible and sustainable IS practices.

2.2 Sociotechnical Perspectives of Digitalisation and Sustainability

We conceptualise digital mining technologies as part of a harmonious and sustainable sociotechnical system (SSTS). Bostrom and Heinen (1977a) argue that computer-based information systems are neutral and, instead, overcome the shortcomings of monological perspectives by understanding the interplay between social and technical systems. Bostrom and Heinen (1977b) leverage a sociotechnical approach to illustrate a more comprehensive view of the benefits of computer-based information systems. However, the arguments made by Bostrom and Heinen (1977a, 1977b) do not refer to sustainability. Starting from nine principles, Cherns (1967) puts forward that sociotechnical thinking requires a better understanding of constant interplay in practice to achieve the desired outcome, exemplified in this research as supporting the UN's SDGs. Similarly, Mumford (2006) emphasises the need to understand humanistic focus goals, how sociotechnical interplay works, and, most significantly, that the means of interplay are as crucial as the desired result. Mumford's (2006) point of how something is done is just as important as the result, which is reinforced by Bostrom et al.'s (2009) argument for the need to privilege neither the technical nor social sub-system in isolation.

As a result, we are encouraged to move away from a dominant technical-focused or social-focused view of the IT artefact and towards a view of IT as a holistic sociotechnical system that promotes a more balanced perspective (Alter, 2003; Sarker, 2019). While we recognise that the sociotechnical perspective has deep roots, has been applied with subtle variations, and has proven helpful in the mining industry (Trist & Bamforth, 1951), we chose Sarker et al.'s (2019) sociotechnical model because it provides an initial transdisciplinary perspective while maintaining an IS distinction (readers are encouraged to read Sarker et al. (2019) for a more in-depth historical review of the sociotechnical perspectives in IS). Moreover, by adopting a sociotechnical perspective, this research contributes to the discussion of IS as a reference discipline (Sarker et al., 2013) while supporting sustainability-linked objectives.

The current IS conception of sociotechnical systems tends to ignore sustainability, emphasising optimisation, which has traditionally been a core focus of IS research (Briggs et al., 2010; Sarker et al., 2019). Given the criticalness of sustainability, we adapt and enhance the Sarker et al.'s (2019) sociotechnical model by using a sustainability lens through which we view the social and technological sub-systems that make up an information system to be part of a broader and more inclusive and interdependent ecosystem (Avgerou & McGrath, 2007; Seidel et al., 2013). Traditionally, the social sub-system is people-oriented and focuses on individuals, their relationships, reward systems and authority structures, whereas the technological sub-system focuses on tasks, processes and technologies for achieving organisational objectives or outcomes (Bostrom & Heinen, 1977; Seidel et al., 2013). Instrumental objectives are concerned with achieving economic objectives, whereas humanistic objectives are concerned with enhanced job satisfaction and higher quality of working life of employees (Bostrom & Heinen, 1977). Following our extended SSTS framework, the fit between the social and the technological sub-systems determines the sustainability of the broader ecosystem, which requires the harmonisation of both organisational sub-systems in sustainability efforts with broader social and environmental concerns (Seidel et al., 2013). We believe that perspectives should shift from instrumental objectives and outcomes towards the sustainability of the larger ecosystem. We also assume that perspectives that simultaneously strive to achieve the payoff of the upside of business sustainability with the upside of social cohesion and environmental sustainability are crucial in building a more sustainable society.

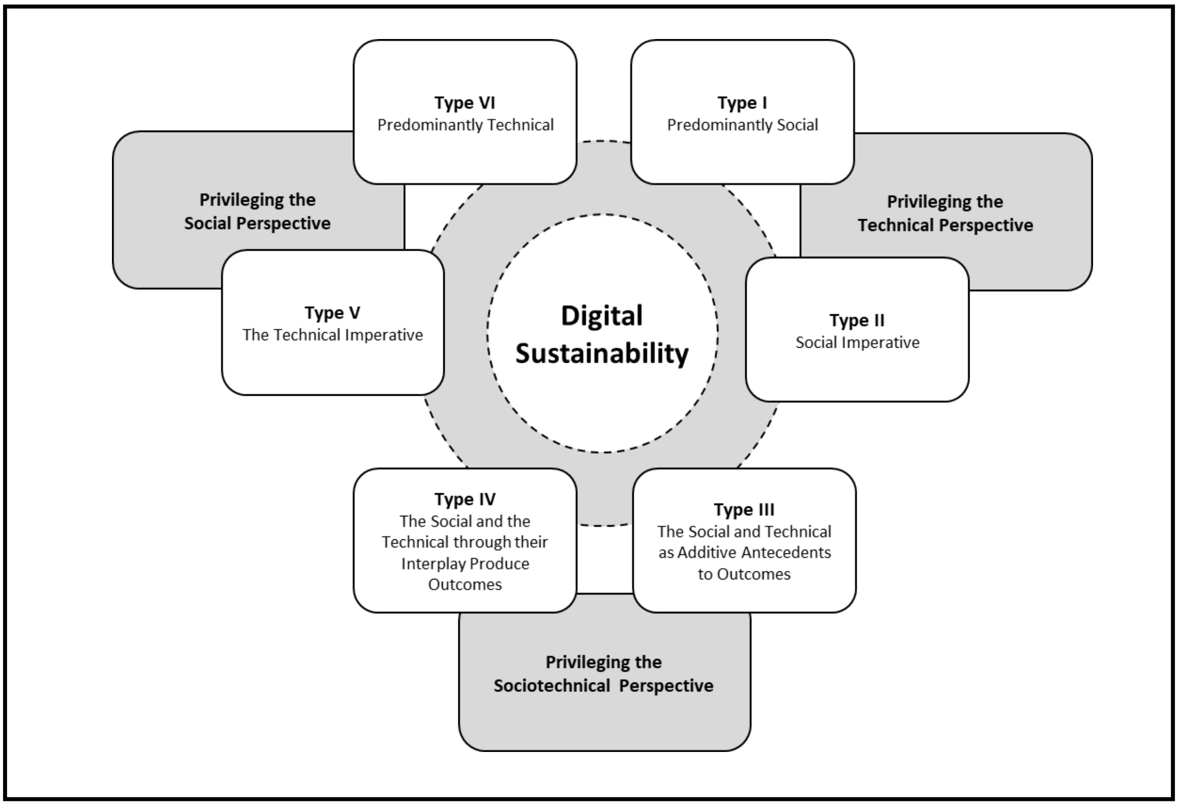

Figure 1. Multiple perspectives of digital sustainability (adapted from Sarker et al. 2019).

Sarker et al. (2019) make use of six types to characterise prevailing sociotechnical perspectives and their influence on organisational outcomes: A Type I perspective is predominantly social and focuses mainly on how human factors explain outcomes in technology-mediated ecosystems. Type II, or the social imperative perspective, considers how social aspects influence the technical component and outcomes. Type III considers how social-technical factors additively deliver outcomes. These perspectives assume that there is no interplay between technical and social components. Type IV perspectives consider how the sociotechnical interplay delivers outcomes. Type V or technical imperative perspectives assume technology is a significant antecedent to social outcomes. Type VI perspectives are predominantly technical and focus on developing or improving a sustainable ecosystem's technical component with little or no consideration of the social component.

Although Sarker et al. (2019) focus on the multiple viewpoints of IS researchers, we believe that the sociotechnical lens and these six perspective types are also an appropriate sensitising lens for analysing how organisations and practitioners strive to harmonise the social and the technical sub-systems to achieve both the organisation's goals and broader sustainability goals. However, a sociotechnical conception of digital sustainability proposes that neither the technological nor social sub-system imperatives should be privileged. Instead, the focus should be on the interplay between these two sub-systems. While there are marked advantages to using a sociotechnical perspective, these are not devoid of contextual limitations. Employees operating in this context may be less flexible to function beyond the norm expected by their employer due to the dominant economic drive and technological orientation of mining businesses, given the seriousness of the consequences of doing so. Furthermore, because this study conducts firm-level analysis, other contextual forces like regulators and governments would limit the social participants' flexibility.

This paper aims to better understand the extent to which participant perspectives, in our case, privilege either a social or technological imperative or whether they consider a harmonious interplay of the sociotechnical within a larger mining ecosystem in delivering broader sustainability outcomes. Figure 1 shows the concepts we will use as an initial guiding framework to analyse the key similarities and differences in viewpoints of our social participants regarding the role of digital mining technologies in leveraging sustainability.

3 Research Methodology

This paper forms part of a more extensive case study research focusing on implementing digital mining technologies. In this part of the study, we explore the sociotechnical perspectives on sustainability by globally distributed digital professionals working in the digital mining environment. Selecting a single revelatory case study can provide a deeper understanding of sustainability perspectives in IS (Dubé & Paré, 2003; Orlikowski & Iacono, 2001; Seidel et al., 2013). We aimed to build a deeper understanding of sustainability within an industry rapidly adopting digital technologies (Sganzerla et al., 2016; Young & Rogers, 2019). Sustainability is a paramount and increasingly prominent focus area within the mining industry (Joy, 2004; Moran et al., 2014). Despite the increasing use of digital technologies to improve the productivity and sustainability of mining operations, research on the sustainability perspectives of digital technologies in the mining context is scarce (Kirsch, 2010; Tost et al., 2018; Whitmore, 2006). We followed the interpretive case study guidelines developed by Walsham (2006) and Klein and Myers (1999) to conduct our study.

3.1 Case Study Site

A privately owned hi-tech digital mining solutions company that enables value co-creation in the mining industry serves as the case study setting for this research. DigiMine, a pseudonym, supports the mining industry by collaboratively creating value through the employment of digital mining solutions such as fleet management, machine guidance, haul-cycle automation, reliability and machine health monitoring, and collision avoidance systems. Established by an American holding company, DigiMine has supported mining operations with digitally enabled equipment ranging from 20 to 1,200 on a single mining site. DigiMine and its American holding company have assisted 90% of the world's largest mining companies, including underground and open pit mining operations focusing on extracting mineral and coal resources. Examples include coal (metallurgical and thermal), diamonds, copper, gold, platinum, iron ore, phosphates and phosphoric acid. Being mindful that the digital mining technology industry operates and supports mining operations across the general mining value chain, DigiMine explicitly provides technology and professional support within the drilling, breaking, loading and hauling sub-activities (Vorster, 2001). Driven by a mission to improve safety and efficiency in mining, DigiMine co-creates value with mining operations that, by way of example, improve the loading efficiency of haul trucks, improve bench elevation, avoid equipment collisions, avoid critical haul truck failure, reduce the number of people needed in hazardous working areas and automate the haul cycle processes. While DigiMine is staffed and collaborates with mine operational staff that are primarily technical-focused professionals (scientists and engineers), there is already acute awareness of digital mining technologies and the role of these technologies in mining sustainability. Senior leadership echoes this awareness by advocating that digital technology powers sustainable mining.

3.2 Data Collection

In following the ethical procedures stipulated by the institution governing this research, clearance was obtained from DigiMine and each social participant individually beforehand to conduct interviews. Research data was collected from primary and secondary sources. Primary data was sourced from semi-structured interviews that were conducted between June 2020 and November 2021. An approved interview guide (please refer to the appendix for further details) was used to ask social participants to share their perspectives and experiences with digital technologies and their role within the mining environment. When the social participant raised their view of sustainability in the digital technology mining environment, the first author would probe for them to elaborate on these views with descriptively rich accounts of contextual scenarios. As a result of the COVID-19 pandemic, these semi-structured interviews were digitally held using MS Teams and lasted between thirty and ninety minutes. All interviews were audio-recorded, with the permission of DigiMine and each participant. The recorded interviews were transcribed using professional software and manually checked to confirm accuracy. Primary data was supported using secondary data collected from DigiMine internal documentation (strategy documents, management reports and production results), business case studies and observations. For example, in a variety of site visits and digital workshops, the first author observed the training of operators to use a machine guidance system for safety and production improvements, engineers conducting operational maintenance of digital and physical enabled digital technologies, engineers optimising mining operations using digital technologies, and operators using heavy asset management solutions. Triangulation was achieved using secondary information sources, collecting primary data over different periods, and interviewing diverse DigiMine staff, partners, and clients. We used triangulation to broaden and deepen our understanding of the social participants' shared and varied sustainability perspectives (Dubé & Paré, 2003). An example is comparing social participants' feedback versus observations where social participants attempted to optimise a mining fleet's production efficiency by analysing the trade-off between social and technical interventions.

Twenty-five social participants informed this research, comprising seven professional staff (Engineers and Specialists), six middle managers (Supervisors and Managers), seven senior managers (Programme Managers and Directors) and five executives (General Managers, Vice Presidents and Presidents). At the time of the interview, the social participants were either employed by DigiMine or collaborating partners and mining clients. All social participants have extensive expertise in the mining industry, specifically with digital technologies. The average professional experience of the social participant is 19 years, with the lowest being eight years and the highest being 30 years. Twenty-three social participants are degree graduates, eleven have a master's degree, and one holds a PhD.

This paper adopts a view of expertise as a collective socio-material practice that, through consistently superior performance, accomplishes repeatable, tangible and successful outcomes (Ericsson et al., 2007; Nicolini et al., 2017). As a result of the social participants' collective proficiency in the mining, digital technology industry and grouping in industry-leading companies, their involvement in consistent digital mining results and coupled with their competence in the intersection of the three, this paper refers to the 25 social participants as an expert group of digital mining professionals.

Pseudonyms are used to anonymise social participants' identities. At the time of this research, social participants were geographically located in Australia, Brazil, Chile, South Africa and the United States of America. When direct quotes are used as examples in the case analysis and the social participants' primary language is not English, an asterisk (*) has been placed next to the corresponding excerpt.

3.3 Data Analysis

Our initial aim during the data collection phase was to gather broad and unfiltered insights about the use and impact of digital technologies in the mining industry without constraining responses to a specific theoretical framework. However, as the study progressed and we moved into the data analysis phase, it became increasingly clear that a sociotechnical perspective was appropriate to fully understand and interpret the findings. This perspective, which considers both the social and technical aspects of digital mining practices, was thus adopted post-interview as a lens through which to analyse and make sense of the data.

Since the sociotechnical perspective privileges neither the technical nor the social but emphasises the interaction between the two, we consider the digital technologies as well as the social (individuals and collectives that implement, use and are impacted by these technologies within the case context) to be part of our analysis. We started the case analysis by developing a coding template to identify and support the identification of key similarities and differences in the viewpoints shared by the social participants (Crabtree & Miller, 1992). The coding template contained sensitising coding categories, sub-categories and definitions informed by Sarker et al.'s (2019) six types of sociotechnical perspectives (See Figure 1). Braun and Clarke's (2006) guidelines for constructing thematic categories were adopted (Figure 2).

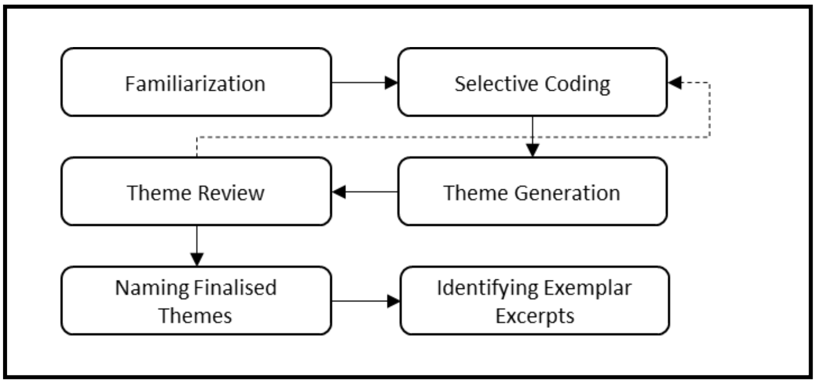

Figure 2. Iterative Thematic Analysis Process

Both authors read the data sets multiple times and worked independently to generate an initial set of thematic categories using an open-coding approach. Both authors then worked collaboratively to find, categorise and assign the common themes for the many codes that emerged during this iterative process to the selected coding categories. For example, themes predominantly of a social perspective (individuals, their relationships, reward systems and authority structures) referred to "*community upliftment*", "*community health*", "*universal income*", and "*employee safety*" as considerations. In addition, lower-level codes that were predominantly technical (tasks, processes and technologies) in perspective were referred to as "*artificial intelligence*", "*robots*", and "*PLC code*". We identified the different perspectives constituted by these thematic categories until we were satisfied that the joint analysis adequately reflected the data set. The Atlas.ti qualitative data analysis and research software tool was used for data storage and analysis. We selected the exemplar excerpts to demonstrate the link between the data and the analysis.

4 Case Analysis and Findings

The thematic map represents an overarching theme, three themes and seven sub-themes (Figur**e** 3). Following multiple iterations, we arrived at 'competing sustainability perspectives in digital mining' as our overarching theme and 'privileging business sustainability over human, social and environmental sustainability', 'privileging automation over human labour' and 'privileging a longer time horizon for sustainability' as the three main themes.

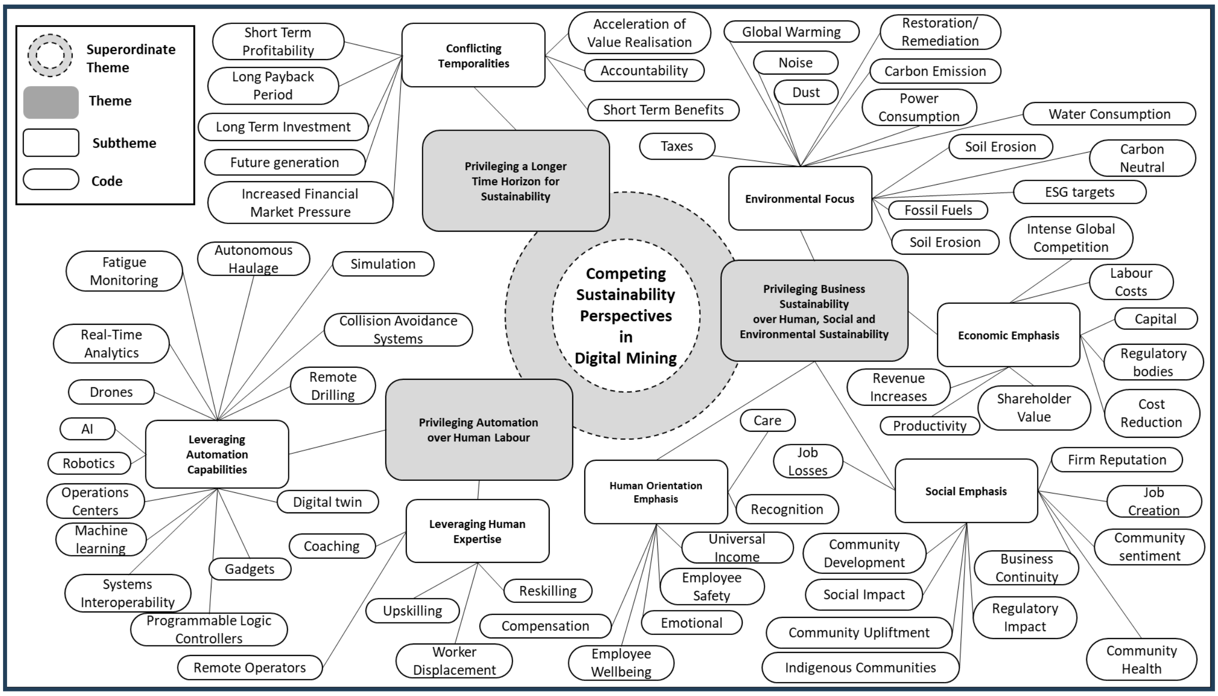

Figure 3. Visual Thematic Map

Evidence of the social participants shared dissimilar and competing perspectives of sustainability in digital mining. Although there is consensus on the criticality of sustainable mining practices and the solutions that digital technologies offer, the social participants tend to focus on instrumental considerations favouring the leveraging of digitalisation for the financial and economic sustainability of mining. This perspective overshadowed approaches that leveraged enhancing social cohesion and minimising the environmental impacts to address sustainability challenges.

4.1 Privileging Business Sustainability over Human, Social and Environmental Sustainability

Our 'privileging business sustainability over human, social and environmental sustainability' theme was linked to four subthemes: a 'lack of environmental focus', 'lack of social emphasis', 'lack of human orientation' and a strong 'economic emphasis'. The evidence highlights that privileging the human, social and environmental perspective of sustainable mining using digital technologies is less prevalent among the social participants. Although these perspectives are far less evident than business sustainability, there were social participants that highlighted the value of sustainability for the community, the preservation of the environment, and employee safety.

Hendrik Jordaan, an executive, explains that *"anything that drives and improves safety is always a kind of a no brainer,"* and that:

> *"Primary value drivers for our customers right now are obviously safety, as well as you know, cost per ton, of course, always productivity and reliability. But now more and more, also sustainability. So that's become a very large driver in the industry."*

While safety and sustainability are being considered core value drivers, Nadine de Wet, a middle manager, puts forward that generating revenue is still prioritised when compared to human, social and environmental considerations. De Wet exemplifies how human, social and environmental perspectives of sustainability, based on their experience in the broader mining industry, have not been prioritised due to the social benefits of sustainability. Instead, it was prioritised because of instrumental outcomes that benefitted the organisation, such as sustainable revenue.

> *"So, value for me is, I think, first of all, generating revenue, generating sustainable revenue where you can employ people that contributes to communities, contribute socially. So, I think it's, first of all, it's about generating money. Second thing is you know to be sort of sustaining, maybe sustaining, you know, communities and supporting communities."**

Similarly, to de Wet, another middle manager, Jacqueline Robertson shares that from *"a mine's perspective, you know, it's about working within a certain cost per ton threshold."* Further emphasising the primacy of instrumental outcomes is a rhetorical question posed by Sarah Graham, a senior manager.

> *"So how do we not just meet the environmental impact requirements, but also how do we sustain the business into the future?"*

Graham's exemplar viewpoint highlights a link between the social perspective of environmental impact and the sustainability of the business. It is the business sustainability primarily for Kevin Campbell, an engineering professional, who succinctly states that the role of digital technologies in the mining industry is to create shareholder wealth.

> *"Essentially, it comes down to the bottom line. It's either revenues through increased production, productivity through cost reduction or risk mitigation."*

This position of financial primacy or privileging business sustainability first is the most common account across the social participant group, despite an exceptional perspective, as one shared by Antoinette van der Merwe, a senior manager.

> *"There is no reason for all the technology and advancements that we are making that people cannot go home to their families, and so it is a responsibility on our end."*

Peter Greeff, a senior manager, explains that the more organisations experiment with sustainable and socially responsible technology that reduces carbon emissions, the lower the negative effect on instrumental outcomes such as operational efficiency:

> *"Yeah, I think, uh, sustainability is a good one, and you know the mining industry is recognised as a contributor, a significant contributor to CO2 emissions [...]. Even moving into things like hydrogen fuel cells and how can this be introduced to mining equipment as an additional option. Outside of that, it's you know really looking at major ways of reducing power consumption, how*

can we optimise the equipment to reduce unnecessary power consumption and water consumption and potentially introduce other technologies that are most sustainable to the overall mining process as well."

Greeff echoes that digital technology is changing the way business is conducted. However, it remains the position that sustainability goals are balanced against the normality of instrumental business requirements such as productivity and efficiency.

"I mean, if you look at [...] the sustainability space, right? It's all driving towards carbon neutrality. So how do we get rid of uh, uh diesel emission [....] So, you know, it's kind of changing the value proposition from hey, here's a productive piece of equipment that will do what you've always expected, but without the carbon output."

4.2 Privileging Automation over Human Labour

Our 'privileging automation over human labour' theme was linked to two subthemes. These included 'leveraging automation capabilities' and 'displacing human expertise'. When sharing their view of the role of digital technologies in the mining environment, most of the social participants preferred the technical perspective and a resultant instrumental outcome despite the negative influence digital technology may have. Mining operations are impacted as a result of digital technologies and can range from influencing the design through to the day-to-day operational running of a mine. Nico Kleynhans, a senior manager, recounts that digitally enabled technology can be used to better balance seemingly ubiquitous instrumental and social perspectives in the mining environment.

"Sometimes it's not directly seen. For example, implementing a collision avoidance system on a site will actually negatively impact your production numbers, but it will definitely increase your safety factor. And so, there's always this challenge between getting the right balance between production and safety. Ultimately, my opinion is that safety should take first priority, and that's one of the big strives to get that safety where we've got no fatalities in a year. And you reduce the injuries as far as possible."

Kleynhans continues by saying that *"the more injuries you see or fatalities you see, that reflects badly on the companies apart from the monetary value that is lost."* Kelly McCormick, an engineering professional, echoes the criticality of balancing the instrumental concern of mining efficiencies with employee safety:

"But if we have an automatic process to do that and you saving that person a lot of time and they can then use a time for other things. That's valuable! And, that yeah, like I said, I think that's pretty straightforward in terms of that saves you money […]. Safety if you can. I mean it's hard. You can't obviously put value to someone's life and well-being. But if you can prevent a death or injury and, in the plant, because you have certain checks in place on your software or in your part of your PLC (Programmable Logic Controller) code or whatever, that's going to stop a catastrophe from happening or stop a fire. Stop breaking the line due to high pressure or something before it becomes an issue. Then that's massive, running it has many apart from the regulatory impacts you save the incidents which is of massive value."

Safety concerns appear to be addressed because of regulatory requirements that entail stopping production flow if there is an injury on duty or a fatality. In other words, the incentives for safety are still largely instrumental rather than social. McCormick continues to emphasise that the use of software for optimising operations provides valuable instrumental outcomes such as improving the speed of decision making and staff productivity:

> *"We try and optimise the haul route cycle. We save time, the time it takes for that entire cycle to take place, meaning we get more loads of material going into the plant, and that in turn provides value because there's a direct monetary link to that. On the other hand, if you can save a person's time to get information, then you freed up that person's time to do other things. So that's another way of providing value."*

Privileging the sociotechnical perspective assumes that the appropriate balancing of the social and technical priorities in a digital mining environment would support safety, increase productivity and improve accuracy in mining activities was shared by social participants. Kleynhans pointedly shares that:

> *"Obviously safer operations will gain more value than others due to the investors, being happy with the safety risk. Obviously, no company in the world would want to injure or kill its personnel, and that improving safety around site definitely does add value."*

In pursuit of a safer mining environment, social participants share accounts where equipment operators are being removed from *"the line of fire of the machine,"* or being *"removed from the field"* ultimately to ensure that the operators are *"outside of that operating envelope"* to where the control and information retrieval from trackless mining equipment (TMM) can be done from a *"mobile"* or a *"smart device."* By *"removing people from harm's way"* and effectively using technology to alleviate safety concerns, the ability to operate, maintain or optimise equipment outside of a *"live fire"* environment is possible.

The replacement of human intervention or modification of how human labour is enacted leads to increases in the accuracy of physical mining operations and increased productivity. Kleynhans recounts an exemplar experience:

> *"We've upgraded some of our old pit viper drill rigs with a new telli-remote system, basically allowing the operator to drill from a control room that's a few kilometres away from the actual drill rigs. This serves a few different purposes. Number one is the safety purpose. You no longer have a person sitting drilling close to a high wall that collapse so you're moving that portion of risk and secondly, your driller motor in your autonomous drill rigs have set parameters within which they can drill, so you've got less wear and tear on your equipment and your overall accuracy of your holes drilled is better."* *

The use of operationally remote digital technology and the enhancement of the working environment account for the social and technical interplay that symbiotically results in an increase in humanistic and instrumental outcomes alike. To elaborate, working from an air-conditioned office environment without high walls and numerous TMMs like shovels, excavators, and haul trucks increases the well-being of the employee and reduces the risk of lost-time injuries (LTIs). From a technology perspective, with increased accuracy in holes drilled, the result of the blast will align more closely to the planned design and require less remedial work. Despite the strong focus on economic outcomes, there is concern for safety and human well-being. This is evident in the statements of Nico Kleynhans and Kelly McCormick, who stress the importance of balancing productivity with safety. The use of digital technologies for improving safety reflects a concern to harmonise technological and humanistic objectives.

An executive, Hendrik Jordaan, describes that the automation of traditionally labour-intensive activities, such as operating a haul truck or shovel, addresses instrumental and humanistic outcomes of revenue, safety and sustainability, respectively. However, autonomous haulage systems also replace traditional TMM operators with fewer digital controllers. In other words, it introduces safety by reducing the human factor, as illustrated by Jordaan's following comment:

> *"The autonomous haulage system addresses safety issues by removing people from harm's way. It addresses the cost per tonne […] Consistent and reliable, more productivity time because you don't have the human factor. […] they (human labour) are not needed then what do you do with the people that are not needed?"*

A DigiMine whitepaper-supported press release also emphasised the instrumental benefits of leveraging automation capabilities. The paper explains that with automation playing an integral part in the mining sector and the demand for cost-cutting increasing, the desire to eliminate human involvement at specific operation points remains a crucial growth driver for the global mining industry. Zandile Twala, an executive, expresses another example of privileging automation over humans:

> *"If you have a lot of automation, then you will make people superfluous […] If we drive with even further with robots and so on, you do not need so many people anymore. […]"**

A technology-centred perspective has the potential for both misuse and a positive effect on employment. Twala continued to share insights about the unintended consequences of robotic automation on the human aspects.

> *"Oh, you have to find the common ground if you have so many people which are not needed any more, you have to take care of these people in a dignified way and then, that's what it is."* *

During both physical and digitally enabled site engagements, TMM operators were observed using a machine guidance system to enhance productivity and safety. It was interesting to observe that the in-person training of operators, which included notes and videos, was supplemented with simulator training in a controlled environment. The digital augmentation of traditional labour, such as driving a truck, can account for significant instrumental value in the mining environment. Anthea Mthembu, a senior manager, explains that in addition to the *"inherent value that we create,"* there is value above *"Fifty million dollars on the table if we make good use of [technology name] across [operations names]."* Privileging automation over human labour in the digital mining environment should come as no surprise, explains Jordaan.

> *"Whether you're looking at HR systems, ERP systems, CRM systems, they're all essentially attempting to accomplish what had traditionally been labour-intensive human activities that have been organised in some kind of process and then put a system to it and try to automate it as much as possible to remove the labour-intensive manual work that doesn't necessarily add a lot of value, right? [….] I mean, it could cover any business process."*

4.3 Privileging a Longer Time Horizon for Sustainability

Our 'privileging a longer time horizon for sustainability' theme was linked to one subtheme, 'conflicting temporalities'. In the case organisation, most social participants felt pressured to focus on leveraging digital mining technologies for short-term economic and financial objectives while presenting the overall sustainability goal as a long-term concern. Brendon Smith, an engineering professional, is acutely aware of the impact and responsibility of sustainability-focused objectives and their impact on society for future generations.

> *"Let's say you destroy Mother Earth in the process of, you know, the work that you do. Then just future generations will be robbed of that value, maybe not short term in terms of the value that*

you create, but in the long run it will be very disruptive, right, you know, for, uhm, let me say for humanity."

Brendon Smith acknowledges the need to balance immediate economic benefits with long-term environmental and social sustainability. This is evident in his emphasis on the responsibility towards future generations and the environment. Such perspectives indicate a shift towards a more integrated and harmonious approach to sustainability.

While Smith's statement is critically important, the primary consideration or legitimisation focuses on short-term instrumental outcomes. Jacqueline Robertson, a middle manager, explains this focus.

"So, you know, there's always those discussions on-site, so you know how much do you want to push your cost threshold vs. the benefits, the short-term benefits."

Digital mining technology that focuses on optimising the value of *"LTIs"*, *"safety"*, *"really caring"*, *"carbon neutral by 2050"*, and *"trying to cut their carbon emissions in half by 2030"* is evident. However, it is the *"cost per tonne"*, *"margin"*, *"production through-put"*, *"revenue,"* and *"bottom line"* that remain the quintessential legitimiser of digital mining technology. To illustrate, Hendrik Jordaan, an executive, highlights how the mining industry is beginning to address the safety and sustainability goals of the business while focusing on ensuring that the business is sustainable:

"In the mining industry right now, I mean, if we look at… the digitisation analytic space. Uh, yeah. Primary value drivers for our customers right now are obviously safety as well as, you know, cost per ton, of course. Always productivity and reliability but now more and more, also sustainability."

Jordaan explains that *"because most mining companies trade in commodities markets, they don't control the price, so all they can really control is their costs and production. So that's how they manage their business."* Traditionally, mining operations have focused on driving down costs and improving efficiency. The increasing importance of social and environmental considerations remains deferential to the dominant, short-term, instrumental perspectives that characterise most mining firms based on institutional pressures (such as the financial market and shareholder expectations).

The positive impact of digital technology on sustainability is also viewed as a long-term initiative. While an account of a remote solution indicates a current moment-in-time representation of outcome synergies, a collision avoidance solution could be synergetic but over a longer time horizon. Robertson explained her temporal perspectives as follows:

"Because of the safety element, you are minimising LTIs, lost time injuries, and fatalities that would, you know, have long-term consequences. So, I would rather drop productivity by maybe 1 or 2 %, but over the long-term period, and I overachieved my safety-related matrices, and my productivity it's quite maintained nicely because, you know, you usually have, you know, peaks and drops due to mine stoppage because of a fatality or lost time injury."

Paula Jarvis, an engineering professional, shares that having a temporal perspective supports effective value creation from digital mining technologies.

*"We build value in a sustainable and more long-term type of approach; otherwise, going to be just a mathematical exercise." **

Antoinette van der Merwe, a senior manager, reinforces this temporal perspective and the pressures of focusing on short-term objectives:

> *"It's just very hard to make the sustainability and the long-term value projections if you're only trying to optimise one part of the process at a time."*

Peter Greeff, a senior manager, is acutely aware of the financial ramifications of the sustainability of the environment on the business. He explains that over a longer period of time, an environmental value perspective can overcome the perceived negative short-term financial value impact.

> *"I think it's something that is being looked at closely and drive a major change in the industry like this. It does carry financial ramifications of sustainability, and I think the key to this is around the broader adoption of this type of new capability and technology. […] It enables us to move forward more effectively and more efficiently and reducing that overall financial impact because we all recognise that this is a critical goal that we need to stick to and go after."*

The acknowledgement of the pressure to focus on short-term objectives, as discussed by Antoinette van der Merwe and some of our other participants above, while recognising the importance of long-term sustainability, also reflects an ongoing effort to find a balance between immediate and future needs, aligning with a more harmonised approach.

5 Discussion

As the convergence of emerging technologies advances, the mining industry has the opportunity to transition away from traditional methods to an increasingly digital future. The IS discipline has the opportunity to positively influence sustainable business practices that leverage promising and powerful digital technologies by using a sociotechnical lens (Sarker et al., 2019; Seidel et al., 2013; Stahl, 2012). This revelatory case study research set out to understand the sustainability perspectives held by digital mining professionals in the mining environment. This study draws on prior sociotechnical research in IS to develop a thematic map to visualise sustainability perspectives in digital mining. By applying a theoretical thematic analysis guided by sociotechnical theory and concepts (Sarker et al., 2019), we could conceptualise sustainability perspectives in digital mining by an overarching theme highlighting competing sustainability perspectives. These competing perspectives were linked to themes that show how practitioners were 'privileging business sustainability over human, social and environmental sustainability', 'privileging automation over human labour' and 'privileging a longer time horizon for sustainability' as the three main themes (Figure 3). This study extends upon prior sociotechnical research in IS by addressing the challenges more salient to sustainability in digital mining (Bostrom & Heinen 1977; Seidel et al. 2013). Findings from this study reveal the multidimensional and multifaceted nature of sustainability perspectives in digital mining. The similarity of our results to those reported in recent IS sustainability research (Nishant et al., 2020; Pan & Zhang, 2020) suggests that the broader challenges and complexities in digital sustainability practices are transferable to other domains (Sarker et al., 2019).

Although social participants in the case were not driven purely by economic motives, fewer social participants shared perspectives of responsible and sustainable approaches to mining. Nevertheless, there are significant subthemes and growing perspectives among the participants that reflect a movement towards harmonising technology, human well-being, and environmental sustainability (Zhang et al, 2011). This indicates an emerging recognition of the need to integrate and balance diverse objectives for sustainable and responsible mining practices. Our thematic map also suggests that those who shared this awareness were struggling with juggling seemingly antagonistic and contradictory social, environmental, financial and economic goals (Haddaway et al., 2019). Our economic emphasis subtheme indicates that digital technology is being implemented to support sustainable business models in mining. Our social participants emphasised using digital technology to support mining efficiency needs and priorities risks neglecting overall sustainability objectives. In contrast, socially focused business models that overfocus on social cohesion and multistakeholder expectations risk neglecting business sustainability goals. First, from a social perspective, social participants articulated humanistic outcomes such as "*zero harm*", "*community health*", "*sustaining the environment*", "*helping people out*", and that "*safety*" is "*first*", "*number one"* or "*top priority*". Second, from a temporal perspective, social participants generally tend to supplement the instrumental objectives of "*revenue*", "*costs*", and "*cash flow*" together with humanistic goals such as '*safety"* to set attainable sustainability objectives in the short term. Third, when social participants tended to privilege the social, they made statements such as the "*emotional*" aspects of mining and "*collaboration*" with stakeholders. When social participants privileged the technological perspective, statements including terms like "*PLC code*", "*mining analytics*" and "*machine intervention*" were emphasized. Finally, when the social participants espoused more holistic sociotechnical perspectives, the pressures of short-term instrumental outcomes tended to foreground mining productivity, cost reduction and profitability goals while understating social issues and environmental concerns. Overall, these perspectives on the role of digital mining technologies appear to suggest a weak rather than a strong approach to sustainability in digital mining (Young and Rogers, 2019).

Nevertheless, digital technology was found to support mainly SDG 9 (Industry, Innovation, and Infrastructure), SDG 8 (Decent Work and Economic Growth), and SDG 3 (Good Health and Well-Being) (United Nations, 2023). Although the study has demonstrated the value of a sociotechnical approach in analysing the digital sustainability perspectives of practitioners in mining, more work needs to be done to understand how IS capabilities can be leveraged to support the complex problem of balancing seemingly opposing sustainability and economic goals. This revelatory case paves the way for future research and analyses of digital sustainability in other contexts.

6 Implications

6.1 Theoretical Implications

This study contributes to theory in four ways. First, our thematic map provides a comprehensive visualised structure of the competing sustainability perspectives in digital mining, highlighting the interplay and conflicting priorities among critical environmental, social, and technical dimensions (Leidner et al., 2022). The competing sustainability perspectives we observed among our participants also suggest a complex relationship between digital technology implementation and sustainability goals in mining. Our findings are similar to prior IS research that suggests that digital technologies can provide several affordances that can be leveraged to improve sustainability in contexts such as mining (Seidel et al., 2013). However, our findings are similar to prior studies that argue that while much is known about how IS affordances can enable digital sustainability, the role of IS in impeding digital sustainability needs further exploration (Binder & Wade, 2024). The notion of competing perspectives emphasises the inherent complexity in sociotechnical systems, particularly in the mining industry, suggesting the need for theorising that can simultaneously address the technical aspects of digital technology and the broader socio-economic and environmental implications of its implementation (Butler, 2011). More specifically, our findings suggest that future research should work towards explicitly situating environmental considerations within the IS sociotechnical framework (Petrini & Pozzebon, 2009). We also call for an expanded version of the IS sociotechnical lens that can form the basis for a digital sustainability framework that sensitises IS researchers to environmental issues in future research.

Second, our analysis extends the discourse on Information Systems (IS) evaluation, revealing the need for a shift in theorising, where sustainability principles are given equal, if not more, weighting than tangible short-term financial benefits (Hertel, et al., 2013). Despite the possibilities presented by digital technologies to provide a more balanced and holistic approach to sustainability in practice, the current sustainability beliefs and actions among many of the digital mining experts in our case were being impeded by an IS evaluation mindset that emphasises financial factors and a short-term orientation over sustainability principles. We refer to this paradoxical challenge as conflicting temporalities. Industry professionals in the mining sector have traditionally prioritised economic gains and technical efficiency, often at the expense of social and environmental considerations. Similar to Binder and Wade (2024), we confirm the difficulties practitioners face in shifting their mindset to incorporate a more balanced approach that values social and environmental sustainability alongside economic and technical objectives. By highlighting this, we provide preliminary insights explaining the difficulty in aligning short-term inducing IS evaluation approaches with the broader concept of corporate social responsibility (CSR) and sustainable development goals (SDGs) to enable the shift towards more sustainable business practices (Porter & Kramer, 2011). Furthermore, our concept of conflicting temporalities shows that participants face tensions between short-term business objectives and long-term sustainability commitments and struggle with the complex trade-offs involved in these decision-making processes. Further research is needed to identify and explain these tensions in IS evaluation research (Hertel, et al., 2013). Moreover, research is needed to understand how experts can apply IS evaluation frameworks in ways that are more mindful and attentive to the multidimensional nature of digital sustainability initiatives (Piotrowicz & Cuthbertson, 2009; Swanson & Ramiller, 2004).

Third, apart from implications for IS evaluation research, our conception of conflicting temporalities also has implications for design science research (Zhang et al, 2011, Baskerville et al., 2016). Some scholars have suggested that IS researchers become 'solution scientists' by engaging in research that focuses on developing and implementing strategies that prevent environmental harm and actively contribute to ecological well-being (Watson et al., 2010; Chen et al., 2011). Our findings suggest that design science research emphasis on building digital solutions speedily and rapid value realisation are significant constraints for sustainable IS designs. Understanding conflicting temporalities highlights the complexity of designs that favour the short-term oriented financial and economic goals over designs sensitive to the interaction of short-term financial goals with environmental, social and human dimensions with their longer-term orientation. This involves rethinking the criteria for success and effectiveness in design science research to include long-term environmental and social impacts (Zampou et al, 2022). For instance, by applying Chern's (1976) design principles, we can simultaneously enhance sustainability affordances on a broad scale and achieve short-term financial results. This implies advocating for designs that are not only technically efficient but also socially and environmentally effective, ensuring that digital technology aligns with human and environmental needs (Naumann et al., 2011). Future research should explore whether design principles that emphasise harmony by operationalising related but lower-level concepts such as compatibility, collaboration, autonomy, adaptability, and participation can be applied in the context of digital mining to create a more balanced and integrated approach. Pertinent design approaches, such as soft systems thinking or participatory design, can be leveraged in design science research to theorise how sustainable solutions are designed and implemented with a deeper understanding of the environmental impacts, ecological balance, and conservation needs in digital mining and similar contexts. The findings in our digital mining case study also highlight the necessity for theories in IS design to account for different time horizons. This implies a shift from designs that are predominantly short-term and financially driven to those that also consider longer-term environmental and social impacts (Watson et al., 2010). This also implies the need to reevaluate and expand existing design science research frameworks in IS to incorporate a dual focus on immediate economic gains and long-term sustainability. Ultimately, this involves integrating considerations of the temporal dimension into the core theoretical constructs of IS design science research.

Fourth, our study not only adapts but also builds upon the framework of Sarker et al. (2019), tailoring it to cater for the distinctive challenges and dynamics of the mining industry within the context of digital sustainability. We integrate additional dimensions that critically assess the complex interaction between technological developments and the environmental and social factors inherent to mining operations. For instance, our refined concept of harmonisation in sociotechnical systems, moving beyond mere optimisation, emphasises the essential integration and balance between technical, environmental, and social elements while prioritising long-term ecological sustainability, inclusivity, and adaptability (Kotlarsky et al., 2023; Steffen et al., 2015). This adaptation enables IS researchers to explore in depth how digital technologies influence not only operational efficiency but also worker safety, job security, environmental stewardship, and community engagement (Bessen, 2019; Gholami et al., 2016). By adopting this environmentally-focused sociotechnical approach, IS researchers can enhance their comprehension of long-term ecological sustainability and resilience in a rapidly evolving digital context (Watson et. al., 2010). Future research should explore the process of attaining and maintaining an environmentally-aligned harmonisation between the social and technical facets of digital mining, understanding the dynamics of this balance and its impact on overall operational and ecological success. Furthermore, future studies could investigate instances of environmental disharmony in digital mining, examining the causes, consequences, and strategies for environmental mitigation or restoration, thereby offering insights into transitions from ecological imbalance to balance and highlighting the challenges, adaptive strategies, and decision-making involved in these critical transitions.

Notwithstanding the above, we believe that the central finding that sustainability processes in digital mining generate competing perspectives among experts can inform future theorising in IS sustainability studies (Elliot, 2011; Watson et al., 2010). In particular, we believe that the notions of competing perspectives and conflicting temporalities, identified in the digital mining case may also broaden our understanding of other concepts noted in IS sustainability research, such as safety, environmental governance, green innovations, and sustainable design (Baskerville et al., 2016; Butler, 2011). Given our findings, we contend that under conditions of competing sustainability perspectives, there is a risk that organisations will overfocus on technical perspectives and short-term economic outcomes. Therefore, the manner in which sustainability discourses circulate in organisations, as well as the consequences of conflicting temporalities, need to be closely examined in future research.

6.2 Practical Implications

Our thematic map provides an understanding of sustainable digital mining as a sociotechnical achievement, underscoring the crucial environmental, social, and technical perspectives that define the sustainability challenges and prospects in digital mining (Watson et al., 2010). It accentuates the imperative of foregrounding environmental considerations alongside the existing focus on social and technical aspects, enabling practitioners to holistically enhance both the instrumental objectives and the environmental and humanistic goals of digital mining. Our thematic map can also guide practitioners in developing sustainable competitive strategies with digital technologies that simultaneously address financial and economic goals and broader corporate social responsibility goals (Watson et al., 2010; Ghoshal, 2005).

First, our thematic map suggests that to address sustainability issues more harmoniously and holistically, practitioners must be mindful of overcoming the different organisational, sociological and psychological barriers that may impede progress (Swanson & Ramiller, 2004). For example, to address social cohesion and environmental sustainability goals more effectively, practitioners should minimise major differences in perspectives and practices by simultaneously addressing the upsides of shareholder value and a viable form of sustainable stakeholder value (Saldanha et al., 2022; Porter & Kramer, 2011). Second, given the conflicting temporalities experienced by the social participants in our study about the goals and priorities in implementing digital technologies in mining, managers and leaders should engage more closely with their employees to develop a shared understanding of how digital technologies can contribute to sustainability goals (Leidner et al., 2022). Furthermore, for organisations to successfully appropriate digital mining technologies to meet their sustainability goals, practitioners should establish a more harmonious perspective of instrumental and humanistic objectives (Washington, 2018). Although both optimisation and harmonisation are valuable concepts and can be complementary in the mining industry and other similar organisational contexts, the success of digital sustainability in mining will depend on more than just proficient professionals in digital literacy, data management, and analytics that utilise digital technologies for enhanced efficiency and gains (Young & Rogers, 2019), but also on those who can design sustainable solutions that consider long-term impacts on the environment, society, and the economy (Kotlarsky et al., 2023). We recommend new educational curricula for mining engineering and IT professionals incorporating this broader digital design skill set that goes beyond energy informatics to sustainability informatics (Watson et al., 2010; Naumann et al., 2011). Moreover, to change attitudes and sustainable business behaviour, practitioners should apply an appropriate mix and synthesis of sustainability performance metrics that go beyond technical and instrumental dimensions. As a start, an environmentally-focused sociotechnical perspective approach can be used by practitioners to understand and eliminate major differences and conflicting perspectives about goals, expectations and priorities that can compromise the needs of future generations. Finally, to leverage information systems in achieving sustainability goals, practitioners should strive toward building more consistent mutual understandings and perspectives about the role of digital technologies in sustainability transitions (Leidner et al., 2022).

7 Limitations and Future Research

The paper proposes a sociotechnical model of information systems to understand the role that digital mining technologies play in addressing seemingly conflicting sustainability goals in mining. Our study was exploratory and limited to the experiences of a group of digital mining experts at a global digital mining solutions provider. The case shows an overfocus on technology imperatives to achieve short-term business sustainability goals. Our findings suggest that establishing appropriate designs for digital sustainability transformations can harmonise the social and technical sub-systems. The unique contextual characteristics of the organisation and the experiences of the experts shaped our insights about sustainability in digital mining. The study was based on the perspective of one community, digital mining experts, who actively shape perspectives of digital sustainability in the mining industry. Future research could extend this work to understand perspectives held by other key social actors such as local community members, employees, governments and regulators. In this case, most social participants recognised that autonomous vehicles increase safety and productivity but were not cognisant of how a reduction in low-skill jobs offsets these outcomes. Future research on digital sustainability could investigate the unintended consequences of sociotechnical solutions on job losses. While this paper introduces a sociotechnical perspective of how digital technologies contribute to sustainable efforts in a mining context, action research or design science research using design thinking approaches could investigate how a mining firm could apply design principles that harmonise the social and technological sub-systems to improve sustainability in the short term. Studies of sustainable IS using an environmentally-focused sociotechnical lens can provide practitioners with new insights into managing seemingly intractable priorities. We hope our conception of sustainable information systems in digital mining will enable practitioners to benefit shareholders and stakeholders significantly. For those who study sustainability in organisations, we call for assessing the importance of the interplay between digital technology and human activities and advancing environmental stewardship in improving overall sustainability to be a greater part of their agenda. While we continue to work toward a better understanding of how digital technologies can support sustainable practice, we hope responsible information systems researchers will contribute to future IS sustainability research and a more sustainable world that will benefit current and future generations.

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APPENDIX

Interview Questions

Considering this research forms part of a more extensive study, exemplar questions that inform this research are presented below.

Questions relating to professional background:

1. What is your academic background?
2. What is your professional background?

Questions relating to sustainability perspectives of digital technology in the mining environment:

1. How have you been involved or affected by information systems within the business environment? Could you perhaps provide a few examples around IS that have affected those involved, specifically regarding reducing carbon footprint and sustainability or safety?
2. Do you have any insights into the financial ramifications of sustainability in any of your experiences so far?
3. What has helped you support sustainability?

Note: Questions were further explored with the use of appropriate probes. Examples include:

1. Could you please give me an example of what you mean by helping out the communities in the social aspect?
2. Could you perhaps expand a little bit on what you meant by sustainability and give an example, please?

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