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Northumbria University NEWCASTLE

Transforming Construction with Off-site Methods and Technologies (TCOT) Conference: Designing Tomorrow's Construction, Today

August 20-22, 2024, Fredericton, New Brunswick, Canada

Application of Off-Site Principles for Small-Scale Gold Mining Optimization in The Built Environment

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Abstract: This study explores the application of off-site principles for the optimization of small-scale gold mining within the built environment. Through a comprehensive analytical review of current mining practices and environmental considerations, the research identified innovative and adoptable off-site strategies for enhancing efficiency, sustainability, and minimizing the environmental impact of small-scale gold mining operations. Small-scale gold mining has been described widely as a destructive and unsafe mineral extraction practice that is largely unmechanized. Hence, concentrating on developing countries where small-scale mining significantly influences local economies, this study, which is although mainly analytical research, employed an initial partisan-systematic approach to narrow its study and a random selection of articles to enable it to present the identified solutions. These solutions were obtained by delving into off-site principles in construction, drawing parallels, and investigating their potential adaptability to the unique challenges presented by small-scale gold mining. By examining the integration of advanced technologies, community engagement, and environmental management, the research purely seeks to provide actionable insights for the development of a more sustainable and optimized approach to small-scale gold mining in the built environment.

Keywords: Off-site Principles; Mining; Small-scale Gold Mining; Built Environment, Sustainability

1. INTRODUCTION

The global gold mining industry has a rich history that spans centuries, shaping economies and cultures worldwide (D. Klemm, Klemm, and Murr 2001). Gold's allure, tied to its rarity and intrinsic value, has fueled exploration and extraction endeavors across diverse geographies (D. Klemm, Klemm, and Murr 2001; R. Klemm and Klemm 2013). From the gold evidence that survived the times of ancient civilizations (e.g., the time of the Pharaohs), to the gold rushes 19th century (which led to the establishment of large-scale mining operations), the industry has undergone significant transformations (Habashi 2009). However, off-site principles have not yet been popular in the mining sector. Although it can be argued that off-site principle, have been around over 127 years ago, because since 1895, it has been discovered that an organisation named Sears had been selling building materials by mail order, and then in 1908, to revitalize that business, they began offering off-site construction plans and kits (Kissell 2018). Klem & Klem (2013) may have argued that ancient civilizations recognized gold's significance, viewing it not only as a symbol of wealth but also as a key element in cultural and religious practices. However, with the advent of industrialization, gold mining evolved into a complex and multifaceted sector (Oggeri and Laker 2023; Libassi 2023). Today, the industry is characterized by a mix of large-scale industrial mining and small-scale artisanal and small-scale mining (ASM), with a significant portion of the latter concentrated in developing countries (Sakakibara et al. 2023; Bester 2023; Tukur, 'Saleh, and 'Omar 2023). It is expected that profitable and efficient methods and principles are to be attracted through cross-sectoral knowledge sharing, but that has not been the case for the mining sector as regards off-site principles.

Consequently, this research tends to examine some of the innovative off-site strategies for enhancing efficiency, sustainability, and minimizing the environmental impact of small-scale gold mining operations, which takes most especially in developing countries (Ogan et al. 2016).

2. LITERATURE REVIEW

2.1 Significance of Small-Scale Gold Mining in Developing Countries

Tukur et., al. (2023) argues that the perception of the mining sector is diverse. That said, small-scale gold mining plays a pivotal role in the economic landscapes of many developing countries (Besada and Golla 2023; Tukur, 'Saleh, and 'Omar 2023). Unlike their large-scale counterparts, small-scale operations are often family or community-based endeavors (Adranyi, Stringer, and Altink 2023). In these regions, gold mining serves as a vital source of livelihood, providing employment opportunities and income for local communities. The sector contributes significantly to poverty alleviation, acting as an economic lifeline for those in resource-rich but economically challenged areas (Adranyi, Stringer, and Altink 2023; Metta et al. 2023; Besada and Golla 2023).

Furthermore, small-scale gold mining often operates in remote regions, contributing to the decentralization of economic activities (Cheng et al. 2023; Fritz, Aichele, and Schmidt 2020). This decentralization can have both positive and negative implications, as it may foster local development but also pose challenges related to governance, environmental management, and social well-being (Fritz, Aichele, and Schmidt 2020). Apart from that challenge, there are other significant environmental and social challenges that cannot be ignored.

2.2 Overview of Environmental and Social Challenges

While gold mining has brought economic benefits to many regions (Cheng et al. 2023; Sasu 2023), it has also presented substantial environmental and social challenges (Orimoloye and Ololade 2020; Ogunjobi 2023). Large-scale mining operations have been associated with deforestation, water pollution, and habitat destruction (Oggeri and Laker 2023). Additionally, the extensive use of toxic chemicals, such as cyanide and mercury, in gold extraction processes poses severe environmental risks, affecting ecosystems and endangering biodiversity (Obuobi et al., 2022).

In the context of small-scale gold mining in developing countries, the challenges are nuanced and equally pressing. Artisanal and Small-scale Mining (ASM) operations (which is an activity that encompasses small-scale gold mining), often lack the infrastructure and technology to implement sustainable mining practices (Morse 2003). As a result, environmental degradation is a common concern, with deforestation, soil erosion, and water contamination being frequent outcomes (Davies et al. 2020). Socially, the lack of stringent regulations in some areas can lead to unsafe working conditions, child labor, and inadequate health and safety measures for miners (Morse 2003).

The interplay between economic necessity, environmental impact, and social well-being underscores the need for a comprehensive and sustainable approach to gold mining in developing countries (Zhang, Meng, and Zhang 2023). In the subsequent sections, we will delve into the exploration of the current state of small-scale gold mining in urban environments, offering a path towards understanding the need for responsible and ethical practices.

2.3 Current State of Small-Scale Gold Mining in Urban Environments

Small-scale gold mining (SSGM) within urban environments represents a complex interplay of socio-economic dynamics, environmental concerns, and regulatory challenges (Awual and Ismael 2014). This section provides an in-depth analysis of the current state of SSGM in urban settings, shedding light on its practices, impacts, and the factors driving its proliferation.

2.3.1 Socio-Economic Drivers

SSGM in urban environments is propelled by a confluence of socio-economic factors (Gratz 2002; Green 2014). In many cases, it serves as a vital source of income for marginalized communities, offering livelihood opportunities where formal employment is scarce (Green 2014). The allure of gold, coupled with its high market value, incentivizes individuals to engage in mining activities as a means of sustenance. Moreover, the informal nature of

SSGM allows for flexible work arrangements, attracting individuals seeking autonomy and self-employment opportunities.

Furthermore, urbanization and population growth contribute to the expansion of SSGM within urban environments. As cities expand, encroaching upon previously rural areas, informal settlements emerge near gold-bearing regions (Gratz 2002). The proximity of these settlements to mining sites facilitates the influx of labour, creating a symbiotic relationship between urbanization and SSGM.

2.3.2 Environmental Impacts

Despite its socio-economic significance, SSGM in urban environments exerts considerable pressure on the surrounding ecosystem (Green 2014). The use of rudimentary extraction methods, such as mercury amalgamation and cyanide leaching, leads to the release of toxic substances into the environment. Contamination of soil, water bodies, and air quality poses serious health risks to both miners and nearby communities.

Moreover, the informal nature of SSGM operations often results in inadequate waste management practices, leading to the accumulation of mine tailings and debris in urban areas (Gratz 2002). This not only degrades the aesthetic quality of the environment but also exacerbates the risk of environmental contamination and ecosystem disruption.

2.3.3 Regulatory Framework

The regulatory framework governing SSGM in urban environments is often fragmented and inadequately enforced (Taylor and van der Velden 2019; Fry 1975). In many cases, informal mining activities operate outside the purview of existing regulations, evading taxation, and environmental oversight. The absence of formal recognition exacerbates the vulnerability of miners to exploitation and perpetuates a cycle of poverty and environmental degradation (Chandler 2013).

Furthermore, conflicting land tenure systems and jurisdictional ambiguities complicate regulatory enforcement efforts (Campbell et al. 2010). Urban areas often encompass a patchwork of land ownership arrangements, ranging from public to private and informal settlements. This multiplicity of stakeholders makes it challenging to delineate responsibilities and enforce compliance with environmental and safety standards (Campbell et al. 2010; Chandler 2013).

2.3.4 Social Dynamics

SSGM in urban environments is characterized by complex social dynamics, shaped by power imbalances, cultural norms, and historical legacies (Chandler 2013; Campbell et al. 2010). In many cases, mining activities are dominated by informal networks and associations, which may operate on the fringes of legality. These networks often exhibit hierarchical structures, with certain individuals or groups exerting disproportionate influence over decision-making processes (Taylor and van der Velden 2019).

Moreover, the influx of migrant labour into urban mining areas can strain social cohesion and exacerbate tensions with local communities (Gibb and O'Leary 2014). Competition for limited resources, such as land and water, may fuel conflict between miners and Indigenous or marginalized groups, leading to social unrest and displacement (Okoh 2013; Hovardas 2019).

2.3.5 Health and Safety Concerns

The informal nature of SSGM operations in urban environments exposes miners to a myriad of health and safety hazards (Zhang, Meng, and Zhang 2023). Inadequate ventilation in underground mines increases the risk of respiratory illnesses, while exposure to toxic substances such as mercury and cyanide poses long-term health risks (Zhang, Meng, and Zhang 2023; Lam and Lau 2000; Akcil 2006). Moreover, the use of rudimentary tools and equipment heightens the likelihood of accidents and injuries, ranging from falls to equipment malfunctions (Sufiyan and Ogunleye 2012; Ogan 2021; Ogan et al. 2016; Schrecker, Birn, and Aguilera 2018).

Furthermore, the precarious livelihoods of SSGM workers perpetuate cycles of poverty and vulnerability (Tarazona, Ceballos, and Broom 2020; CPRC 2014; Dukiya, Ojoye, and Morenikeji 2023). Limited access to healthcare, education, and social protection exacerbates the socio-economic marginalization of mining communities, trapping them in a cycle of exploitation and deprivation (Dukiya, Ojoye, and Morenikeji 2023).

In summary, the current state of SSGM in urban environments is characterized by a complex interplay of socio-economic, environmental, regulatory, and social dynamics. Addressing the myriad challenges associated with urban SSGM requires an integrated approach that integrates regulatory reform, environmental management, community engagement, and sustainable livelihood strategies. By understanding the root causes and complexities of SSGM in urban settings, policymakers, practitioners, and stakeholders can develop targeted interventions that can optimize off-site principles to promote sustainable development and improve the well-being of affected communities. In order to address these challenges, we discovered from literature, that adapting some off-site would significantly influence the implementation of sustainable practices in order sectors, such as the mining sector and the SSGM in particular. However, how can off-site principles be relevant in optimizing the activities of small-scale gold mining? The limitation of this study is critically based on the lack of research work addressing this subject, amongst other gaps.

3. METHODOLOGY

An analytical research study was conducted, with a partisan-systematic approach. The study involved critically analysing and interpreting off-site principles from contents of research articles that were available within a chosen database. A total of 783 publications were identified, when a search of off-site construction was conducted on Scopus. The search result was reduced (to 528 articles) when a search filter was applied to place the results within the range of (2013 – 2023) and was limited to Modular Construction publications (86), and further limited to journal articles only (49). Thereafter some random selections for the study were made based on related topics, quality abstracts, and based on internal searches for benefits and application, aimed at the study's points of interest (see figure 1). That was executed because, the primary aim of this analytical research is to provide insights, interpretations, and judgments about the subject matter based on a thorough examination of its components, arguments, evidence, and implications.

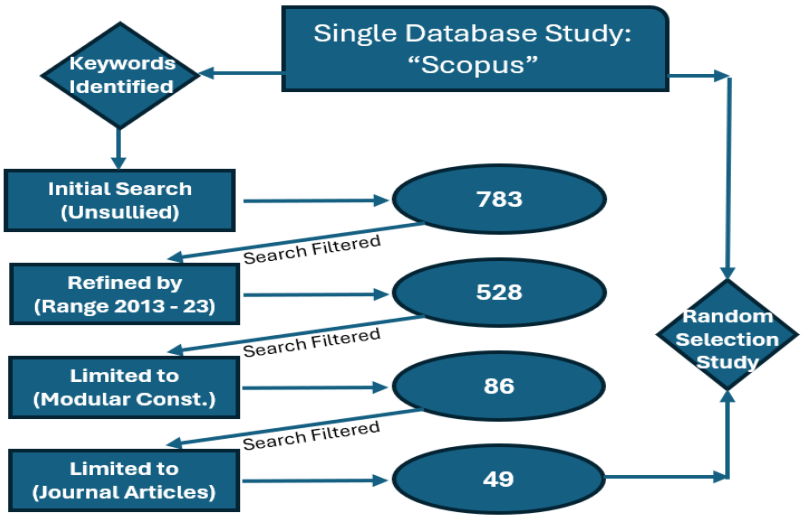

Figure 1: A Systematic Single Search Strategy (Single Database Study)

During this study, we briefly carried out:

i. **A Critical Analysis of Off-site Principles:** This study involved critically examining offsite principles, identifying strengths and weaknesses, evaluating the validity of arguments, and assessing the reliability of evidence presented.

ii. **An Interpretation of Off-site Principles:** A brief but in-depth review was done, seeking to understand the underlying meaning, themes, and implications of the principles within their broader context. This brief review was concluded by identifying patterns, connections, or contradictions within the scope.

iii. **A Synthesis of Off-site Principles:** This study involved synthesizing information from multiple sources or perspectives to provide a comprehensive understanding of how off-site principle can be applied further in small-scale gold mining. Further studies would report the comparing and contrasting of different viewpoints, theories, or empirical findings identified.

iv. **An Evaluation of Off-site Principles:** This study assessed the quality, relevance, and significance of the off-site principles from a construction viewpoint, considering factors such as its contribution to the field, its methodological rigor, and its potential impact on theory or practice in a new context such as SSGM.

v. **An Argumentation of Off-site Principles:** Thereafter, the study narrowly presents some coherent arguments as benefits and challenges based on the analysis and interpretation of the materials that were analytically reviewed with a systematic approach. The arguments have been supported with the evidence and reasoning provided and have been backed with a few relevant references.

vi. **An Engagement with some Context of Off-site Principles:** The study also analysed off-site principles while exploring its broader socio-cultural, historical, or theoretical contexts. Which is why at intervals, discussing relevant background information, proposing theoretical frameworks, or emphasizing contemporary possibilities related to the subject were attempted. Although most of this aspect was not fully captured in this study.

Overall, this study goes beyond analytically reviewing content; it involved a deep engagement with the scope of study, offering critical insights, interpretations, and judgments that has now contributed to a deeper understanding of the application of off-site principles in a related subject, such as small-scale gold mining.

4. DISCUSSIONS AND FINDINGS

4.1 Identified Possibilities with Off-site Adaptations

Off-site principles can be argued to represent the implementation of innovative and sustainable approaches to construction and related sectors. Hussein et al. (2021) claims that effective management of its supply chain would emerge as a crucial determinant of its success. Conversely, Chen et. al (2023) opined that the implementation of prefabricated projects is hindered by the high required cost. Nonetheless, recent research has prominently centered on modeling Off-site Supply Chain – Supply Chain systems which could enhance their efficacy and sustainability (Hussein et al. 2021). Although costs remain an issue, researchers claim that modular construction, an aspect of off-site principles, does have a place in the future (Wrigley et al. 2021; Chen et al. 2023).

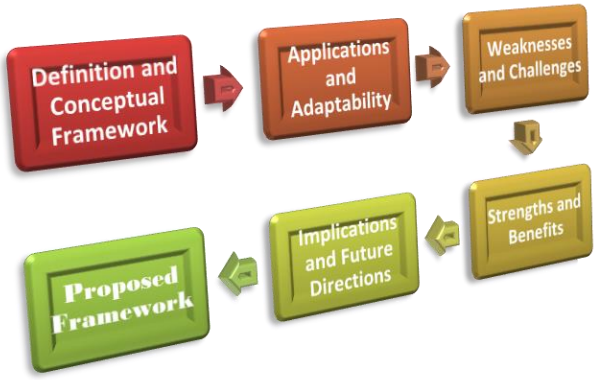

Figure 2: Analytical framework for Exploring the Adaptability of Offsite Principles in the Mining Sector

From the body of literature, the application of a simple framework to critically analyse the adaptability of off-site principles was implanted (see figure: 1). It was interestingly discovered that off-site principles have developed around its concepts, applications, strengths, but not without its weaknesses, challenges, and implications within various contexts particularly in industries such as construction and manufacturing. However, how can we adapt such developments to other sectors such the mining sector? Working with the simple analytical framework, that was developed during this study, revealed a great deal of what is possible.

4.1.1. Definition and Conceptual Framework: Off-site principles encompass a set of strategies aimed at optimizing processes, reducing environmental impact, and enhancing efficiency by relocating certain activities away from the primary site of operation. This concept originated primarily in manufacturing and construction industries, where prefabrication and modularization have been utilized to streamline production processes (Peiris et al. 2023). In the context of mining, off-site principles would involve decentralizing certain functions or activities to alternative locations to minimize environmental impact and improve operational efficiency.

4.1.2. Applications and Adaptability: Off-site principles have been widely applied in various industries, including construction, manufacturing, and logistics, with notable success. In construction, off-site manufacturing of building components has led to cost savings, reduced construction time, and improved quality control (Arashpour et al. 2015). Similarly, in manufacturing, off-site assembly and modularization have enhanced production efficiency and flexibility (Peiris et al. 2023; Anane, Iordanova, and Ouellet-Plamondon 2023). From this discussion, tied to the lead researchers 'deep field and rich regulatory experience', it can be strongly stated that in mining, off-site principles can be adapted to optimize small-scale operations by relocating certain functions, such as ore processing or waste management, to centralized facilities, thereby reducing environmental impact and improving resource utilization.

4.1.3. Strengths and Benefits: Off-site principles offer several potential benefits, including:

i. Environmental Sustainability: By relocating certain activities away from the primary site (Wang, Zhao, and Yin 2023), off-site strategies can minimize environmental degradation and reduce the ecological footprint of operations.
ii. Efficiency and Optimization: Off-site decentralization can streamline processes, optimize resource utilization, and improve operational efficiency, leading to cost savings and productivity gains.
iii. Risk Reduction: Decentralizing certain functions can mitigate operational risks associated with on-site activities, such as accidents, spills, and environmental incidents.
iv. Community Engagement: Off-site strategies can foster positive relationships with local communities by minimizing the impact of some of the mining activities on nearby residents and the ecosystems.

4.1.4. Weaknesses and Challenges: Despite their potential benefits, off-site principles face several challenges and limitations (Xue et al. 2021; Hussein et al. 2021; ortega, Mesa, and Alarcón 2023), including:

i. Infrastructure and Logistics: Establishing off-site facilities may require significant investment in infrastructure, transportation, and logistics, particularly in remote or inaccessible areas.
ii. Regulatory Compliance: Off-site strategies must comply with applicable regulations and environmental standards, which may vary depending on the jurisdiction and regulatory framework.
iii. Stakeholder Engagement: Effective stakeholder engagement is critical for the success of off-site initiatives, but it may be challenging to address concerns and solicit feedback from local communities and Indigenous groups.
iv. Technology Integration: Integrating advanced technologies into off-site facilities requires specialized expertise and investment, which may pose barriers for small-scale operators with limited resources.

4.1.5. Implications and Future Directions: The adoption of off-site principles in mining has the potential to transform small-scale operations, enhancing sustainability, efficiency, and community relations (Hussein et al. 2021; Xiao et al. 2022; Xue et al. 2021; Yi, Zhen, and Jin 2021; Zaalouk, Moon, and Han 2023). Future research and development efforts should focus on addressing the challenges and limitations associated with off-site strategies, exploring innovative technologies and approaches, and promoting collaboration between industry stakeholders, regulators, and local communities.

4.2 Possibility of Promising Opportunities

Off-site principles offer promising opportunities for optimizing small-scale mining operations, but their successful implementation requires careful consideration of contextual factors, stakeholder engagement, and technological integration. By addressing the challenges and limitations associated with off-site strategies, mining companies can achieve sustainable and socially responsible outcomes while maximizing operational efficiency and minimizing environmental impact.

5. RECOMMENDATIONS & CONCLUSION

The application of off-site principles for the optimization of small-scale gold mining (SSGM) offers a promising avenue for enhancing efficiency, sustainability, and environmental responsibility. In view of the possibilities that this study points out, it is important to sketchily elaborate and recommend our findings based on the discussions captured in sections 4.1 and 4.2. It is also imperative to recommend that more research should be conducted to explore these strategies in narrow details, as gaps for further studies regarding the application of off-site principles in optimizing SSGM activities. That said, in terms of their relevance to the context of SSGM operations, this study would finally highlight the identified key strategies in sections 5.1. to 5.4 that are recommended for adaptation.

5.1. Definition and Context

It is important to define the principle, its application, and its implication. Thus, off-site principles in small-scale gold mining would refer to a set of strategies and methodologies aimed at optimizing processes, reducing environmental impact, and enhancing sustainability by relocating certain activities or functions away from the primary site of operation. While traditionally associated with manufacturing and construction industries, the principles of off-site optimization hold significant potential for application in the mining sector, particularly in the context of SSGM within the built environments.

In the context of SSGM, off-site principles would involve the relocation or decentralization of certain mining activities or functions to alternative sites or facilities, thereby minimizing the environmental footprint of on-site operations and enhancing overall efficiency (Verbrugge, Lanzano, and Libassi 2021). This may include the adoption of pre-processing facilities, centralized waste management systems, off-site leaching, and/or off-site beneficiation plants, among other strategies.

5.2. Rationale and Objectives

The adoption of off-site principles in SSGM operations can be motivated by several key objectives:

i. **Environmental Sustainability:** By relocating certain activities away from the primary mining site, off-site strategies aim to minimize environmental degradation and reduce the ecological footprint of mining operations. This includes mitigating soil and water contamination, reducing air pollution, and minimizing habitat destruction.
ii. **Efficiency and Optimization:** Off-site optimization seeks to streamline mining processes, enhance resource utilization, and improve overall operational efficiency. By centralizing certain functions or implementing advanced technologies off-site, miners can achieve economies of scale, reduce costs, and increase productivity.
iii. **Risk Reduction:** Off-site strategies offer opportunities to mitigate operational risks associated with on-site mining activities, such as accidents, spills, and environmental incidents. By decentralizing certain functions or implementing redundant systems off-site, miners can minimize the likelihood and severity of adverse events.
iv. **Community and Stakeholder Engagement:** Off-site principles emphasize the importance of engaging with local communities, stakeholders, and regulators to ensure transparent and responsible mining practices. By relocating certain activities away from populated areas or sensitive ecosystems, miners can reduce conflicts and build trust with surrounding communities.

5.3. Key Strategies and Implementation Approaches

Several key strategies and implementation approaches can be employed to operationalize off-site principles in the context of SSGM within urban environments, such as *"Pre-Processing Facilities, Centralized Waste Management, Advanced Technologies, and Community-Based Approaches".*

	Key Strategies	Implementation Approach(es)
Strategy 1	Pre-Processing Facilities	Establishing off-site pre-processing facilities for ore beneficiation, crushing, and milling can help reduce the environmental impact of on-site mining operations. These facilities can be strategically located to optimize logistics, minimize transportation costs, and facilitate the recovery of valuable minerals.
Strategy 2	Centralized Waste Management	Implementing centralized waste management systems, including tailings storage facilities and treatment plants, can mitigate the risk of environmental contamination and ensure responsible disposal of mining waste. By consolidating waste management activities off-site, miners can minimize the impact on surrounding ecosystems and communities.
Strategy 3	Advanced Technologies	Leveraging advanced technologies, such as remote sensing, data analytics, and automation, can enhance the efficiency and sustainability of SSGM operations. By integrating these technologies into off-site processing facilities or monitoring systems, miners can optimize resource utilization, improve safety, and reduce environmental risks.
Strategy 4	Community-Based Approaches	Engaging with local communities and stakeholders is essential for the successful implementation of off-site strategies. By involving affected communities in the planning, design, and operation of off-site facilities, miners can build trust, address concerns, and ensure the equitable distribution of benefits.

Figure 3: Key Strategies and Implementation Approaches

5.4. Challenges and Considerations

While off-site principles offer significant potential for optimizing SSGM operations, several challenges, and considerations, such as infrastructure and logistics, regulatory compliance, stakeholder engagement, and technology integration, must be addressed:

i. **Infrastructure and Logistics:** Establishing off-site facilities may require significant investment in infrastructure, transportation, and logistics. Miners must carefully assess the feasibility and cost-effectiveness of off-site solutions relative to on-site operations. On the flipside funding organisations should consider furthering the research to build upon this study and to generate reliable information that could further improve the possibilities of implementing these findings.

ii. **Regulatory Compliance:** Off-site strategies must comply with applicable regulations and environmental standards. Miners must navigate regulatory requirements and obtain necessary permits and approvals for the establishment and operation of off-site facilities.

iii. **Stakeholder Engagement:** Effective stakeholder engagement is critical for the success of off-site initiatives. Miners must proactively engage with local communities, indigenous groups, regulators, and other stakeholders to address concerns, solicit feedback, and ensure transparency and accountability, especially as stakeholders may not understand these principles, and may likely feel unsafe to accept them, when initially proposed in the Community Development Agreement (CDA) and the Community Social Responsibility (CRS).

iv. **Technology Integration:** Integrating advanced technologies into off-site facilities requires specialized expertise and investment. Miners must assess the technical feasibility, scalability, and cost-effectiveness of technology solutions and consider potential risks and limitations. On the flipside research institutions, government agencies, and the private sector, should consider all the available possibilities that could ensure the application of these findings.

In conclusion, the adaptation and application of off-site principles as soundly argued, would offer a holistic approach to optimizing SSGM operations within the built environments. Not by merely relocating certain activities or functions off-site, but because miners can minimize environmental impact, enhance efficiency, and foster responsible mining

practices. However, the successful implementation of these principles would require as discussed earlier, careful planning, stakeholder engagement, and consideration of regulatory, logistical, and technological factors. Through strategic adoption of off-site principles, miners can achieve sustainable and socially responsible mining practices that would benefit both the environment and their local or host communities.

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