Mine Closure 2022 - M Tibbett, AB Fourie & G Boggs (eds)

doi:10.36487/ACG_repo/2215_18

The 5R Model: facilitating decision-making on repurposing of industrial and ancillary infrastructure

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Abstract

Closure of mining landscapes is widely discussed within, and investigated by, the mining industry with increasingly innovative alternative uses found for open pits, underground workings, waste rock landforms, tailings storage facilities and water dams. When it comes to industrial and ancillary infrastructure though, many mining companies elect only to decommission and dispose of this infrastructure onsite. However, there is a growing need for efficient, effective and sustainable ways to find alternative purposes for these features, particularly in the face of increasing resource scarcity.

The concept of 'adaptive re-use' is not new: it is common in the construction industry where re-use of materials and equipment is considered to be a win-win strategy, in modern communities, where recycling and even upcycling has become second nature, and in urban renewal, where there is a focus on repurposing of heritage buildings and other structures. Further, there is growing support for the 'circular economy' ethos, which favours careful management of resources and intelligent re-use of products and reconsidering the term 'market' more broadly.

Many mining companies are now adopting a circular approach in selected areas of their business and while this is mainly focused on active operations, it is considered that there is an opportunity to extend this thinking to mine closure. However, identifying what materials can be 'mined' for re-use or repurposing can be challenging, partly due to obsolescence but also because of tenure restrictions, liability issues, transport costs, legal constraints and other factors. On this basis, the '5R Model' has been developed to facilitate decision-making in relation to the alternative uses for industrial and ancillary infrastructure associated with mining and mineral processing operations.

This paper outlines the basis of the 5R Model and the way in which this classification system can be used to guide investigations and decision-making for repurposing of industrial and ancillary infrastructure, including blue-sky options. Drawing on case studies on alternative closure scenarios for mining and mineral processing infrastructure and lessons learned from 'urban mining', this paper also discusses potential pathways to achieve these uses and facilitate custodial transfer of physical assets, and ways in which this model can also assist companies meet their waste minimisation, carbon reduction and other targets during closure of their sites.

Keywords: *infrastructure closure, repurposing, adaptive re-use, circular economy, carbon reduction*

1 Introduction

There is significant discussion within the mining industry and in literature on repurposing of mining landscapes, with increasingly innovative alternative uses found for open pits, underground workings, waste rock landforms, tailings storage facilities and water dams. These even include uses as diverse as gravitricity facilities (Hall 2020) and subterranotherapy facilities (Tyson 2020).

The most common repurposing land uses have been found to be community and culture, construction and commercial, conservation and ecosystems, non-intensive recreation, and intensive recreation (Holcombe &

Keenan 2020). However, most of the discourse in this regard relates to repurposing of features such as open pits and underground workings rather than the industrial and ancillary infrastructure that supports mining operations. Consequently, opportunities for re-use, repurposing and regeneration of physical assets are being missed. On this basis, the '5R Model' was developed to facilitate decision-making in relation to the alternative uses for industrial and ancillary infrastructure associated with mining and mineral processing operations.

This paper initially describes the 5R Model and provides a hypothetical case study as a worked example of how to apply the model (Section 2). In this example, and in the remainder of this paper, the focus is on repurposing of infrastructure that tends to be overlooked, particularly where there are gaps in our understanding of societal–environmental relationships in the lead-up to and following mine closure (Holcombe & Keenan 2020). Key factors that need to be considered in making a decision on whether to repurpose infrastructure are summarised in Section 3, and an assessment of selected options in this regard is provided in Section 4.

2 Definition and application of the 5R Model

The '5R Model' was developed to guide proponents in decision-making in relation to the next use of mining and mineral processing infrastructure, but it can also be used in decisions regarding the next use of a whole mine. This model comprises five broad categories that consider options for the future use of infrastructure, as follows:

- Relinquish: Infrastructure is transferred to a government agency or NGO on behalf of the government (e.g. for conservation purposes) in a condition that could enable use by that agency or another party for an agreed purpose.
- Retain: The proponent maintains ownership of the infrastructure with an intent to use it again in the future for the same or different purpose(s). This option supports a 'cradle-to-cradle' approach, where the idea of 'closure' for those structures is, in essence, redundant. This may also form part of a rental agreement with other operators.
- Retail: Under this option, another party takes possession of the infrastructure under a rental or sales agreement. The infrastructure may be retained at its current location or transferred to another site, but its purpose and use are unchanged.
- Repurpose: The infrastructure is retained on site, but transitions from a mining to a non-mining use (e.g. tourism, residential or commercial) or combination of uses. Under this option, the main structural features may not be significantly modified other than through regeneration, refurbishment or renovation essential to realising the next use of those structures. However, this option may include extraction of certain infrastructure for recycling or re-use elsewhere. In some instances, infrastructure is re-used or repurposed while the primary business of mining and mineral processing is ongoing. This is known as 'co-purposing' and often occurs after, or alongside, other closure activities (Holcombe & Keenan 2020).
- Rehabilitate: The proponent completely decommissions the infrastructure and rehabilitates the land. The land can then be released for future development as a 'clean slate' on which other infrastructure can be developed.

Selecting a preferred 'next-use' option(s) for mining infrastructure can be a complex process, so this 'shallow dive to deep dive' model was developed to allow an efficient elimination of impractical scenarios. The decision tree provided as Figure 1 outlines some of the questions that can be asked in screening options and demonstrates in a simplified manner that there are natural 'dead ends' that could be eliminated quickly, allowing the proponent to focus instead on more viable options. To minimise the risk of overlooking or dismissing viable options, blue sky thinking and stakeholder engagement are encouraged.

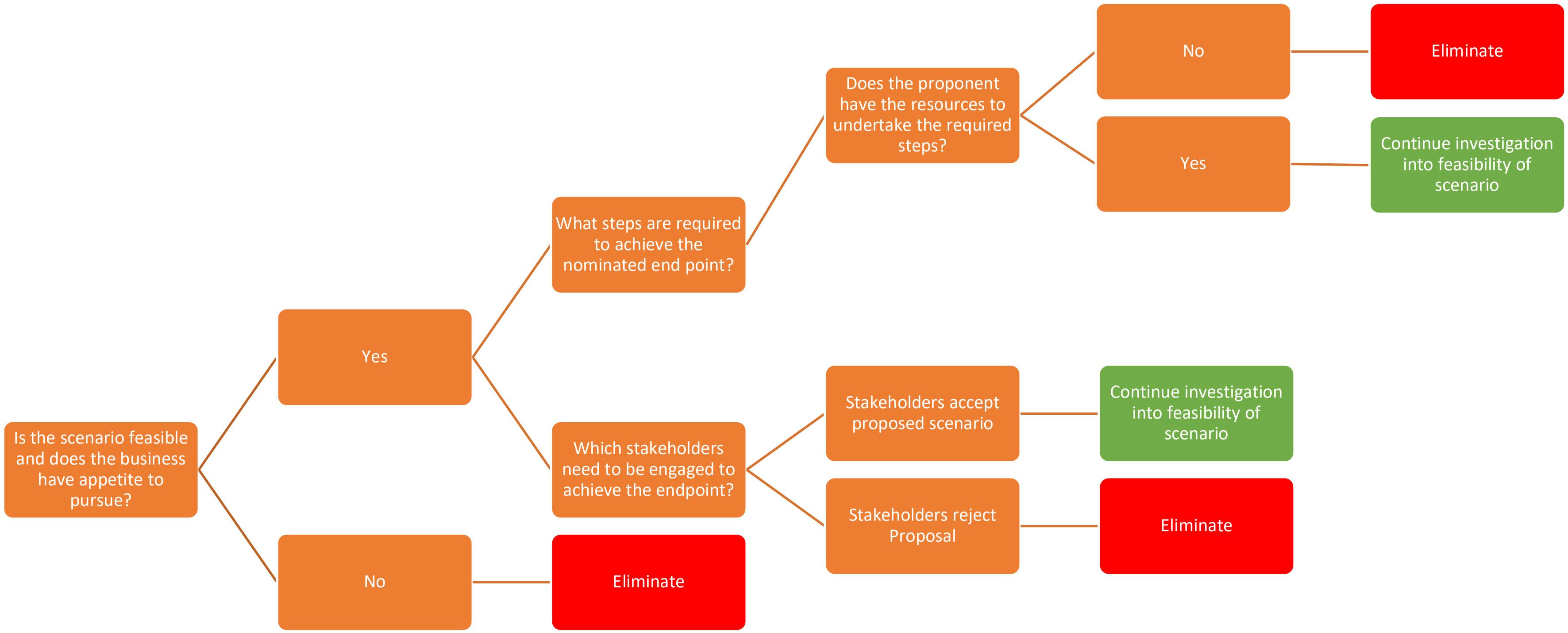

Figure 1 **Example decision tree that provides sample questions for determining option viability**

To aid with the conceptualisation of the model, a hypothetical case study is provided below. While the scenario is fictional, it is applicable to many mine sites across Australia and globally.

Our case study considers the fate of a railway network owned by the fictional company ‘MegaMining’, a global mineral miner and processor of precious metals. For the purposes of this case study, we have assumed that the company has mines across several regional hubs that are connected by a full service rail network. The network uses the gauge of an industrial freight network and can be adapted to a smaller gauge for other purposes if needed. An agreement is in place between the company and the state government that includes an option for most or all of the network to be transferred to the government when no longer required by the company. This is considered by the company to be the default position for closure, but under the agreement, the govenment has the option to refuse to accept the railway in full. MegaMining has therefore determined that it would be prudent to understand its options if the government decides not to take ownership of this infrastructure.

Our case study assumes that much of the rail line is in regional areas and that it passes through or is near to several regional population towns and tourist hotspots. Based on blue-sky thinking and after long and fruitful discussions with regional tourism operators, local government agencies and special interest groups, it is considered that a portion of the railway between two regional hubs could be used by commuter trains and to access a national park. However, there is some concern about whether a sufficiently qualified operator could be found to operate the rail and support infrastructure and prevent this from falling into disrepair. For this option to be viable, it is likely that MegaMining would need to train the next operator and may need to provide additional resources. The state government would also need to provide techncial support, along with funding until the new operator has a self-sufficient business.

Using the flow chart presented as Figure 1, MegaMining analyses various options to understand if there are any critical blockers and determines that the proposal to repurpose the rail infrastructure should be further investigated. No critical flaws have been identified at this stage, so MegaMining decides to undertake a feasibility study to better understand the option and determine the next steps.

A brief worked example of MegaMining’s decision-making process is provided as Figure 2. This omits decision-making timelines for simplicity, though it is recognised these could be lengthy. For example, in Figure 2, the process of obtaining stakeholder acceptance and in-principle agreement on the option of repurposing part of the railway network appears to have been simple. However, in reality, this could take several years of engagement and multiple iterations of concept plans before in-principle agreement is reached and a decision to progress to the next stage is made.

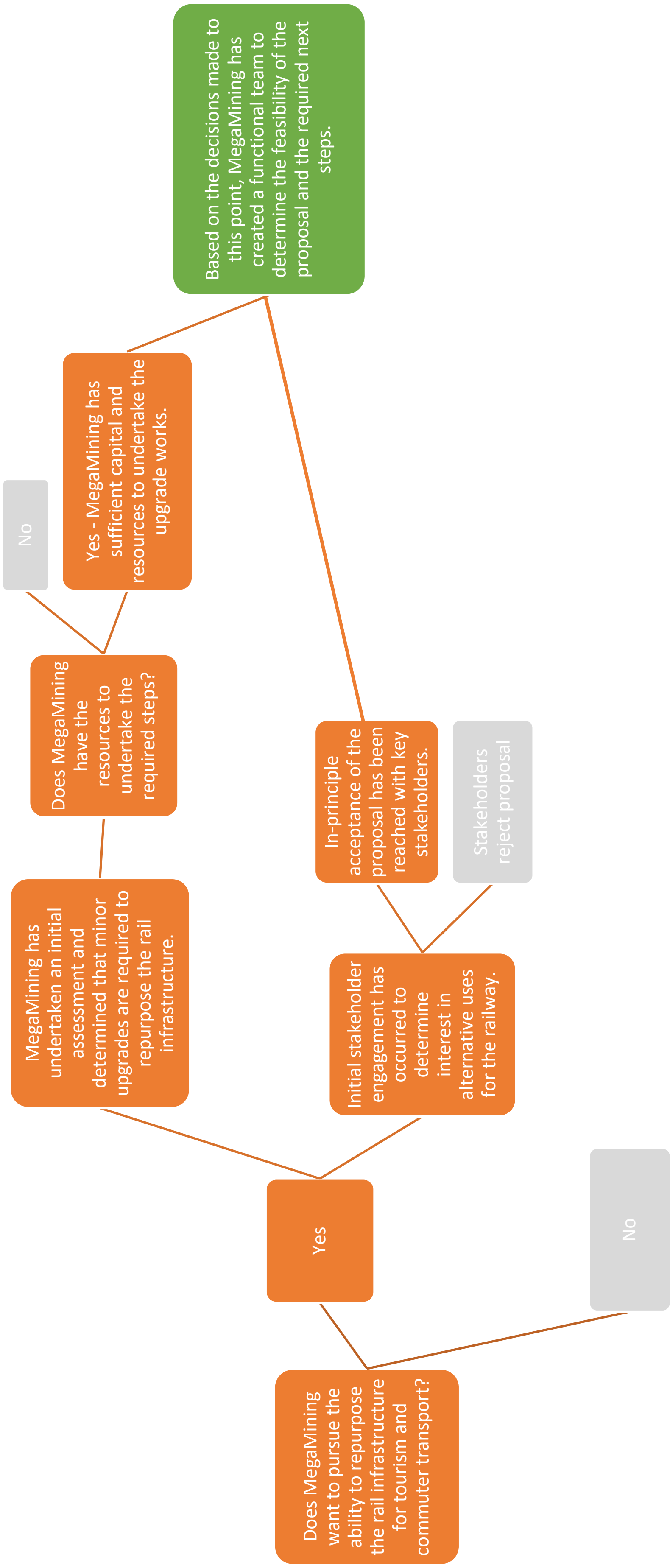

Figure 2 Worked example of a decision tree for the hypothetical MegaMining case study

3 Influencing factors

Effective repurposing and custodial transfer of mining and industrial infrastructure couples "the science with the social" (Holcombe & Keenan 2020) and assesses not only the engineering and environmental considerations, but also the politics and social dimensions of this process. These considerations include, but are not limited to, those listed in Table 1. This table is not exhaustive, but includes the influencing factors identified through the experience of the authors of this paper as well as a review of selected literature (Beuemann 2020; Finucane & Tarnowy 2019; Holcombe & Keenan 2020; Hu 2021; Iacovidou & Purnell 2016; Keenan & Holcombe 2021; Kretschmann 2020; Murphy et al. 2019; Wallis et al. 2019; Worden 2020). The way that these and other factors manifest at each site influences whether they are catalysts or barriers for repurposing of infrastructure.

Table 1 Factors influencing decisions on whether to repurpose mining infrastructure

Factor	Considerations
Characteristics of infrastructure	Type and scale of infrastructure
	Age and likely condition of infrastructure at closure, noting that infrastructure built to a high standard is more likely to be re-used or moved to, and reinstalled at, other locations
	Materials used to construct infrastructure, noting that where hazardous materials (e.g. asbestos, radioactive materials) have been used in construction, this infrastructure may not be suitable for repurposing
	Functional limits of infrastructure
	Suitability of infrastructure for intended repurposing use
	Obsolescence
	Aesthetics
Mine site context	Life-of-mine
	Extent of progressive rehabilitation that may provide for early transition of infrastructure to its next use or opportunities for co-purposing, but which may also limit or remove opportunities for repurposing
	Length of care and maintenance periods or other inactivity (including duration of abandonment of a legacy site)
	Ability for extractive companies to diversify into other industries (including alternative energy or commercial industries)
Location	Proximity to townships and other communities
	Proximity to other mines and industries
	Connectivity to existing infrastructure (transport, energy, accommodation, water and communication)
	Proximity to other attractions
Regulatory environment	Requirements specified in closure-specific legislation, regulations and guidelines, and in non-closure-specific instruments
	Land zoning and tenure
	Planning requirements, including fire safety, disabled access and heritage constraints
	Historical commitments to stakeholders
	Need to amend aspects of the regulatory framework to support the proposed next use of infrastructure

Factor	Considerations
Environmental	Ecological values and potential to support ecosystem function, habitat and associated community values
	Physical, chemical and biological hazards within the environmental setting
	Environmental risks associated with the proposed next use
	Global impacts from the loss of finite resources to landfill
	Land capability
	Climate change and resilience
	Landscape design strategies
	Ecotoxicological risks to ecosystems
Economic	Appetite and need for economic diversification
	Level of demand for the next use (e.g. tourism)
	Cumulative supply of infrastructure available to be repurposed
	Synergies with adjacent or nearby land uses, particularly if these improve the economic effectiveness of the next site use under consideration
	Need for development partners
	Cost (and practicality) of deconstructing, relocating and/or renovating infrastructure
Social and cultural	Level of community attachment to towns and other places, which may encourage local residents to champion repurposing and economic transitions
	Historical values
	Predicted population growth and demographic change
	Urbanisation of adjacent areas
	Social and cultural risks associated with the proposed next use
	Human health risks
Community engagement and involvement	Extent, inclusiveness and effectiveness of stakeholder engagement, including outreach for input and innovation, collaboration, etc.
	Engaging at all stages of closure planning and implementation, and, where appropriate, partnering with community to develop shared goals, responsibility and ownership
	Engagement with Indigenous peoples
	Potential to establish partnerships, foundations, trusts or other mechanisms to enable local communities to develop and implement new ventures involving the use of mining and industrial infrastructure

Factor	Considerations
Preparedness and intent	State policies and regional plans Company vision, policies, structure, leadership and guidance to support repurposing and transition to next use of a site and its infrastructure Planning horizons (recognising that the level of detail at which closure planning occurs often depends on the time left to closure) Ability to identify and implement local solutions to fit local circumstances Level of industry investment in post-mining land uses and economic transitions, with companies that 'put down roots' and develop attachments with the local community tending to take an interest in, and responsibility for, establishing a post-mining land use and economic transition at closure Ethics Perceptions desired by the company and perceptions of the infrastructure held by the future owners
Capacity	Funding opportunities, including state financial support (noting that without this, socio-economic transition in post-mining regions can be very challenging) Company structure, financial resources, social performance, etc. Most examples of industry-led repurposing of mining and industrial infrastructure seem to come from major companies, suggesting that smaller companies may not have the resources Capability within the community to develop and implement a business case, and time/resources to build capacity if lacking Financial ability, physical ability and skills available among future owners to maintain and/or operate repurposed infrastructure
Access to knowledge base	Publication of case studies, lessons and other information sharing to improve collective understanding of successful repurposing, important challenges encountered (and how they were overcome), etc. Access to industry and other databases Access to outcomes of industry initiatives Lessons learned from outside of the mining industry Accessibility of knowledge and information, including language, IT proficiency, distribution platforms, etc. Representation of different perspectives Level of detail and reliability of information Future research

4 Options analysis for repurposing of infrastructure

4.1 Overview of options

Not all infrastructure will be amenable to repurposing in part or in full. All old structures experience natural decay and fatigue degradation with time or may have been damaged such that future structural performance is unlikely to be adequate without substantial structural changes or additional protective measures that may be costly, may consume significant materials and/or be energy intensive. However, where repurposing is feasible, there are essentially three broad options available, as illustrated in Figure 3. These are:

- Retention and onsite re-use of infrastructure or redirection following any necessary refurbishment or renovation.
- Recovery of selected structural components to be re-used for the same function without destruction.
- Recycling of material that would otherwise be disposed following demolition but instead are reprocessed into raw material for new products.

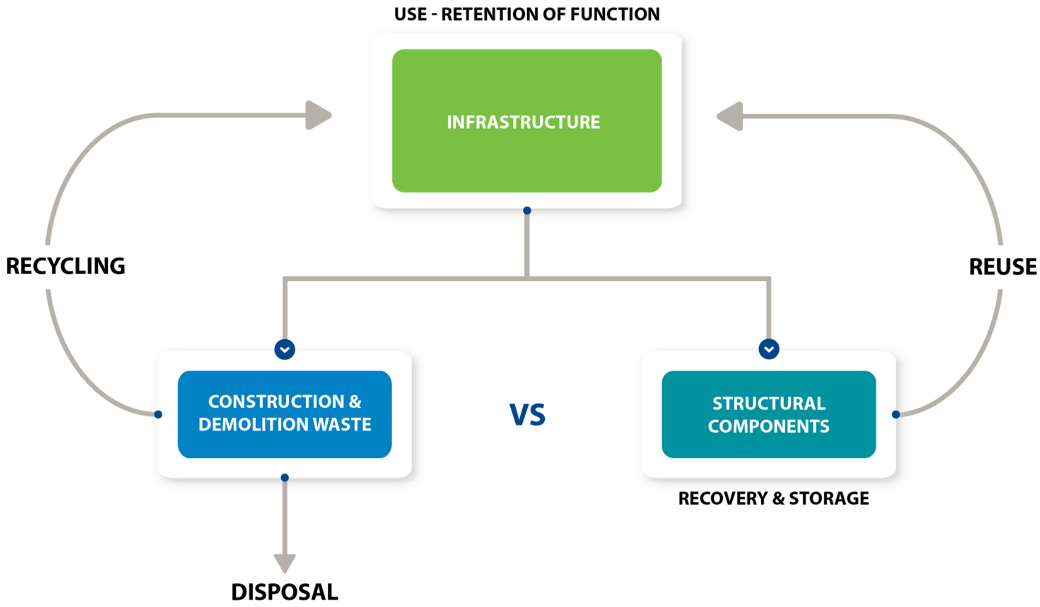

Figure 3 Typology for repurposing of mining infrastructure, modified from Iacovidou & Purnell (2016)

4.2 Retention or redirection of function

Where no use for mining and industrial infrastructure can be found, these are often demolished. This can result not only in widescale physical changes, but also in significant social changes. For example, van de Weijer (2018) reports that during the clean-up operation that occurred after the Dutch coal mines in Parkstad were closed:

> *"…mining landscapes were wiped clean and industrial relics were all but demolished. The radical efficiency of this transition has, in current day, induced a public feeling of remorse over the lost architectural relics of the mining period".*

However, when constructed to a high quality, the infrastructure used for mining and mineral processing can be re-used in situ or can be relocated and rebuilt at another site. Where repurposing of mining infrastructure for other activities occurs in situ, this assists in transitioning the local economy and mitigates the loss of the mine by building on and/or establishing new forms of attachment to the site and region (Holcombe & Keenan 2020).

Repurposing former mine infrastructure for tourism and recreation accounts for around 25% of the uses for these features identified by Finucane & Tarnowy (2019), while repurposing for community and business purposes (e.g. offices, hotels, retail facilities and residential usage) also accounts for around 25% of the identified uses. It was noted by Finucane & Tarnowy (2019) that opportunities for community and business use are more likely to exist where mines occur near settlements and larger population centres. Indeed, a more recent study by Hu (2021) found that adaptive re-use of collieries as industrial heritage could enhance the viability of urban regeneration for mining cities in China. This study considered historical, cultural, natural, aesthetic and economic values, and found that opportunities to adaptive re-use depended on the principles of integrity, authenticity, sustainability, and multi-party cooperation. In assessing opportunities for preservation of industrial heritage in Jiaozuo City, Hu (2021) recommended that conservation efforts not only protect the integrity of the infrastructure, but also consider the relationship between the infrastructure and the surrounding architecture and urban environment so that it can be integrated into the modern urban environment. Further, this author considered that steps should be taken to ensure no secondary damage so that the 'true state' of these features can be preserved, along with relevant historical information.

At this point, it is worth mentioning though that of all the features that architectural preservationists try to save, industrial buildings are considered to be the most difficult due to a range of factors, including their size, financial constraints, planning and other regulatory requirements (Alter 2020; van de Weijer 2018). Further, as pronounced so aptly by Alter (2020), "they are not cute". Consequently, the effort made to reconfigure mining infrastructure at the Zollverein Coal Mine in Germany, where processing facilities were repurposed as an entertainment hub, has been extolled as responsible for starting an international movement in renovating for aesthetic needs, not just practical needs (Holcombe & Keenan 2020).

4.3 'Mining' the infrastructure

It is considered that deconstruction and re-use of infrastructure offer higher environmental and economic benefits than demolition and recycling when evaluated over the whole life of the structure (Bender & Bilotta 2019; Iacovidou & Purnell 2016). For example, re-use of construction materials and waste products from industrial processes (such as fly ash and slag, which can be used to replace cement in concrete production) facilitates resource conservation through reclamation of structural components and the carbon embedded in them, which in turn helps companies address both waste and carbon emission regulatory targets. Further, re-use reduces pressure on landfills, slows natural resource depletion and reduces the risk of ecological degradation caused by increasing extraction of raw materials (Iacovidou & Purnell 2016).

It is now commonplace to actively seek reusable materials to provide environmental and social benefits, and to ensure that much of their value is retained for as long as possible. Within the construction industry, this is known as 'urban mining' where 'prospecting' of buildings is conducted prior to renovation or demolition to identify usable materials and products that can be recovered and re-used rather than treated as waste materials for disposal. The concept of urban mining is not new, but increasing material demand and reduced building lifetimes, coupled with the scale of the climate crisis, has resulted in urban mining being projected as a crucial measure for improving resource efficiency (Arora et al. 2021; Blok 2021). It is a circular economy strategy on a macro level, as it is capable of returning construction and demolition wastes as raw materials in the industrial processes (Bender & Bilotta 2019).

It is considered that mining and mineral processing operations have much scope for adopting a circular approach to business (International Council on Mining & Metals [ICMM] 2022). However, when it comes to industrial and ancillary infrastructure, many mining companies elect only to decommission and dispose of this infrastructure onsite. This occurs partly in the face of obsolescence but also because of tenure restrictions, liability issues, transport costs, legal constraints and other factors. However, there is a growing need for efficient, effective and sustainable ways to re-use and repurpose industrial and ancillary infrastructure, particularly in the face of increasing resource scarcity. The cyclical approach to manufacturing and resource management is particularly well suited to the mining and metals industry (ICMM 2022).

4.4 'Mining' the waste

In addition to 'mining' infrastructure for re-use or repurposing, it is possible to 'mine the waste'; in other words, to re-use or recycle materials that would otherwise be disposed of as waste. Almost anything within buildings and infrastructure on a mine site can be recycled. For example, on the whole, metals are infinitely recyclable as their inherent durability, strength and anti-corrosive properties help to enhance the longevity of products in which they're used. The high value of many metals and minerals also incentivises the recovery of such materials at the end of a product's lifecycle, and hence there are many methods in place to facilitate their re-use and recycling (ICMM 2022).

In general, recycling of materials at mining and mineral processing operations undergoing closure is easier when the mine is in close proximity to urban areas, particularly those in rapidly growing regions where the volume of construction may eclipse the volume of demolition. For example, Blok (2021) found that more than five million tons of building materials were needed to meet the demands of a region in the Netherlands in 2018–2022, which is 20 times more than the estimated supply of those materials from the 'urban mine' in that region. In regions such as this, the ability to use materials sourced from demolition and disassembly of buildings and other infrastructure on a mine will depend on the availability of inventories on the harvestable materials present on the site, the value in, and cost of, reusing these materials, scheduling and other factors.

Mining and mineral processing operations also produce a steady stream of electronic scrap, including computers, telephones and domestic appliances. This has prompted companies such as Mitsubishi Materials Corporation to adopt a group-wide recycling-oriented business model that promotes recycling of materials and resources, including home appliances and aluminium beverage cans (ICMM 2022). JX Nippon Mining & Metals also recycles and repurposes a wide range of materials, from industrial waste oil to used mobile telephones, with its copper recycling system enabling recovery of around 26% of its total scrap production. Sumitomo Metal Mining has also made significant progress in recycling of copper scrap, with recovery rates almost doubling in the five years following 2010 (ICMM 2022).

In addition to recycling of materials, increasing attention is being paid to finding beneficial use of mining waste. Motivated by the depletion of natural resources, the promotion of sustainability and the concept of a circular economy, and development of new technologies to unlock the intelligent re-use of waste materials, considerable effort has been made into finding ways in which mining waste can be used in the manufacture of concrete and fired bricks, as landscaping material or as aggregate in road construction, and in production of resins, glass, ceramics, glazes and pigments (Ally et al. 2021; ICMM 2022; Kuranchie 2015).

Not all materials can be readily re-used or recycled. For example, the fate of used tyres is an ongoing challenge. A recent analysis on the consumption and fate of mining industry off-the-road tyres by Randell & Baker (2020) on behalf of TyreStewardship Australia found that only 3% of mining tyres report to landfill. At first glance, this appears to be a positive finding. However, these authors confirmed that the low volume of used mining tyres reporting to landfill was because most jurisdictions do not allow landfilling of whole tyres due to poor handling and compaction, which results in very poor use of airspace. With few other options available, the fate of most of these materials (80%) was onsite disposal. The analysis found that used mining tyres could be stored and disposed onsite with no limits on the quantities or locations in New South Wales, Queensland, and the Northern Territory (NT). It was reported by Randell & Baker (2020) that the NT Environmental Protection Authority would like to see the tyres recovered, but that onsite burial was seen as the only option due to the remoteness of mines.

Randell & Baker (2020) found that 57% of mine sites nationally are within 500 km of a used tyre processor, but that few of these facilities are able to process large used mining tyres. It was recognised that investment would be required to enable this processing with the suggestion that these costs would be around 2–5% of the cost of new tyres depending on the proximity of the mine to a tyre processing facility. However, while mining companies are allowed to stockpile or dispose of used mining tyres onsite (which they can do at effectively no cost), the recovery of mining tyres in Australia is unlikely to be widespread. To improve recovery of used mining tyres, various strategies have been recommended. These include leasing rather than sale of mining tyres by tyre retailers, co-regulatory or mandatory product stewardship to fund tyre recovery, and development of onshore energy recovery markets for tyre-derived fuel where used mining tyres could be processed and used to offset the use of thermal energy production in the future (Randell & Baker 2020).

The challenges associated with recovery and re-use of used mining tyres are not unique to Australia, with potential regulatory and other solutions being investigated by many countries. For example, Chile has implemented legislation that requires 100% recovery of mining tyres by 2026 (Randell & Baker 2020).

5 Conclusion

Recycling, re-use and repurposing has become second nature to modern communities as we strive for environmental sustainability (Department of the Environment and Heritage 2004). Further, there is growing support for the circular economy ethos that favours careful management of resources and intelligent re-use of products. More mining companies are now adopting a circular approach in selected areas of their business, and while this is mainly focused on active operations, it is considered that there is opportunity to extend this thinking to mine closure. The 5R Model can be used to analyse options and support closure planning for mining features and infrastructure. This in turn will provide confidence to the regulator and other stakeholders that any decision to repurposing mining and industrial infrastructure has been made in a way that balances economic considerations with the need to retain the intrinsic value of the past while meeting new demands (Wu et al. 2021).

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