

Beyond Extraction: How Doubt and Cognitive Flexibility Drive Sustainable Quarry Rehabilitation

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Abstract

The rehabilitation of quarries presents a significant environmental and socio-economic challenge, requiring the reconciliation of industrial interests with ecological sustainability. Traditionally, rehabilitation efforts have been constrained by rigid perspectives, prioritizing economic feasibility over ecological restoration. This paper explores how doubt and cognitive flexibility serve as critical mechanisms in reshaping stakeholder perceptions, ultimately fostering more adaptive and sustainable rehabilitation strategies. By challenging entrenched beliefs, doubt stimulates the reconsideration of conventional methods, while cognitive flexibility enables stakeholders to integrate innovative, nature-based solutions into rehabilitation frameworks. Using Lebanon's cement quarries as a case study, this paper examines how collaborative dialogues between government authorities and industry stakeholders have facilitated shifts in perception. The Ministry of Environment (MoE) advocates for stricter regulations to mitigate environmental degradation, while quarry operators express concerns over economic constraints and operational feasibility. Through a mediated process emphasizing cognitive flexibility, both parties have explored hybrid rehabilitation models that balance environmental restoration with economic viability. Drawing on international case studies-including the Eden Project (UK), Karuizawa Quarry (Japan), and Alentejo (Portugal)-this paper highlights how successful rehabilitation projects leverage doubt and adaptability to drive transformative change. The concept of ecotones, as transitional zones fostering biodiversity and collaboration, serves as a metaphor for the intersection of industrial and ecological interests. By embracing doubt and cognitive flexibility, stakeholders can move beyond extraction toward a future where quarry rehabilitation is not merely a regulatory obligation but an opportunity for sustainable ecological and economic integration.

Keywords: Quarry rehabilitation; Cognitive flexibility; Environmental psychology; Stakeholder perceptions; Ecotones; Nature-based solutions; Sustainable restoration; Industry-environment balance; Adaptive management; Ecosystem resilience

Abbreviations: MoE: Ministry of Environment; NBS: Nature-Based Solutions; EIA: Environmental Impact Assessment; CBD: Convention on Biological Diversity; SDGs: Sustainable Development Goals; UNFCCC: United Nations Framework Convention on Climate Change; UNCCD: United Nations Convention to Combat Desertification; CO₂: Carbon Dioxide

Introduction

Quarries play a fundamental role in urban and economic development, supplying raw materials essential for constructing infrastructure, buildings, and roads [1]. This industrial activity is a cornerstone of modern living, significantly contributing to economic expansion. However, the extraction processes involved in quarrying impose severe environmental costs, including habitat destruction, biodiversity loss, and disrupted water systems [2]. These consequences are often long-lasting, posing major challenges for environmental

restoration. Quarry rehabilitation is not just a legal requirement but an ecological necessity aimed at restoring and healing degraded landscapes [3]. When effectively implemented, rehabilitation can convert depleted sites into thriving habitats that promote biodiversity and ecological balance. However, the process is often met with conflicting interests among ecologists, local communities, and industry stakeholders [4]. Each group has divergent priorities regarding rehabilitation objectives, methodologies, and timelines, often leading to tensions between ecological restoration goals and economic interests. This conflict underscores the broader challenge of quarry rehabilitation: achieving a compromise that satisfies community needs while aligning with scientific and environmental imperatives. Traditional rehabilitation approaches have frequently prioritized short-term economic gains over long-term ecological sustainability, leading to suboptimal outcomes [5]. Environmental psychology offers a framework for bridging these gaps by fostering dialogue, trust, and collaboration among stakeholders [6]. Through psychological insights, cognitive flexibility can be enhanced to help individuals reconsider rigid perspectives, leading to more adaptive and sustainable rehabilitation strategies. Cognitive flexibility refers to the ability to shift perspectives, adapt to new information, and generate innovative approaches [7,8]. This adaptability is essential in addressing unpredictable environmental conditions and the evolving demands of ecological restoration. Encouraging cognitive flexibility can also help overcome psychological barriers such as confirmation bias, where individuals seek information that reinforces their pre-existing beliefs [9]. This is particularly relevant in the context of quarry rehabilitation, where entrenched industry norms and local skepticism often hinder progressive restoration efforts. This paper contends that doubt, when paired with cognitive

flexibility, plays a crucial role in transforming perceptions and fostering innovative solutions. By analyzing real-world case studies, this study demonstrates how introducing doubt in deeply held assumptions can lead to greater acceptance of ecologically sound and economically viable rehabilitation practices. Additionally, it highlights how integrating doubt with cognitive flexibility enables experts to design holistic rehabilitation strategies that balance economic viability with ecological resilience.

The role of doubt and cognitive flexibility in human perception

Understanding doubt as a catalyst for change: Doubt plays a crucial role in reshaping perceptions and fostering innovative thinking, particularly in contexts that require paradigm shifts, such as quarry rehabilitation. Festinger's [10] theory of cognitive dissonance suggests that when individuals experience doubt, they face psychological discomfort that compels them to either reinforce existing beliefs or seek alternative perspectives. In environmental decision-making, this cognitive tension can be a driving force behind questioning unsustainable practices and adopting more ecologically sound strategies. In the context of quarry rehabilitation, doubt can prompt stakeholders to reconsider traditional restoration methods, many of which have historically prioritized economic feasibility over ecological sustainability. Research in environmental psychology [11] highlights how psychological barriers, such as denial and resistance to change, often impede the adoption of sustainable behaviors. By introducing doubt about the long-term viability of conventional quarrying practices, it becomes possible to create openings for new approaches, such as Nature-Based Solutions (NBS) that align industry goals with ecological integrity.



Figure 1: Illustrates acceptability process: Reconciling and adapting community perception and expectations with field reality.

Cognitive flexibility as a tool for adaptation: Cognitive flexibility, the ability to adapt thinking patterns in response to new information or environmental changes, is central to shifting perceptions in quarry rehabilitation. Ionescu [7] and Miyake

[8] define cognitive flexibility as the capacity to shift between different conceptual frameworks, allowing individuals to adjust to novel circumstances and integrate innovative solutions. This adaptability is particularly relevant in environmental governance,

where rigid policies often fail to accommodate the complexities of ecological restoration. For example, in Lebanon's cement industry, quarry operators initially resisted new rehabilitation requirements imposed by the Ministry of Environment (MoE) due to perceived financial constraints. However, by engaging in facilitated discussions that encouraged cognitive flexibility, stakeholders were able to explore hybrid rehabilitation models that incorporated both ecological restoration and economic viability. Similar trends

have been observed in international case studies, such as the Eden Project [12] and the Alentejo Quarry Rehabilitation in Portugal [13], where cognitive flexibility allowed decision-makers to integrate multidisciplinary solutions that were previously dismissed as impractical (Figure 1). No matter how good the idea is, the main challenge remains to make the decision makers and stakeholders endorse it and overcome the preset ideas and lowering their resistance to change (Figure 2).

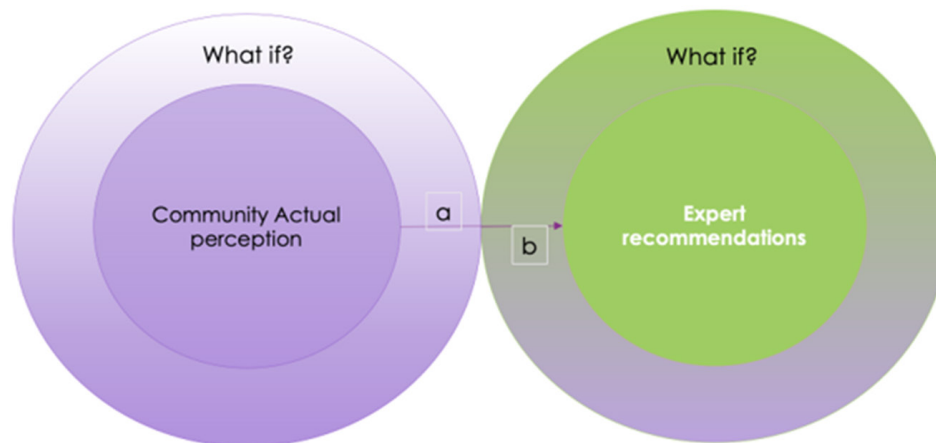


Figure 2: Illustrates the role of doubt to induce change.

The interplay between doubt and cognitive flexibility in quarry rehabilitation: While doubt serves as the initial trigger for change, cognitive flexibility ensures that this doubt leads to constructive adaptation rather than resistance. Kahneman [9] emphasizes that cognitive biases often prevent individuals from objectively assessing new information, leading to a tendency to reaffirm pre-existing views (confirmation bias). However, cognitive flexibility enables individuals and organizations to process contradictory information without immediate rejection, fostering innovative thinking. This interplay is evident in the case of Velka Amerika Quarry, Czech Republic [14] where initial skepticism about rehabilitating an abandoned limestone quarry into a functional ecosystem gradually gave way to an experimental approach leveraging ecological restoration techniques. Similar transformations have been observed in Karuizawa Quarry, Japan [15] where industry stakeholders transitioned from skepticism to active participation in wetland restoration once the feasibility of such projects was demonstrated. In the Lebanese context, the quarry rehabilitation initiative led by the Ministry of Environment demonstrated that by first introducing doubt about existing industrial practices, followed by guided engagement that promoted cognitive flexibility, stakeholders could gradually shift their perception from resistance to collaboration. This shift highlights the necessity of mediated dialogues that create an ecotone between industrial and ecological interests, allowing for adaptive co-management strategies [13] to emerge.

Ecotones as a metaphor for environmental perception and change

The concept of an ecotone—a transition area between two biological communities where different ecosystems meet and interact—offers a powerful metaphor for understanding the role of doubt and cognitive flexibility in environmental perception. Just as ecotones represent areas of rich biodiversity and dynamic interaction, the intersection of doubt and cognitive flexibility creates fertile ground for new ideas and approaches in environmental management. In the context of quarry rehabilitation, the “ecotone” between traditional industrial practices and emerging Nature-Based Solutions (NBS) is where significant potential for change lies. Doubt about the adequacy of conventional approaches, coupled with cognitive flexibility, allows stakeholders to explore this transition zone, integrating diverse perspectives and practices. This process mirrors the ecological dynamics of an ecotone, where different species and processes come together to create a more resilient and adaptive system [16].

Doubt, cognitive flexibility, and environmental decision-making: Environmental perception is shaped by a complex interplay of social, cultural, and psychological factors. Doubt can disrupt established perceptions, particularly in industries like quarrying, where economic incentives often outweigh environmental considerations. Cognitive flexibility enhances this process by enabling stakeholders to reconsider their priorities and explore alternative approaches. For example, the shift from

traditional rehabilitation practices to NBS in the Eden Project in Cornwall, UK, exemplifies the role of doubt and cognitive flexibility in environmental decision-making. Initially, the idea of transforming an exhausted clay pit into a global garden was met with skepticism [17]. However, as doubts about the sustainability of conventional rehabilitation methods grew, cognitive flexibility allowed stakeholders to envision and implement a more innovative solution. The Eden Project now serves as a model for integrating ecological restoration with public engagement and education [12].

Practical examples of quarry rehabilitation projects

Eden project, Cornwall, UK: As mentioned, this project transformed an old clay pit into a thriving ecological and educational center. The success of the Eden Project was due in large part to the stakeholders' willingness to doubt traditional rehabilitation methods and adopt a more flexible, innovative approach that integrated ecological restoration with public education [11].

Karuizawa quarry, Japan: In Japan, the Karuizawa Quarry was rehabilitated into a wetland habitat, focusing on restoring native vegetation and creating a habitat for local wildlife. This project required a shift from conventional industrial rehabilitation to an approach that prioritized biodiversity and ecological integrity. The success of the Karuizawa project highlights the importance of cognitive flexibility in integrating conservation goals into industrial rehabilitation [12].

Velka Amerika Quarry, Czech Republic: The rehabilitation of Velka Amerika Quarry involved converting the abandoned limestone quarry into a lake surrounded by natural vegetation. The project was initially met with doubt, as stakeholders questioned the feasibility of creating a sustainable ecosystem in such a degraded environment. However, through the application of nature-based solutions and the willingness to experiment with different ecological approaches, the site was successfully rehabilitated, becoming a popular destination for both wildlife and visitors [14].

Quarry rehabilitation in the Alentejo Region, Portugal: The rehabilitation of quarries in the Alentejo region involved restoring areas of significant environmental degradation into productive landscapes, often integrating agricultural activities with ecological restoration. The project emphasized the use of indigenous plant species and involved local communities in the rehabilitation process, illustrating the importance of cognitive flexibility in aligning ecological and economic objectives [13].

Case example: Rehabilitation of cement quarries in Lebanon

Background: Lebanon's cement industry has long relied on limestone quarries for raw material extraction. However, these operations have caused significant environmental degradation, including deforestation, soil erosion, and biodiversity loss. The government, through the Ministry of Environment (MoE), has sought to implement stricter rehabilitation guidelines to mitigate these impacts. However, quarry operators have expressed concerns over the economic feasibility and operational disruptions of

rehabilitation requirements. To address these challenges, a collaborative approach was adopted to reconcile government priorities with industry interests [18].

Project overview: A group of environmental researchers and mediators facilitated discussions between the MoE and quarry operators, aiming to challenge each party's perception and conviction regarding quarry rehabilitation. The process involved:

a) Identifying core stakeholder concerns

- a. The MoE emphasized the need for ecological restoration, compliance with national environmental laws, and alignment with international sustainability commitments.
- b. Quarry operators highlighted financial constraints, land-use rights, and concerns over the practicality of rehabilitation measures.

b) Shifting mindsets and encouraging flexibility

- a. Traditional rehabilitation methods in Lebanon focused on soil stabilization and basic replanting, but stakeholders were encouraged to explore alternative models that integrated ecological restoration with economic activities.
- b. Successful international case studies were presented to showcase the potential of blending conservation with sustainable land use.

c) Developing a hybrid rehabilitation model

- a. A phased rehabilitation strategy was devised, allowing quarries to continue limited operations while progressively restoring exhausted sections.
- b. The model incorporated nature-based solutions, including reforestation with native species, soil regeneration techniques, and habitat restoration for local wildlife.
- c. Sustainable economic uses, such as eco-tourism and agroforestry, were proposed to make rehabilitation efforts more financially viable for quarry operators.

d) Implementation and lessons learned

- a. Initial pilot projects demonstrated that a science-driven, negotiated approach could lead to mutually beneficial outcomes.
- b. The success of the program relied on cognitive flexibility, requiring both government officials and industry leaders to reconsider rigid positions and adopt innovative, adaptable solutions.
- c. Continuous stakeholder engagement, including the involvement of local communities, was crucial in ensuring long-term sustainability and compliance.

Ecotones as spaces of collaboration

The ecotone metaphor also underscores the importance of collaboration in quarry rehabilitation. Just as ecotones are areas where different species and ecosystems interact, the transition

from traditional to sustainable rehabilitation practices requires the collaboration of diverse stakeholders—industry representatives, environmental experts, and local communities. This collaboration is facilitated by cognitive flexibility, which allows stakeholders to navigate the complexities of the rehabilitation process and find common ground. Participatory decision-making processes that involve all relevant parties can create a social “ecotone,” where different perspectives and knowledge systems come together. This approach aligns with the principles of adaptive co-management, which emphasizes learning, flexibility, and the incorporation of multiple perspectives in environmental governance [13]. A practical example of this approach is the collaborative rehabilitation efforts in the post-mining landscapes of the Ruhr area in Germany, where former industrial sites were transformed into public parks, integrating ecological restoration with cultural and recreational uses [14].

Conclusion: Integrating Doubt and Cognitive Flexibility

Quarry rehabilitation presents a multifaceted challenge that necessitates harmonizing economic priorities with ecological restoration. This study has demonstrated that doubt and cognitive flexibility are pivotal mechanisms for transforming deeply ingrained perceptions and fostering innovative rehabilitation strategies. Doubt acts as a catalyst for critical reassessment, prompting stakeholders to question conventional methods that may prioritize short-term economic gains over long-term sustainability. Meanwhile, cognitive flexibility facilitates the exploration and adoption of adaptive, nature-based solutions, allowing stakeholders to bridge industrial imperatives with ecological objectives. Grounded in environmental psychology, this study underscores the significance of perspective shifts in overcoming psychological and institutional resistance to change. The examination of international rehabilitation case studies, including the Eden Project (UK), Karuizawa Quarry (Japan), and Alentejo Quarry (Portugal), illustrates how successful projects emerge from environments that encourage doubt as a mechanism for re-evaluation and promote cognitive flexibility as a tool for adaptation. Likewise, the Lebanese cement quarry case study highlights how facilitated dialogues between the Ministry of Environment and industry operators can challenge preconceived ideas and lead to mutually beneficial rehabilitation strategies. Findings from this research indicate that introducing doubt about traditional rehabilitation practices encourages critical engagement and exploration of alternative models. When paired with cognitive flexibility, this shift allows for a more balanced integration of economic and ecological objectives. The ecotone metaphor further reinforces the importance of transitional spaces—whether in ecosystems or in decision-making frameworks—where different perspectives can coexist, interact, and foster dynamic, resilient solutions. Ultimately, this study highlights the critical role of psychological adaptability in shaping future environmental policies. As climate change and biodiversity loss continue to challenge global sustainability efforts, the capacity to question assumptions, integrate interdisciplinary insights, and implement flexible, context-specific strategies will be essential for

advancing sustainable quarry rehabilitation. By embracing doubt and cognitive flexibility, stakeholders can navigate uncertainty, dismantle entrenched resistance, and develop innovative solutions that balance industrial needs with ecological integrity.

Conflict of Interest Statement

The authors declare that there are no financial interests or conflicts of interest associated with this study. The research was conducted independently, with no external influence from funding agencies, industrial stakeholders, or governmental bodies that could affect the integrity or objectivity of the findings.

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