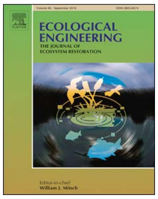
ARTICLE IN PRESS

Ecological Engineering xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Ecological Engineering

journal homepage: www.elsevier.com/locate/ecoleng



Developing a framework for the sustainability assessment of eco-engineering measures

S.B. Mickovski*, C.S. Thomson

School of Engineering and Built Environment, Glasgow Caledonian University, Cowcaddens Road, G4 0BA Glasgow, Scotland, United Kingdom

ARTICLE INFO

Keywords:
Sustainability
Eco-engineering
Ground bio-engineering
Key performance indicators (KPI)
Resilience

ABSTRACT

The assessment of the sustainability impacts of eco-engineering strategies can be challenging and remains neglected within the literature and in practice. The challenge lies in achieving a balance between the delivery of project objectives and their alignment with the emerging principles of sustainable design which seek to provide an appropriate and satisfactory environmental and financial performance whilst delivering social benefits. Whilst it is possible to assess various aspects of the long term performance of soil bioengineering measures and the relevant projects in their delivery through cost evaluations, risk assessments and environmental impact assessments, there is currently no agreed means of assessing the sustainability performance of such measures in an integrated framework which captures the environmental, social and economic dimensions of sustainability.

To remediate this, we propose an integrated sustainability assessment framework which can be applied on any eco-engineering project. It is underpinned by a review of current sustainability indicators commonly applied in the range of sustainability assessment methods (SAMs) and best practice guidance within construction and geotechnical engineering. The framework comprises a set of key performance indicators (KPIs) reflective of the both engineering and sustainability requirements for eco-engineering in the context of stability, active use of vegetation and long-term sustainability for eco-engineering projects. Recognition is provided of the unique nature of each eco-engineering measure and provision is established within the framework for a contextual KPI subset to be developed through stakeholder engagement.

The potential of the framework was explored through an expert workshop highlighting its value to promote benchmarking across the sector between eco-engineering projects and would allow standards to emerge for establishing best practice. Through a real-life case study, we demonstrate the benefits of the adoption of such a framework at an early stage of a project but also the benefits for stakeholders which stem from double-loop learning.

1. Introduction

1.1. Background

Eco-engineering or ground bio-engineering measures comprise the use of vegetation, either alone or in combination with traditional geotechnical structures, for control of soil erosion and shallow landslides (Mickovski, 2016). The characteristic that sets them aside from the traditional civil engineering or geotechnical engineering structures with a similar purpose is the fact that the vegetation is employed to perform an engineering function (e.g. soil reinforcement) but also to enhance the resilience capacity of the bioengineered structure due to the self-repairing characteristics of the vegetation used. The advantages of eco-engineering measures over traditional civil engineering solutions include value for money, ease of construction, and low landscape impact (Norris et al., 2008.). The main disadvantages in the design of these measures include the unknowns related to the living material, i.e. plants with roots and their characteristics (e.g. survival rates, spread, strength, engineering characteristics), biodiversity benefits and maintenance considerations (Stokes et al., 2014).

Eco-engineering encompasses soil bioengineering (Norris et al., 2008) and bio engineering (Stokes et al., 2010) approaches for the design of sustainable ecosystems that integrate human society with its natural environment for the benefit of both (Mitsch and Jørgensen, 2004) and, as such, should be aligned with the principles of sustainable development (Mickovski, 2016). Whilst it is possible to assess various aspects of the long term performance of soil bioengineering measures and the relevant projects in their delivery through cost evaluations, risk assessments and environmental impact assessments, there is currently no agreed means of assessing the sustainability performance of such

---

* Corresponding author.
E-mail address: Slobodan.Mickovski@gcu.ac.uk (S.B. Mickovski).

http://dx.doi.org/10.1016/j.ecoleng.2017.10.004
Received 5 January 2017; Received in revised form 4 October 2017; Accepted 5 October 2017

measures in an integrated framework which captures the environmental, social and economic dimensions of sustainability. A debate exists around how an assessment method should interpret the definition of sustainability with regards to a strong definition (based around boundary limits) or a weak definition (based around accepting tradeoffs between the dimensions; Bromley, 1998) with the distinction recognised to greatly influence decision making. Common practice within construction and engineering tends to focus on the triple bottom line approach (Kucukvar and Tatari, 2013) which is focused on communicating sustainability performance to stakeholders to support their development of project goals and in helping shape project outcomes. In this context, the effectiveness of a sustainable assessment method (SAM) will depend on the consideration of the three dimensions (or pillars) of sustainability (economic, social, and environmental), identification of the overlapping zones and solution to the conflicts and trade-offs that exist between the dimensions therefore tending to align with the more pragmatic weak sustainability definition (Bromley, 1998). This approach seeks to present alignment with standards and best practice but not to pass a judgement on whether the project has breached resource limits as would be the case with a method such as ecological footprint which follows a strong sustainability definition (Raudsepp-Hearne et al., 2010).

Eco-engineering systems include the environment (soil, water, air, flora/fauna, society), inert and live construction materials and the interactions between these. The main purpose of these systems is the stabilisation/reinforcement of the soil (Schiechtl and Stern, 1996) or to avoid major disruptions and collapses while hedging against instabilities and discontinuities, thus seeking to ensure physical resilience and long term sustainability of the system (Costanza and Patten, 1995). Eco-engineering measures are often said to provide a combination of sustainability benefits such as protection against soil erosion in the short-term and the long-term stabilisation due to the reinforcement effect of the roots on the soil (Gray and Sotir 1996; Norris et al., 2008). While the biological and ecological aspects of ecological engineering have been extensively studied, the technical aspects and the socio-economic issues associated with soil bioengineering are not usually quantified in practice (Stokes et al., 2014). Furthermore, eco-engineering measures comprise systems and subsystems with a necessarily finite life span (longevity) which are hierarchically interconnected over a range of time and space scales which is another characteristic of sustainability.

Because of the above, eco-engineering measures are considered by many to be a more sustainable alternative to traditional hard engineered solutions due to their greater alignment with natural systems (e.g. Stokes et al., 2014). Traditionally, eco-engineering works would take place either very early in the project to allow for vegetation establishment or very late to allow for monitoring of the performance. Eco-engineering practices can significantly help in reducing costs and risks (Norris et al., 2008) while, at the same time, achieving the sustainability credentials of the project both from a biomimicry perspective but increasingly from its contribution to society through its aesthetics, potential for resilience and whole life value. However, not unlike the concept of "fitness" in evolutionary biology, the determination and quantification of sustainability can only be made after the measure has been put in place and only with an appropriate structured set of performance criteria applicable to eco-engineering practices (Swan and Kyng, 2004). The sustainability benefits of eco-engineering measures have not been quantified in the past, perhaps due to, a lack of awareness of the sustainability agenda or its value; lack of an agreed means of interpreting it in the context, lack of mechanisms and frameworks for quantification of these benefits and lack of emphasis on long-term monitoring (Mickovski, 2016). These challenges have contributed to the dominance of the objective-based assessments such as BREEAM (http://www.breeam.com/http://www.breeam.com/), LEED (https://new.usgbc.org/leedhttps://new.usgbc.org/leed) and CEEQUAL (http://www.ceequal.com/http://www.ceequal.com/) which are sustainability assessment methods (SAMs) developed for the wider built environment and focus on benchmarking sustainability performance of construction projects. They reflect a mix of quantifiable and subjective indicators with the aim of providing stakeholders a holistic view of a construction project's sustainability performance (Swan and Kyng, 2004) whilst acknowledging the difficulties of providing accurate measures which engineers would otherwise rely on.

Key Performance Indicators (KPIs) are part of the benchmarking process commonly used in the construction industry (Swan and Kyng, 2004) and are an important basis for establishing an objective based SAM. A benchmark is a level of performance that allows comparison between projects in order to achieve 'best practice' through continuous improvement of the performance. KPI is the measure of a process that is critical to the success of the project and a common set of KPIs within an industry based on best practice and regulations allow benchmarking of an organization or a project against the standards achieved within industry. While KPI benchmarking systems relating to sustainability have been introduced to the construction industry as a whole in the last decade (Swan and Kyng, 2004), there is a lack of KPIs and benchmarking systems for the eco-engineering industry which would enable knowledge acquisition and transfer and promote the best practice within the practitioners' and managers' community (e.g. Studer and Zeh, 2014). Such a system would also demonstrate compliance with internal/external reporting regulations (e.g. ISO 2004, ISO 9000 and ISO 14000 series) and facilitate transparency for information sharing. This would increase the visibility of eco-engineering as a specialist and multidisciplinary branch of the construction industry. For this, a comprehensive set of KPIs will be essential to underpin an objective based assessment seeking to enable the measurement of accomplishments, demonstrate transparency to stakeholders and build a knowledge base for the professionals involved.

1.2. Research aim

The aim of this research is to critically review the most widely used SAMs applied across the broader construction industry and their KPI frameworks to adopt a suitable integrated framework that will satisfy the requirements for assessing a project's sustainability performance in relation to eco-engineering aspects. The framework will seek to capture quantifiable measures as well as the more subjective dimensions of sustainability in an acceptable manner. A set of common benchmarks (KPIs) will be developed reflective of the principles of sustainability which can then be contextualised for the individual context of an eco-engineering project through stakeholder consultation/engagement. The application of such a framework and the associated KPI will then be illustrated with a case study from Scotland at Bervie Braes, Stonehaven and its potential explored through an expert workshop. The framework and lessons learnt will provide the basis for the future development of a SAMs for eco-engineering.

2. Materials and methods

2.1. Research strategy

To identify an appropriate sustainability benchmarking framework and set of KPIs specific to eco-engineering, the research followed a pragmatic approach with published information drawn on to establish an initial framework based on existing research and best practice, policy and regulations. This was contextualised through a set of interviews with industry and engagement on four construction projects comprising eco-engineering component (case studies) where more than 40 site visits were carried out within a four-year period to inform the development of the framework (Fig. 1). Twelve semi-structured