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Life cycle analysis of a new modular greening system

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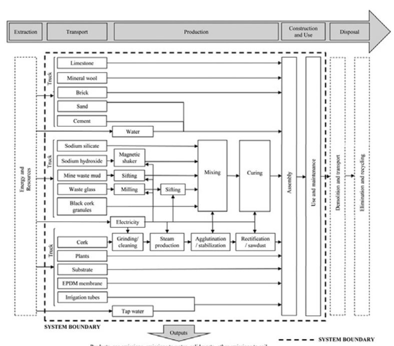
HIGHLIGHTS

- This study presents the LCA study of a new green wall and green roof system.
- Its support represents 96% of the total environmental burden in Global Warming.
- The alkali activated precast slab curing process has the highest impact.
- Curing process changes allowed reducing 74% the overall GWP.
- The comparison with other cladding systems revealed lower environmental impacts

GRAPHICAL ABSTRACT



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ABSTRACT

The construction and use of buildings represent about half of the extracted materials and energy consumption, and around one third of the water consumption and waste produced in the European Union. Therefore it is becoming more important to use sustainable materials that reduce the environmental impacts of construction, by conserving and using resources more efficiently.

Green walls can be used as a sustainable strategy to reduce the environmental impact of buildings. The aim of this study is to evaluate the environmental impact of a new modular system for green roofs and green walls (Geogreen) which uses waste and sustainable materials in its composition. A life cycle analysis (LCA) is used to evaluate the long term environmental benefits of this system. The life cycle analysis (LCA) is carried according to ISO 14040/44 using GaBi software and CML 2001 impact category indicators. The adopted functional unit is the square meter of each material required to assemble the Geogreen system. This study also compares the environmental performance of the Geogreen system with other living wall systems and other cladding materials using data from the literature.

This LCA study of the Geogreen system became relevant to identify a curing process with a major impact on GWP due to the energy consumed in this process. A change on this process allowed reducing 74% of the overall GWP. After this change it can be noticed that the Geogreen System presents one of the lowest environmental burden when compared to other construction systems.

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1. Introduction

1.1. Background

The construction and use of buildings represent about half of the extracted materials and energy consumption, and around one third of the water consumption (Matos et al., 2013) and waste produced in the European Union (E. Comission, 2014). These result from different stages of a building life cycle like materials production, building construction, use, renovation and building waste management. To improve the efficient use of resources it is becoming more important the selection of suitable materials and resources (energy (Chastas et al., 2017) and water use (Meng et al., 2014) in different building stages) to reduce the environmental impacts of buildings. Materials selection can be based on using raw materials from local sources, materials with low carbon emissions (Chen et al., 2011) and low embodied energy (Han et al., 2013) or materials with potential to be recycled or reused.

To overcome the increasing concern of resources depletion and to address environmental considerations, life cycle assessment (LCA) can be used to help with decision making (Khasreen et al., 2009) in order to improve sustainability in construction industry (Ortiz et al., 2009; Teixeira et al., 2014). LCA can also help to identify what materials or processes have more environmental impact and how materials and techniques can become friendlier to the environment.

Green walls and green roofs can be used as a sustainable strategy to reduce the environmental impact (Li and Yeung, 2014) of buildings. In fact, green areas are becoming scarce in densely populated cities. Therefore, these systems can be used as a strategy to integrate vegetation in the urban environment without land occupation (Virtudes and Manso, 2011). They are also mentioned in the Horizon 2020 Final Report "Nature Based Solutions and Re-Naturing Cities" (E. Commission, 2015) as a potential strategy of urban rehabilitation (Virtudes and Manso, 2016). Several studies have proven that green walls and green roofs have the potential to reduce air temperature in urban areas (Alexandri and Jones, 2008; Klein and Coffman, 2015), decrease flood risk and water runoff (Speak et al., 2013; Razzaghmanesh and Beecham, 2014) and air pollution (Rahman et al., 2011; Bruse et al., 1999; Rowe, 2011), increase biodiversity (Weiler and Scholz-Barth, 2009; Francis and Lorimer, 2011; Lundholm, 2006), encourage the fruition of urban areas (Virtudes and Manso, 2012) and improve quality of life (Virtudes and Manso, 2012). Greening solutions have also not only the capacity to improve buildings aesthetics but also contribute to improve buildings envelope and indoor conditions, acoustically (Ismail, 2013; Wong et al., 2010; Manso et al., 2017; D'Alessandro et al., 2015) and thermally (Alexandri and Jones, 2008; Castleton et al., 2010), while reducing energy demand for heating and cooling in buildings (Bass, 2007; Yoshimi and Altan, 2011; Pérez et al., 2014).

There are different types of green walls. Most systems can be integrated into two main categories, green facades and living walls. Green facades are simpler solutions, with less material input, use climbing plants that grow along the wall. Most recent concepts of green walls are called living wall systems (LWS). These include materials and technology to support a wider variety of plants, creating a uniform growth along the surface (Manso and Castro-Gomes, 2015).

Green roofs can be classified as intensive, semi-intensive or extensive. Intensive green roofs include a thicker layer of substrate which allows the integration of grass, shrubs and small trees. These systems require regular maintenance and irrigation (Peck et al., 1999). Semi-intensive green roofs have intermediate thickness, allowing the integration of a large number of plant species than extensive solutions and minimizing the maintenance and watering needs (Dunnett and Kingsbury, 2010; Newton et al., 2007). Extensive green roofs are lighter and have a thin layer of substrate which limits the type of plants included. They are frequently used to improve the conditions of non-accessible roofs, without overloading the building structure (Peck et al., 1999). Extensive green roofs have been evolving into simpler solutions, allowing the creation of vegetation covers in a shorter period of time using pre-planted mats or modular elements.

The object of this study is a new modular system for green roofs and green walls hereinafter referred to as "Geogreen". It has an innovative design and buildability, integrating simultaneously the characteristics of a modular extensive green roof and the properties of a modular living wall system. The design concept of a new modular system (Geogreen) for vegetated surfaces was developed to create more sustainable green roofs and green walls. This modular system results from the incorporating industrial waste materials and industrial sub-products into a construction system with added value. This system not only contributes to improve the aesthetic of buildings, as other greening solutions, but also improves the thermal comfort (Manso and Castro-Gomes, 2016) and acoustic conditions (Manso et al., 2017) of buildings envelope.

This study aims to demonstrate how the integration of sustainability strategies (e.g. use of recycled materials, reduction of embodied energy, industrial waste reuse) into the design of a solution for green roofs and green walls can contribute to a lower environmental impact and therefore make green roofs and green walls more competitive cladding solutions. More specifically, this study evaluates the environmental impact of an innovative greening solution (Geogreen). A life cycle analysis (LCA) is used to evaluate which materials and processes of the Geogreen system have greater environmental burden and determine how these impacts can be minimized. These results were also compared with other publications on life cycle analysis of green wall systems, green roof systems, other claddings and innovative composite solutions for external walls.

1.2. System description

Geogreen is a modular system of prefabricated elements with vegetation, suitable for new buildings and retrofitting and for the rehabilitation of existing buildings. This solution is based on the development of a modular living wall system (LWS) which incorporates industrial waste materials and industrial sub-products.

Each module of Geogreen system consists of a bottom layer of alkali activated precast slab and a top layer of expanded black cork board (Fig. 1). The modules were designed to allow its adaptation to different supports, and obtain a continuous and uniform layer of vegetation. The system can be applied manually and each module can be easily removed for maintenance purposes. The materials and plants used in the system aim to minimize the irrigation needs (Savi et al., 2016; Razzaghmanesh et al., 2014), to improve buildings thermal behaviour (Manso and Castro-Gomes, 2016) and their acoustic conditions (Manso et al., 2017).

Several studies have demonstrated that mineral wastes can be used as precursor materials for alkali-activated binders. Panasqueira tin tungsten mine, located in Portugal, is one of the largest tungsten mines in the world. It is an active industry that operates since 1890's. From the tungsten extraction process result two types of mine waste, coarse aggregates derived from rock blasting and waste mud conveyed by pipelines into lagoons, amounting to several tonnes of deposited material every year (Torgal et al., 2007). In fact recent research shows that mine waste mud from Panasqueira mines are rich in silica and alumina and show good reactivity with alkaline activators and other sources of silica (Centeio, 2011). Therefore the favourable mineralogical composition of mining waste for alkali activation combined with its continuously large production makes it an attractive and environmentally friendly feedstock for alkali activation binders (Kastiukas et al., 2017). Recent studies demonstrate that these alkali activated binders show good compressive strength and durability performance regarding abrasion and acid resistance (Castro-Gomes et al., 2010). Besides adding value to mine waste, the activation process, when complete, allows to encapsulate the arsenic and other heavy metals present in the mine waste mud, preventing its leaching to the environment (Castro-Gomes et al., 2010).