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Life Cycle Assessment applied to circular designed construction materials

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Abstract

Following the Waste Framework Directive, new solutions must be identified for the management of Construction and Demolition waste. Circular economy would provide the strategic key for addressing this issue: construction industry may, in fact, become an elective consumer of its own waste, where construction materials are circular and eco-designed.
A comprehensive case study has been built, starting from evaluation of different management options for this waste to be applied in the municipality of Bologna and prosecuting with the design of concrete mixes, implementing construction and demolition derived aggregates as partial replacement for natural aggregates. Life Cycle Assessment (LCA) has been applied to evaluate the environmental impact of the options designed, in comparison with standard concrete already on the market. In particular, 25% replacement of natural aggregates leads to almost equal decrease in respiratory inorganics related impact and more than 39% decrease in land occupation indicator, even though ozone layer depletion impact indicator shows a negative performance. Nevertheless, partial aggregates replacement should be coupled by a limited cement replacement, in order to trigger a substantial decrease of the environmental impact in concrete production.

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1. Introduction

Construction and Demolition (C&D) activities are among largest waste sources in many countries. About half of the non-renewable raw materials consumed in the world could be ascribed to the construction industry, resulting in about half of the total amount of the solid waste generated.

The recycling of Construction and Demolition Waste (CDW), is, therefore, essential in order to reduce the dependency on finite natural resources such as geological and energy reserves and to promote a new production of secondary raw materials, as required by a circular economy approach. According with Circular Economy principles, a 'Re-Thinking Progress' explores how, through a change in perspective, we can re-design the way our economy works - designing products and utilizing raw materials that can be 'made to be made again', in an eco-design perspective. This would whole construction sector on these purposes, leading it toward the next century challenge.

Today, there is an urgent need for the governments worldwide to reduce the amount of waste, considering regulations and legislations that have been framed for the construction and demolition waste stream management. The same last EU directives on waste management define a 70% in CDW recycling rate by 2020 [1].

There are now clear opportunities for business and industry to invest in activities that will create profit and improve environmental outcomes by taking valuable resources from inert waste recycling...

Up to the recent years, landfilling has been the traditional disposal method for CDW, considered mostly as inert waste. However, in accordance with EU waste management hierarchy and circular economy objectives, recycling must take over as a major management method for this waste

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demolition condition. While recycling of such material has the added benefit of valorising raw materials and reducing overall costs, prevention is the most desirable approach to waste management, since the elimination of unseparated waste removes the need for subsequent handling, transportation and treatment of discarded materials. Selective demolition as waste management support, in this sense, maximizes efficiency in waste management by reducing the total amount of waste production, repurposing reusable materials, and, consequently, decreasing environmental impact.

At the same time, building sector could be excellent consumer of several secondary raw materials deriving by recycled waste, such as fly ashes from waste incineration, fine powder or sludge, several end-of-life polymers, rubber and by-products from different industrial production, as well as inert solid waste, deriving from quarry activities, etc.

Nowadays, green building certifications consider as added value the utilization of recycled raw materials in building and construction: the U.S. Green Building Council (USGBC) and the LEED® Green Building Rating System™, for examples, seek to optimize –and to minimize- the use of natural resources, promote regenerative and restorative strategies also for component and raw materials. LEED, in particular, sets a challenging, yet achievable, set of whole building and neighborhood benchmarks that define green building: i.e. one LEED point is awarded for a recycling rate of 50% and a second for a recycling rate of 75% [2].

Construction activities have several environmental impacts at each step of the building process: extraction of raw materials, processing, manufacturing, transportation, construction, demolition and disposal at the end-of-life with consequent generation of huge amount of solid wastes and various types of emissions. The application of Life Cycle Assessment (LCA) methodology can be useful to identify the main impact spots and, therefore, to support eco-design of construction materials.

In this paper authors would show the results of a comprehensive research aiming to demonstrate both the environmental and economic advantages deriving from the utilization and valorization of construction and demolition waste. A case study has been built, starting from evaluation of different management options for CDW for the municipality of Bologna and prosecuting with the design of concrete mixes, implementing CDW derived aggregates as partial replacement for natural aggregates. Using a LCA approach, it was possible to assess the environmental impact related with the CDW utilization, at different rate of percentage, and to compare different scenarios in recycling, with the aim of outlining the most suitable solution for the case study proposed and highlighting the weak points to be improved by further research activity.

2. Materials and methods

A general overview of the opportunities offered by building sector's residuals has been performed, on the basis of several studies, evaluating:

- CDW collection, storage and transport in terms of combinations of processes and environmental impacts related [3];
- CDW treatment process, considering the environmental impact triggered, as well as benefit generated [4, 5];
- recycled CDW addition to concrete recipe, as partial replacement for natural aggregated, assessing the environmental benefit related [5].

CDW early management was evaluated with different scenarios, as presented by Simion et al. [3, 4]:

- Scenario 1: the simplest, organized on temporary storage, collection and transport to landfill,
- Scenario 2: first intermediate scenario, adding leachate treatment, to limit the environmental impact of landfilling phase,
- Scenario 3: second intermediate scenario, with temporary storage, sorting and recycling phase applied to material extracted from the waste steam, collection and transport to sanitary landfill (implemented with leachate collection and treatment),
- Scenario 4: integrated CDW scenario, with temporary storage, collection and transport to sanitary landfill (implemented with leachate collection and treatment), sorting for recycling and incineration of residual material.

An actual case study of implementation of CDW derived aggregates into a concrete production process has been evaluated. Inert waste preparation phase has been modeled on the basis of the integrated management system currently implemented in the urban framework of the case study proposed (i.e. municipality of Bologna), corresponding to Scenario 3 presented by Simion et al. [3, 4]. This option has been compared, in terms of environmental impact, with Scenario 1, considering only CDW final disposal in landfill, i.e. *option zero*.

The choice of the allocation method proved to be the most challenging aspect of the present study, involving waste-derived materials. The issue of impact allocation between the first application of virgin material and its second life as secondary raw material is highly disputed and different approach are reported [5]. The study was carried on following the concept of "recycled content" approach, as presented by Allacker et al. [5]. Therefore, the entire environmental impact of the virgin material has been attributed to the product in which it was first used (i.e. the dismantled construction), whereas impacts generated by collection, transport, sorting and recycling are allocated on the CDW derived aggregate. This approach, reported as "cut-off" or "100-0 output" approach, although not comprehensive, avoids double counting the environmental impact at a system level.

The case study is based on foundation concrete preparation. In particular, different recipes for concrete, characterized by partial replacement of natural aggregates with inert waste derived aggregates have been evaluated with the application of LCA methodology, in a *cradle-to-gate*

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