Circularity and Energy Production in the Built Environment

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Building materials, due to their mass and energy-consuming production processes, drastically increase the embodied energy of construction. There is a significant decrease in environmental impacts results from a shift to recycled materials in the construction phase, as well as from changing the landfill disposal method to recycling. In particular, it was found that the use of recycled building materials (such as recycled cement, metal, concrete, or glass) during the construction phase and recycling disposal methods lead to an overall decrease of impact up to 65%.

Keywords: circularity ; recycled materials ; building materials ; life cycle assessment ; renewable energy systems

1. Introduction

Energy is consumed directly during building construction, use, and demolition while indirectly through producing and manufacturing of materials (embodied energy) used in building [1]. The building industry accounts for 40% of the energy consumption and ~50% of the greenhouse gas emissions in Europe [2][3][4][5]. The exploitation of natural resources, particularly non-renewable resources, for construction purposes leads to millions of tons of construction and demolition waste (CDW) every year. Since most countries have no specific processing plan for these materials, they are sent to landfills instead of being reused and recycled in new construction [6]. There is a high potential for reusing and recycling construction and demolition waste since most of its components have a high resource value. Furthermore, there is a reuse market for recycled aggregates derived from CDW in landscaping, road construction, cementitious mortars, and concrete [7].

The concept of the circular economy is proposed to change current production and consumption patterns that put a significant burden on our planet and its environmental capacity. This requires not only closing loops by reusing ‘waste’ and resources but also slowing material loops by developing long-lasting reusable products [8][9]. While the concept of circular economy is the process of obtaining global momentum in politics, business, and academia, the knowledge and tools for bringing it into practice still largely need to be developed, especially for the building sector [10][11]. According to the IPCC [12], buildings accounted for 32% of total global final energy use in 2010. Moreover, the building industry consumes 40% of the materials entering the global economy, while only an estimated 20–30% of these materials are recycled or reused at the end of a building’s life [13][14].

Life cycle assessment (LCA) is defined as a systematic analysis used to measure industrial processes and products and is accepted internationally as a tool to improve processes and services environmentally that can be applied to a wider field, including the building industry [11][15]. Within the last decade, research on LCA in the built environment increased considerably; nonetheless, quantitative information about the environmental impact of producing construction materials or the actual process of construction and demolition is limited [16]. In a study, an LCA was performed in a building situated at Turin (Italy), and the demolition phase and its recycling potential were studied. The results demonstrated that building waste recycling is not only economically feasible and profitable but also sustainable from an energetic and environmental point of view [17]

Other current research found that embodied energy accounts for a significant proportion of total life cycle energy [18]. Nonetheless, Langston and Langston [19] suggest that, while measuring operating energy is easy and less complicated, determining embodied energy is more complex and time-consuming. Furthermore, there is currently no generally accepted method available to compute embodied energy accurately and consistently, and as a result, wide variations in measurement figures are inevitable, owing to various factors [20][21]. Moreover, as stated by Walter Stahel [22], the circular economy is a strategy that considers that everything generated is not dismissed in landfills, with an inevitable loss of value, but it is kept to serve new functions. A study conducted involving seven European nations reported that if the resources were used longer (circular economy), greenhouse-gas emissions could be reduced by more than 70%, also contributing to a workforce increase of 4% [23].

2. Circularity and Energy Production in the Built Environment

In the EU, the amount of waste generated is approximately 2.5 billion tonnes, which accounts for approximately 5 tonnes per capita, each year. Some EU members such as the Netherlands, Germany, France, and Italy generate significant amounts of recyclable waste in the building sector, whereas other countries' recycling share is lower. For the building sector to become more sustainable, it needs to comply with the 'sustainable use of resources' approach set by the European Building Products Regulations; stating that products' environmental declarations should be used when assessing the sustainable use of resources and the environmental impact of building works [24]. The specification of reusable building materials during the building design and construction phase is a major factor that determines the level of reusability of recoverable materials at the end-of-life of a building [25][26][27]. The three main waste minimization strategies are collectively called the 3R's: reduce, reuse, recycle [28]. Construction waste causes significant damage since it accounts for about one-third of all refuse nationwide. Recycling construction materials can significantly reduce the environmental impact of the industry. The construction sector takes 50% of raw materials from nature and creates 50% of the total waste. Approximately 500–1000 kg/habitant are created annually in developed countries [29]. CDW is mainly generated by the demolition of old buildings, remainders from new constructions, building repair and maintenance, manufacturing debris, and natural disasters [30]. Energy generation via renewable energy systems (RES) in the built environment is a way towards cleaner and greener buildings. RES have major economic importance and further help mitigates carbon emissions to promote environmental quality [31].

Besides having several advantages, there are some considerations and barriers that need to be resolved with RES. Barriers for the diffusion of RES as a reliable power supply are the main topic of many research work and efforts [32]. Additionally, an overall assessment of their use in the built environment must consider their embodied energy from the construction phase of their primary materials. Although power generation using a photovoltaic (PV) system or wind energy system is free from greenhouse gas emissions and fossil fuel use, the energy and emissions involved in the manufacturing, transport, and disposal of its elements must be considered. The highest environmental impacts of solar technologies derive from the manufacturing processes of the solar cells due to the large amount of energy consumed and the use of toxic chemicals and scarce minerals [33]. However, due to the advent of energy-efficient equipment and appliances, along with more advanced and effective insulation materials, the potential for curbing operating energy has increased, and as a result, the current emphasis has shifted to include embodied energy in building materials [34][35].

In a work by Bonoli et al. in 2021, the sustainability in building and construction and the contribution of concrete recycling is investigated. It summarizes that a more effective circular economy approach is mandatory, allowing waste to be reprocessed or remanufactured. This will extend the life cycle of the material, reducing the CDW. The work also states that recycling can be an efficient strategy for reducing the environmental impacts of the building industry [36]. In another work, the potential energy savings obtained from recycling 1 tonne of CDW in Naples was assessed with the use of LCA software. The results underline that recycling is preferred over landfilling and that the transition to a circular economy offers many opportunities for improving the energy and environmental performance of the construction sector. Recycling strategies using input from other sectors (agri-food by-products) can also be incorporated in the manufacturing of construction materials [37].

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