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Financial assessment of reusing materials in buildings: comparing financial potential of wood, concrete, and glass reuse

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Financial assessment of reusing materials in buildings: comparing financial potential of wood, concrete, and glass reuse

Julia LK Nußholz[1] and Katherine Whalen[1]

[1]International Institute for Industrial Environmental Economics, Tegnérsplatsen 4, 223 50 Lund, Sweden

Corresponding Author, julia.nussholz@iiiee.lu.se

Abstract. Buildings are responsible for a third of global greenhouse gas emissions, with much of their life cycle impacts resulting from embodied impacts of building materials. One solution to reduce embodied emissions is to use of secondary materials such as by-products and waste materials for producing building materials (in this study referred to as reuse solutions). While this is reported to have positive environmental and economic impact, many financial barriers to economic application remain, centering on labor-intensive recovery processes, low end-of life value, fluctuating material volumes and qualities. This paper aims to advance understanding of the financial potential to reuse different end-of-life materials for building materials by presenting a cost structure analysis of three reuse solutions developed by a Scandinavian case company for wood, glass, and concrete. Findings indicate that profit margins differ considerably by material stream and application. Expenditure for production processes (i.e. cutting wood to planks, assembling glass into windows, mixing aggregates to new concrete) was a significant cost driver in all three reuse solutions. Costs for purchasing end-of-life materials also differed significantly in each case, reflecting the differences in residual value of each material stream. Future research is needed to expand the financial assessment to consider the upscale potential and effect of economies of scale for each case. In addition, we suggest to investigate other dimensions of value such as economic aspects (e.g. job creation and societal costs savings from environmental impacts), as well as the environmental improvement to advance understanding of the relevance of material reuse for buildings.

Keywords: Circular economy, circular business models, sustainable buildings, life cycle management, embodied emissions, financial assessment

1. Introduction

Buildings are responsible for a third of global greenhouse gas emissions, with a large share of their life cycle impacts stemming from embodied impacts of building materials. A solution to reducing embodied impacts is the use of secondary materials such as by-products and waste materials for producing building materials (in this study referred to as reuse solutions) [1-4]. Research indicates significant potential for reduction of environmental impacts [5], but also financial benefits from using embedded materials longer, reducing material input costs and organizing value adding activities [3, 6-8]. For economic viability, reuse solutions need to be accompanied by business models capable of delivering strong mitigation outcomes and being economically viable. Innovating a company's business model helps align the company's logic of doing business with reusing materials [9]. This can help remove barriers to using secondary materials or establish partner networks to capitalise on the embedded economic and environmental value in materials [10].

Despite the financial potential, companies in the buildings sector still experience significant barriers to fully capitalize on the residual economic value embedded in resources [11]. To be competitive with primary materials, secondary materials need to be produced at similar costs with highly-efficient and mature value chains of primary materials. Main financial barriers reported in literature include high collection costs, low material value at the end-of-life, labour intensity as current buildings are not designed for disassembly and recycling [5, 11, 12]. In addition, upfront investments and fluctuations in material volumes and quality are reported to hamper financial viability of material reuse. Barriers and financial potential meanwhile differ with material streams [5, 13-16].

Despite the experienced barriers, a number of pioneering companies have successfully developed and commercialized building products based on secondary materials [12], such as reusing bricks. To help diffusion of business models for material reuse in the building sector, next to the environmental impacts, more understanding of their financial viability is needed. How does financial potential differ with different materials streams and applications, what are main cost drivers, and how can financial barriers be overcome? This research aims to advance the understanding of the financial potential of reuse solutions by performing a financial assessment and cost structure analysis of three reuse solutions from different material streams. A comparative case study design of a Scandinavian company that developed business models for three commercialized reuse solutions is employed to identify factors that hamper or increase financial potential. Data was collected from internal company accounting data and semi-structured interviews. The paper proceeds with providing background on business models for material reuse in buildings and financial barriers (section 2), the description of the method (section 3), and the results (section 4). Section 5 presents the discussion and section 6 the conclusion.

2. Business model innovation for material reuse in buildings

Material reuse and recycling has since long been promoted in the resource efficiency and cleaner production field as a strategy to reduce primary material use and waste generation, and associated environmental impacts [10, 17]. Although companies in the building sector have applied circular practices for some time, such as reusing metals, stricter regulation and internalization of externalities [11, 18] are driving companies to incorporate circular principles in their business models, moving towards recovering material flows that are more difficult to reuse (e.g. concrete). Producing with secondary materials has been identified to have high potential for environmental impact reductions, although to varying degrees depending on material streams and products. Research on carbon saving potential of brick reuse for instance was found to have potential of 99% of carbon saving and wood and plastics reuse for façade material and concrete for structural elements about 30-40% in the investigated applications [5].

Next to the environmental value, material reuse and recycling is associated with economic value from reducing costs for input materials and organizing value adding activities [18, 19]. Especially in the building sector application of such circular economy strategies is thought to have high potential for economic and environmental value creation [7, 20]. However, as the current building stock is rarely designed for disassembly and recycling, companies engaging in recovery activities and reuse solutions experience various barriers that can outweigh the costs of linear value chains with primary material input

[5, 12]. To disseminate business models for material recovery and production with secondary materials in the industry, production processes need to be cost competitive with virgin production. Financial assessments of circular business practices emphasize higher associated risks [20, 21], including uncertainty about the residual value of secondary materials after use as well as their price compared to primary material [22].

Few financial analyses of the business case for reuse have been published within the building and construction sector [13]. Using recycled content may help to reduce costs associated with new material production [23] [24], however, the addition of new (and costly) materials can be necessary to reach regulatory requirements [25]. Jung et al. [26] suggest end costs are dependent on the value chain structure, finding transportation distances, site conditions, and materials quantities to influence costs in concrete recovery and reuse. Furthermore, recovering materials for reuse may compete with their use for energy recovery, such as the case of waste wood used in the building and construction industry in Finland [27]. Literature in other sectors also emphasizes high costs associated with labor [28] and reverse logistics [29]. To overcome these barriers, business model innovation is often required to establish partnerships for collection, processing, material design, or identify customers open to building with secondary materials.

3. Methods

This study employs a comparative case study design of three reuse solutions for building application developed by a Scandinavian company from three different material streams, i.e. secondary glass, wood, and concrete, described in Table 1. Although case studies are sometimes criticised for lack of generalisability, they are beneficial for providing in-depth descriptions [30] of a small number of research units that comprise a strategic sample of a phenomenon [31]. Characteristics in regard to customer, location, and business context are the same for each reuse solution as they were produced for application in the same building. This provides a baseline level of similarity to enable reflection on the financial viability of each reuse solution by comparing variables such as their value chains, material cost factors, and production steps.

Table 1. description of the three reuse solutions.

Material	Characterization recovery strategy	Process description
Wood	*By-product use*	*Wood is obtained from by-products and lower-grade production of a plank producer in proximity of the case company. Through cutting, surface treatment and mounting, the wood is developed into floor and façade cladding (indoor and outdoor).*
Glass	*Material reuse*	*Post-consumer windows are collected from demolition sides and dismantled to obtain glass. Glass is assembled into new windows by adding customized frames and a second layer to comply with energy efficiency standards.*
Concrete	*Material recycling*	*Post-consumer concrete from demolition side is crushed into aggregates and through mixing with*

primary cement and other concrete components developed into new concrete.

Data was collected from the company's internal accounting data as well as through semi-structured interviews with company employees to model the three value chains, their activities and inputs (Figure 1-3). Company employees were consulted to verify accurate understanding of financial data and value chains. A cost structure analysis was conducted to identify the cost associated with various value chain steps and inputs. Labour costs for development and management occurring for the case company were not included in the analysis as these were partly covered by an innovation fund. For each reuse solution, the main cost drivers in the value chain were identified. Each reuse solution was then analysed by performing a financial assessment of the profit margin by deducting total costs from total revenue. By comparing cost drivers and profit margin, we reflect on factors that increase or hamper financial value.

4. Results

Figures 1-3 the share of total costs for each value chain activities and inputs. Comparing the share of total costs for each of the three cases' value chain activities, costs associated with manufacturing (i.e. cutting wood to planks, assembling glass into windows, mixing aggregates to new concrete) were a significant share of total costs in all three cases. However, a variety of extra value chain steps were needed for the concrete case and resulted in additional expenditures. Furthermore, additional innovation costs (e.g. R&D and consultancy) were required for the concrete case as it is a structural building product that underlies various safety regulations and legal requirements

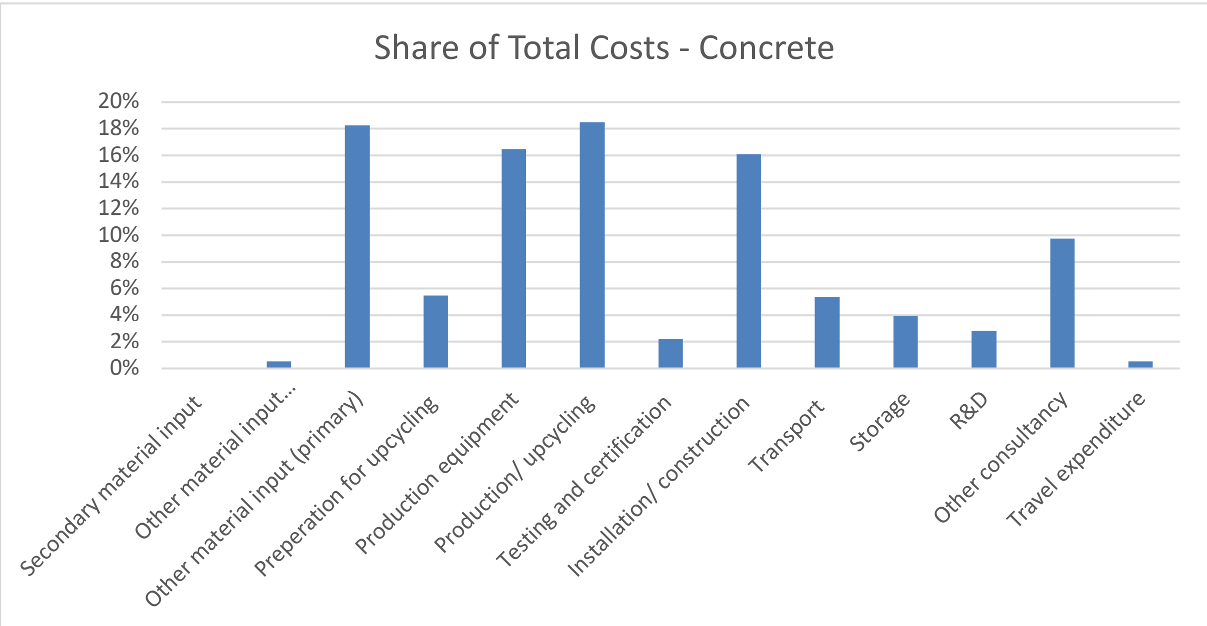

Figure 1. share of total costs of value chain activities and inputs for concrete reuse.

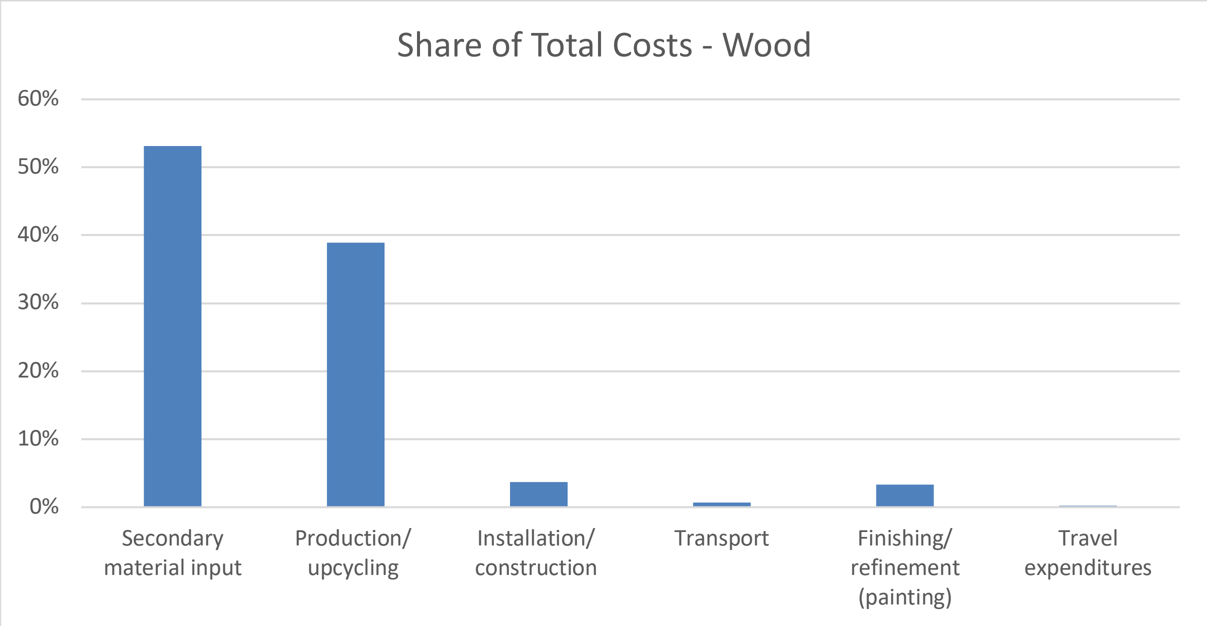

Figure 2. share of total costs of value chain activities and inputs for wood reuse.

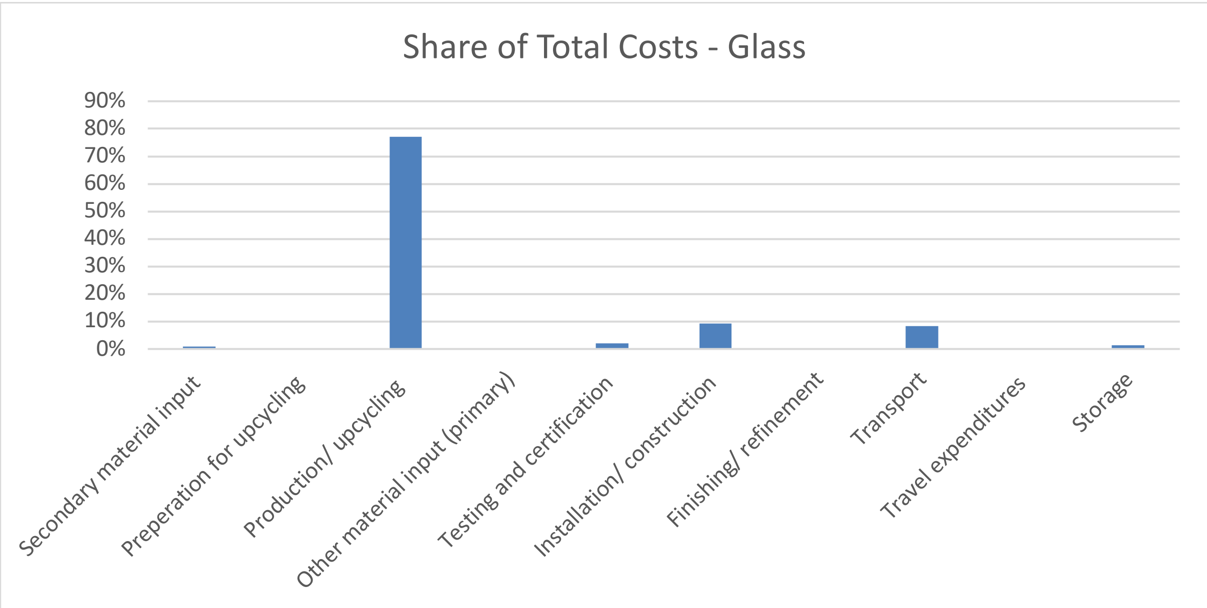

Figure 3. share of total costs of value chain activities and inputs for glass reuse.

Comparing the material costs for the three cases, in the case of wood, the majority of total costs (53%) resulted from purchasing secondary material, but no primary materials needed to be added. For glass, only 1% of total costs were spend on secondary materials, but virgin materials needed to be added that equalled 20% of the costs. For concrete, no direct costs for secondary materials occurred as collection and processing was done by a partner company and who is paid for collecting end-of-life concrete by demolishers. However, additional virgin materials needed to be added which were 18% of the total costs.

5. Discussion

5.1. Financial assessment of three reuse solutions
Comparing total costs to the company's revenue for the three cases showed a mixed-result in terms of financial performance. While the wood and window cases were calculated to have positive profit margins, in the case of concrete not all investment costs were covered yet. However, as all three cases were product innovations that were produced for the first time, the value chains were characterized by experimentation and unforeseen challenges that could be avoided in future production lines. Thus, financial viability needs to be seen in context of an immature innovation whose financial performance could be improved through leaner production. For example, regarding future profitability, the concrete case had upfront investment costs for testing and certification, R&D and other consultancy service (15% of total costs) that would not need to be paid in future production lines and could help reduce future production costs.

5.2. Factors influencing financial potential
The financial assessment revealed a number of factors that hinder or improve financial potential. Firstly, the *value of end-of-life materials* influences the price. In the case of wood, an expenditure for secondary materials were high compared with other cases. A reason for this might be that they are an industrial by-product with known material content and clean fraction, unlike the other secondary materials in this study. Unlike in the other cases, for concrete, collectors are paid for collecting concrete from demolition sides. Secondly, *labour intensity* impacts the costs of production process, but also the amount of *machinery* needed can be a significant cost driver. Thirdly, although collection side and construction side were in geographical proximity, in all three cases the weight of concrete waste and aggregates resulted in a relatively high share of costs for transport. Fourthly, *legal requirements* influence innovation costs as more expenditure for research and development, testing and certification need to be undertaken to meet standards, as observed in the case of concrete. Finally, all cases represent first production lines of product and material innovations and hence a number of inefficiencies (e.g. unexpected difficulties in installing windows and labour-intensive cleaning).

6. Conclusion
This paper compared the financial performance of three building materials produced with secondary wood, glass and concrete by a Scandinavian pioneering company that implements circular economy practices in the building sector. A key finding is that the cases' financial potential differs considerably, most likely due to differences in material and value chain processes. A cost structure analysis revealed that in all three cases, expenditures for production processes (i.e. cutting wood to planks, assembling glass into windows, mixing aggregates to new concrete) were a significant cost driver, partly due to labour intensity of the process. Also costs for acquiring secondary materials differed between the three cases. While costs for secondary materials were a significant share of costs in the case of wood reuse (as sourced as an industrial by-product of better quality), for concrete, collectors are paid for collecting and handling concrete from demolition sides. In the case of concrete, a significant cost driver was expenditures for research and development as well as testing and certification occurred as it is a more complex product and subject to safety regulations. Financial performance could potentially be improved through economies of scale, and future research on the cases' different upscale potential appears relevant.

Furthermore, comparing these reuse solutions to conventional, linear business model of the same products would increase understanding of the difference in cost structure between a value chain with secondary material versus a linear value chain with primary materials. Such an analysis could be used to identify cost factors that make material recovery financially (un)feasible. In addition, future research could include a larger number of cases for each of the various types of reuse strategies (Table 1) and compare economic viability among different recovery strategies. A sensitivity analysis could also help identify the critical factors increasing or reducing total costs for different strategies.

Finally, as this paper was a first step to determine the financial feasibility of recovering and producing with secondary materials, other aspects of value creation (such as economic, environmental and customer value) that are important to determine benefits of such reuse solutions were considered outside the scope. An economic assessment could advance understanding of the economic costs and benefits, including societal benefits as job creation and saved expenses for avoided emissions. In addition, non-financial value for the company, customers and other stakeholders could be investigated as well as the environmental improvements to get a more holistic understanding of the relevance of producing with secondary materials in the building sector for advancing sustainability.

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