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Why Bother? Environmental and Social Implications of Using Durable Building Products

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Abstract: The circular economy (CE) has emerged with the promise of conserving resources through approaches such as durability and extended product lifetimes. At the same time, buildings negatively contribute to resource use and waste production, making buildings a key target for CE strategies. However, the question of how durability and lifetimes affect the social and environmental impacts of building products remains largely unexplored. In this study, we applied environmental and social life cycle assessments (E-LCA and S-LCA, respectively) to a common building component, roof covering, to investigate the effects of durability and different lifespans, and the tradeoffs between social and environmental impacts. We tested different lifespan scenarios for three materials with different durability: thermoplastic polyolefin (TPO), zinc-coated steel, and galvanized aluminum sheets. The results suggest that it is critical to consider the tradeoffs of social and environmental benefits: steel had the most promising social performance, followed closely by aluminum, while the least durable material (TPO) had the worst environmental and social performance. However, the environmental impacts resulting from the production of aluminum sheets were significantly lower than the impacts from steel, which made aluminum the preferred choice for this case study. Moreover, product lifespans impacted the results in both E-LCA and S-LCA due to the number of replacements needed over the life of a 100-year building. We discuss key limitations of integrating E-LCA and S-LCA approaches, such as data aggregation and spatial issues, lack of standards on how to account for product durability, and concerns surrounding S-LCA results interpretation.

Introduction

This study investigated how social and environmental impacts of building products is affected by material durability. With the advancement of Circular Economy (CE) in the building sector, it is essential to consider environmental impacts and to ensure that CE strategies do not result in unintended social consequences. Specifically, we compared roof covering products under different durability scenarios and material alternatives, examining both the social and environmental lifecycle impacts.

Circular economy and product lifespans in the built environment

The construction sector is the most material intensive industry and thus has a key role in the transition towards a circular economy (Pomponi & Moncaster, 2017). CE aims to design out waste and use fewer, more durable resources (Ellen MacArthur Foundation, 2013). Circular buildings are designed with durability, adaptability, and future disassembly and reuse in mind (Cruz Rios & Grau, 2020). However, the concept of circular built environments is still at an early stage, partly because of the complexities inherent to buildings' lifespans when compared to short-lived manufactured products (Pomponi & Moncaster, 2017).

A building is made of several layers of products and materials with varying service lives (Figure 1). The service lives depend on material durability, owners' preferences, and the emergence of new technologies (Castro & Pasanen, 2019). For example, while the building structure may last 100 years, the building skin may be replaced every 20 years.

Quantifying the impacts of building components is key to understanding material flows within built environments and the impact of CE strategies like urban mining (Castro and

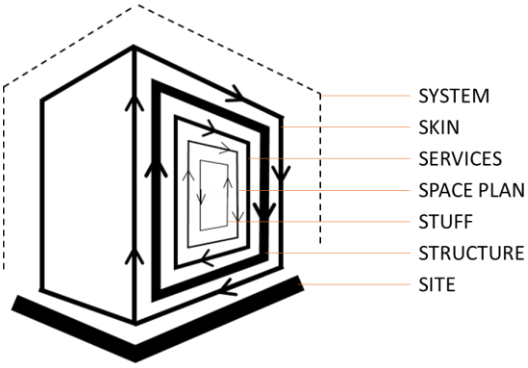

Figure 1. Building layers and varying lifespans. Adapted from Brand (1994) and Arup (2016).

Pasanen, 2019). Environmental life cycle assessment (E-LCA) is a widely used and robust method for estimating the environmental impacts of building products over their life cycle. However, there is limited guidance on how to consider the life cycle of building components when they do not coincide with the life cycle of the building (Aktas & Bilec, 2012b, 2012a; Bourke & Kyle, 2019; Gardner et al., 2020; Hasik et al., 2019b; 2019a). Perhaps as a result, maintenance and replacement processes are often neglected in most studies of embodied carbon reduction in the built environment (Pomponi & Moncaster, 2016). Meanwhile, in a previous study led by co-author Bilec, material replacements accounted for 62% of the embodied carbon of the Frick Environmental Center, a highly sustainable building in Pittsburgh with estimated lifespan of 100 years (Gardner et al., 2020). This is consistent with the findings of Francart and Malmqvist (2020), who concluded that the relative impact of material replacement was largest in buildings with low energy use or long lifespans.

The social justice gap and frameworks for just and regenerative economies

The environmental impacts of materials are important to consider, but there is also an unfortunate history of environmental initiatives that, despite good intentions, resulted in social harms (Agyeman et al 2003). Take for example the introduction of "green buildings" intended for redevelopment that resulted in long-time residents being forced out due to higher tax rates (Checker, 2011; Tretter, 2014), or urban development programs that prioritized "green" technologies but put hundreds of local residents out of work (Patel, 2015). Some CE advocates have therefore argued that the concepts of well-being and justice must be at the very heart of the circular economy (Schröder et al., 2020). The movement toward circularity is, in this frame, seen both as a means to prevent the violation of planetary boundaries and a strategy to ensure basic human welfare. Concepts like consumption corridors (Fuchs et al., 2021) and doughnut economics (Raworth, 2017) acknowledge that our economic systems should ensure environmental sustainability and that all humans can fulfil their basic needs. In this conceptualization of the CE social life cycle assessments can help to make clear the social impacts of materials production and trade, aiding in decisions related to both sustainable supply chains and international development (Parent et al., 2013; Vasconcellos Oliveira, 2020).

Social life cycle assessment

Social life cycle assessment (S-LCA) is a relatively new and fragmented field with growing but still relatively little research (Kühnen & Hahn, 2017; Sakellariou, 2018). The method provides information on human well-being, an important gap in contemporary LCA practice (Sutherland et al., 2016). S-LCA follows the same phases as E-LCA: goals and scope, life cycle inventory, life cycle impact assessment, and interpretation. One of the possible applications of S-LCA is to identify social hotspots (SH), that is, locations or activities with high social risks over a product's life cycle (UNEP Setac, 2020). In S-LCA, there are different categories, subcategories and indicators of social risk. For example, for the category "workers", one of the subcategories is "equal opportunities", which can be measured by indicators like the share of underrepresented populations in a company. Although quantifying social impacts is inherently challenging and uncertain, S-LCA is an important step towards the convergence between "those who see engineering as techniques and those who believe that engineering needs to be socially and politically contextualized" (Sakellariou, 2018).

S-LCA applications are still rare in the building sector. Yet some recent work has proposed S-LCA frameworks for building construction (Dong & Ng, 2015; Liu & Qian, 2019), with others focusing on building materials (Hossain et al., 2018; Hosseinijou et al., 2014). These studies identified both risks and positive social impacts associated with construction and materials performance, yet there was little attention to the issue of durability.

Research questions and structure

In this paper, we investigate how durability and lifespans affect environmental and social impacts of building products. More specifically, we ask:

- Are more durable alternatives environmentally and socially preferable? What are the trade-offs?
- How does extending product lifetimes affect the social and environmental impacts of building materials?

In the following sections, we explain the research methods and results for E-LCA and S-LCA, followed by a combined discussion and conclusion section.

Methods

We conducted a comparative analysis of the social and environmental impacts of three different roof coverings. We selected the roof because it has a relatively long lifetime but is typically replaced for maintenance purposes, rather than aesthetics. The three roof covering alternatives considered were: thermoplastic polyolefin (TPO), zinc-coated steel sheets, and galvanized aluminum sheets. While TPO has an approximate lifespan ranging from 20 to 30 years, the metal alternatives are estimated to last between 40 and 60 years. All the alternatives were assumed to be mechanically installed over a similar section of metal deck and continuous insulation, with similar thermal properties. The two metal alternatives were assumed to be coated with white acrylic paint to reach a reflectivity level comparable to the TPO membrane. The functional unit chosen for the study is one square foot of roof covering material over a building with a design lifespan of 100 years in Pittsburgh, PA, United States.

E-LCA

To estimate the environmental impacts of the three alternatives, an E-LCA was conducted. Data from the production and end-of-life of the materials were collected from the ecoinvent database and analyzed. The use phase was excluded from the comparison due to the similar thermal properties of the roofing systems. Transportation emissions were included in the analysis, and the installation and disassembly were assumed to be negligible and excluded from the analysis. Following current industry practices, the metal roofs were modeled with 100% recycled content and recycling as end-of-life scenario, while TPO was assumed to be recycled at the end-of-life but produced with no recycled content. Given the CE main goal of preserving resources and the fact that CE is considered a low-carbon economy, the impact categories chosen for this study were global warming potential (GWP) and damage to resource availability (midpoint and endpoint categories of the ReCiPe 2016 method, respectively). Finally, to illustrate the effects of product life extension, we compared different lifespan scenarios for each material. In the baseline scenario, steel and aluminum roofs were assumed to last approximated 50 years (1 replacement over the building's life cycle), while the TPO roof was assumed to last 20 years (4 replacements). Alternative lifespan scenarios were tested and included two replacements for aluminum and steel roofs and three and five replacements for TPO.

S-LCA

To identify the main social risks associated with the production and recycling of the roof materials, a SH analysis was conducted with the SH database (SHDB). The SHDB uses an input-output model based on the Global Trade Analysis Project (GTAP) and contains country-specific data for social indicators in several industry sectors and geographical locations (Benoit-Norris & Norris, 2015). The SHDB requires a dollar input (e.g., roof cost per square foot) and generates results based on the number of worker hours associated with the monetary unit. The results are presented in the form of a SH index: the lower the score, the lower the social risks associated with a product. In addition to the alternative lifespans mentioned above, we tested two scenarios regarding the product's country of origin (i.e., manufactured in the US vs. imported products). To identify the countries with the largest imports to the US for each material, we used international trade data from United Nations Comtrade database (United Nations, 2021).

Results

Figure 2 shows the E-LCA results for the three material alternatives under different lifetime scenarios. In the baseline scenario, the aluminum roof performed better in the two categories analyzed in this study. The TPO roof with the expected lifespan of 20 years had the worst performance in both GWP and resources categories. Considering all the scenarios, the aluminum roof with a lifespan of approximately 50 years (one replacement) performed better in both categories, followed by the 25-year lasting TPO roof in GWP and the aluminum roof with two replacements over the building's life cycle.

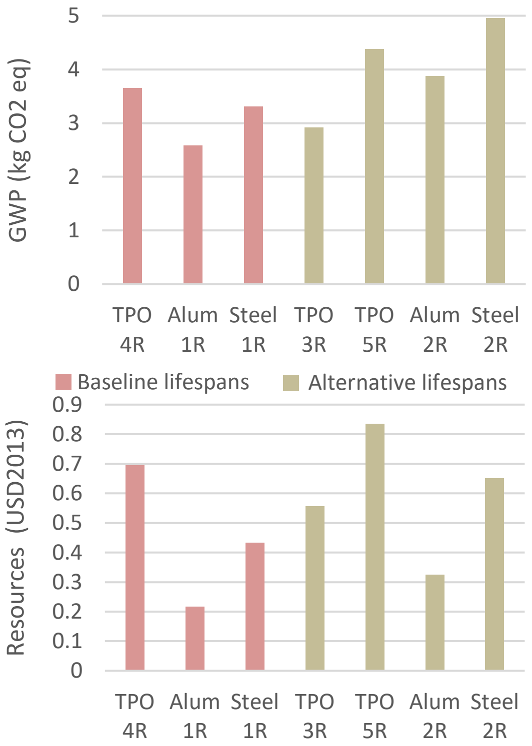

Figure 2. E-LCA results. LCIA method, ReCiPe 2016. R = Replacements over a 100-year building's lifespan.

Overall, the results suggest that using aluminum as a more durable alternative would increase the environmental performance of the roof in the two categories. However, as expected, the analysis needs to be done in a case-by-case basis, as not all materials with longer lifespans would result in lower impacts. For example, two replacements of the steel roof resulted in higher GWP than four replacements of TPO. The results also highlighted the importance of increasing the durability of each material while considering the number of replacements over a building's lifespan. For example, an increase of the TPO's lifespan in five years (from 4 to 3 replacements), resulted in a GWP reduction of 9.5% compared to the baseline scenario.

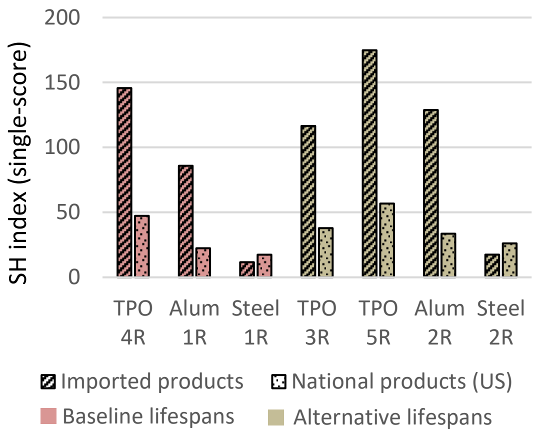

Figure 3. S-LCA results (single-score). R = Replacements

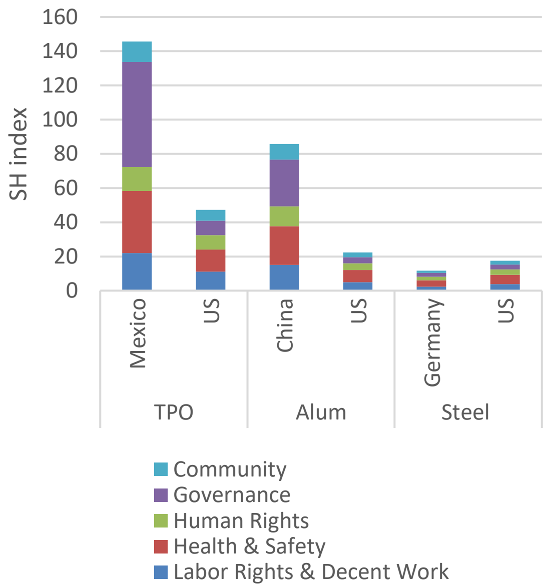

Figure 4. S-LCA results by category for the baseline lifespan scenarios (TPO 4R, Alum 1R, Steel 1R)

As expected, the longer the product lifespan, fewer replacements are needed over the building service life, which results in fewer worker hours at risk. However, as in the E-LCA results, increasing the durability of the TPO roof is not enough to offset its higher "embodied" social impacts. That said, the product with best social performance in this analysis was the steel roof sheet, both in National (domestic) and imported scenarios, followed closely by US-produced aluminum roof sheets. However, given the somewhat lower environmental performance of the steel roof alternatives, aluminum roofs produced in the US achieved the best overall outcomes when only one replacement is required. However, if the aluminum sheets are produced in China, the social risks increase due to concerns about Governance, Health and Safety (e.g., occupational toxics), and Labor Rights and Decent Work (e.g., right to strike, collective bargaining, migrant labor) (Figure 4). Conversely, the main social risks for all national products in the US (both plastics and metals sectors) were associated with Health and Safety (e.g., workplace injuries and fatalities) and Labor Rights and Decent Work (e.g., social benefits like parental leave, freedom of association, and issues from migrant labor).

Discussion and conclusions

In this paper, we explored environmental and social impacts of building products under different durability and lifespan scenarios. We found that, in the context of a 100-year building, the most durable roof products had better social and environmental performance than the least durable alternatives. The number of replacements over the building's life cycle and the country where the products were manufactured impacted the results.

However, this study has limitations. Currently, there are few standards outlining how to account for product durability in either E-LCA or S-LCA methodologies, and there is little guidance on how to interpret the results of a combined E-LCA and S-LCA approach. A key shortcoming is the difference in the way the data is reported and aggregated across databases. For example, the UN Comtrade data is very specific to the type of material (e.g., imports of alloy steel, flat-rolled, electrolytically plated or coated with zinc). Environmental data from ecoinvent is more aggregated but still specific to each process and material (e.g., steel sheet rolling). Finally, SHDB aggregates data by sector (e.g., metal products in the United States) which means that the SH data for US-produced steel and aluminum were the same, and the different scores can be attributed to the price difference between the two materials. Moreover, one of the primary issues of E-LCA has been resolving spatial issues. The integration of S-LCA with E-LCA further emphasizes the need to resolve E-LCA spatial issues. For example, in E-LCA, we aggregate emissions across a product's lifetime, and do not consider where the actual emission occurred in the results. This approach is appropriate for global impacts, such as climate change. However, in S-LCA, a focus on the spatial resolution is perhaps more acute and needed as we are developing results that are highly relevant to regional issues, such as human rights. At the same time, the SHDB findings are presented at the country level, requiring more spatially refined S-LCA data through site-specific analysis. In summary, there needs to be integration of spatial scale for E-LCA and S-LCA results, while improving S-LCA regional data.

Finally, while it is useful to use a SH score to roughly approximate justice conditions of production, it is critical to understand the inconsistencies in this approach to better reflect the social impacts of materials. As shown in Figure 4, the SH index is an aggregate of scores from categories that reflect community issues, governance, human rights, health and safety, and labor rights. Each of these categories is made up of subcategories with their own underlying assumptions and indicators. For example, the production of TPO in Mexico has a high SH index in the category of health and safety due, in part, to measures associated with occupational injuries and fatalities – a measure with direct relevance to our exploration of the social impacts of production. Similarly, the production of aluminum roofing has a high SH score in the category of health and safety, due in part to employee exposure to occupational toxics and hazards. These subcategories are critical to understand the social impacts of production. Yet the usefulness of these measures becomes less clear when other subcategories are considered. Poverty, a subcategory within Labor Rights and Decent Work, is perhaps less related to the social impacts of production than to the country's level of development. We caution that in some cases low social scores might indicate the need for additional trade, rather than less. In short, we propose that it is essential to consider the social impacts of production, but that this must be done with context rather than the broad application of a score with a single dimension.

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