Parametric life cycle assessment of a reusable brick veneer

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Abstract. A possible design strategy to improve the sustainability of building products is facilitating their future reuse. This strategy inspires some manufacturers to design innovative products, such as reusable façade products. Although these products might have a higher environmental impact for production, their reusability could lead to an environmental saving from a life cycle perspective. A possible method to evaluate their environmental performance is life cycle assessment (LCA). Nevertheless, LCA studies of reusable products are still rare. Furthermore, although the general LCA frameworks is fixed by ISO and CEN standards, some methodological choices must still be made by LCA practitioners. This paper first presents a method (as four methodological choices) for a parametric life cycle assessment of reusable building elements. Then, this method is applied to a comparative LCA of reusable and brick-and-mortar veneers. With proposed method, the reusable brick veneer is environmentally advantageous if it is reused at least once and if it is properly recycled at its end-of-life. The parametric method also indicates the relative influence of various parameters such as reuse rate, number of interventions, transport distances and waste treatment. The manufacturers can use this LCA study as a retrospective assessment to validate the relevance of design choices, but also as target-driven product management support to know hot-spots in the product' life cycle management. This study will hopefully inspire other designers and manufacturers and accelerate the transition towards a sustainable built environment.

1. Introduction

To achieve a sustainable built environment, circular economy principles advise designers to reuse construction products. However, using and reusing a product has also an environmental impact is henceforth no guarantee for environmental benefits [1,2]. These benefits can be quantified by performing a life cycle assessment (LCA). However, the link between LCA results and the design and use parameters is not always explicit, though important for designers. Therefore, governmental initiatives are developing tools, such as the Belgian TOTEM [3] or the French Elodie [4], to facilitate the use of LCA by the architectural practice. Nevertheless, these tools do not yet integrate the principles of circular economy. Further, the standards for LCA remain ambiguous when a product has more than one use cycle, for the reasons explained in Section 2. Some researchers even question whether LCA is at all suitable to evaluate so called ‘circular’ products [5,6]. To understand to what extend reusable products can be evaluated with LCA, we conducted a case study of a reusable brick veneer. In this paper, we present first four difficulties when evaluating reusable products with the LCA framework defined by the international (ISO) and European (CEN) standardization committees and propose a parametric LCA method to overpass them (Section 2). The proposed method uses parameters to understand the impact of decisions made at product design stage, production, or when the product is installed in a building. The method is then illustrated with the comparison of the environmental impact of reusable and conventional brick veneers (Section 3). We finally summarize our findings (Section 4) and conclusion (Section 5).

2. Parametric LCA of reusable products

When performing a life cycle assessment (LCA) of reusable or recyclable products, a recurrent difficulty is setting relevant system boundaries and allocating the environmental impact for production and waste treatment over the different products, as shown by the efforts invested in the search for an appropriate End-of-Life formula in the context of the Product Environmental Footprint calculation [7]. Often, an LCA assessor must choose to take the perspective of either the first use cycle (i.e. the ‘new’ reusable product), the second use cycle (i.e. the ‘reused reusable’ product), or the last use cycle before waste treatment (i.e. the ‘reused non-reusable’ product). To this difficulty is added the lack of (reliable) data about parameters influencing the life cycle inventory, such as products’ lifespan, maximum amount of use cycles and necessary remanufacturing processes. The difficulties can be summarized into four methodological choices in the next paragraphs. These choices constitute the proposed parametric LCA method for reusable products and supports the case study in Section 3.

2.1. Should we take a product or building perspective?

Depending on the goal of the LCA, the assessment is performed either at building or product level. In the present case study, the goal of the LCA is to position the product on the market and the results are intended mainly as a marketing instruments. Therefore, SETAC recommends to take a product perspective, though the products must be brought into the building context in order to make a valid comparison [8]. Notably from the perspective of a reusable product, an LCA would then consider in module B, all use cycles, including the impact of relocating and reconditioning a product, until the end of its technical lifespan, which is usually longer than the building lifespan. A second reason for taking a product perspective is that approximating at once all the avoided products thanks to reuse is more abstract than defining scenarios including successive reuses. This second option implies a *system expansion*, which consequently solves the problem of allocating the impacts over multiple use cycles (i.e. multiple ‘reused reusable’ products). Nevertheless, the avoided products due to recycled content and product recyclability must still be accounted through an appropriate allocation procedure. Allocation procedures are not discussed in this paper.

2.2. How do we define the system boundaries in time?

Circularity means in theory endless use. If we take a product perspective, the period of analysis should not be limited to the lifespan of the assembly the product is part of, neither it can be endless. So, when to start and when to stop the inventory? We decide to define the period of analysis based on the technical lifespan of the reusable product. After all, no manufacturer guarantees that its product will last forever.

2.3. *How to define use scenarios at building level that make sense for all compared products?*

Use scenarios are conventionally defined at building level, by defining what creates the need for, and triggers, relocating/replacing the product. Then the product's 'response' to this need for change is evaluated. Nevertheless, the need for change at building level can be influenced by the feasibility of change at product level (i.e. rebound effect). This feasibility differs in both products. A conventional product can, in practice, be less often altered than a reusable product because of the burdens each intervention generates (which is the reason why we design reusable products). Here, because the reusable and conventional products must be comparable in terms of their 'resilience to change', we choose to test both products for identical use scenarios (i.e. the same need for change). Hence, they both have the same amount of use cycles (Figure 1).

2.4. *How to (time-efficiently) evaluate many different use scenarios?*

Because of the system expansion, the two products go through multiple cycles with multiple use scenarios to consider, and hence more uncertainty (e.g. different reuse rate, different transport distance, etc.). Even the amount of cycles can be unknown. To model these many scenarios efficiently modelled, parameters are introduced in the calculation of the total environmental impact (E), as in equation (1)

$$E = E_{prod} + E_{trans,c} + E_{cons} + N \times (E_N) + E_{dec} + E_{trans,w} + E_w \qquad (1)$$

in which the potential environmental impact of the Nth reuse cycle (E_N) is defined by equation (2).

$$E_N = E_{dec} + E_{cons} + E_{trans,N} \times R + \left(E_{prod} + E_{trans,c} + E_{trans,w} + E_w\right) \times (1 - R) \qquad (2)$$

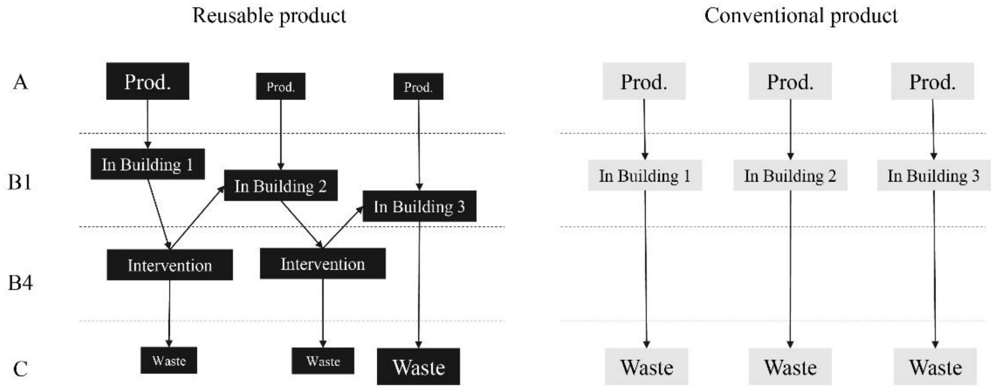

Figure 1. The reusable product is used over three cycles (with some losses), while the conventional product must be produced three times. ('Prod.' = production; 'Waste' = waste treatment)

in which,
E is the total environmental impact;
E_{prod} is the environmental impact of production;
$E_{trans,c}$ is the environmental impact of transport to construction site;
$E_{trans,w}$ is the environmental impact of transport to waste treatment;
$E_{trans,N}$ is the environmental impact of transport to next construction site;
E_{cons} is the environmental impact of assembly or construction;
E_{dec} is the environmental impact of deconstruction or demolition;
E_w is the environmental impact of waste treatment;
R is the reuse rate (i.e. the percentage in mass of the whole product that is reused in the next cycle);
N is the number of interventions, hence the number of use cycles occurring after the initial use, during the period of analysis.

The two main parameters are the reuse rate (R) and the number of interventions (N). R depends on the design but also on the use: it's not because a product is design for disassembly that it will be disassembled. By this parameter the level of 'circularity' of the system is represented. The higher the reuse rate, the more materials remain in use. A low R characterises a linear use of materials, while a high R characterises a circular use of materials. N depends on the need for functional changes (e.g. aesthetics, necessity to access and alter an internal layer, reconstruction of the whole system), and not on the need for technical changes. N is identical for both products, although in practice N might be higher for a reusable product than a non-reusable one due to rebound effect.

All the parameters and their interaction can be visualized in a process diagram (figure 2) which supports the case study presented in the next section.

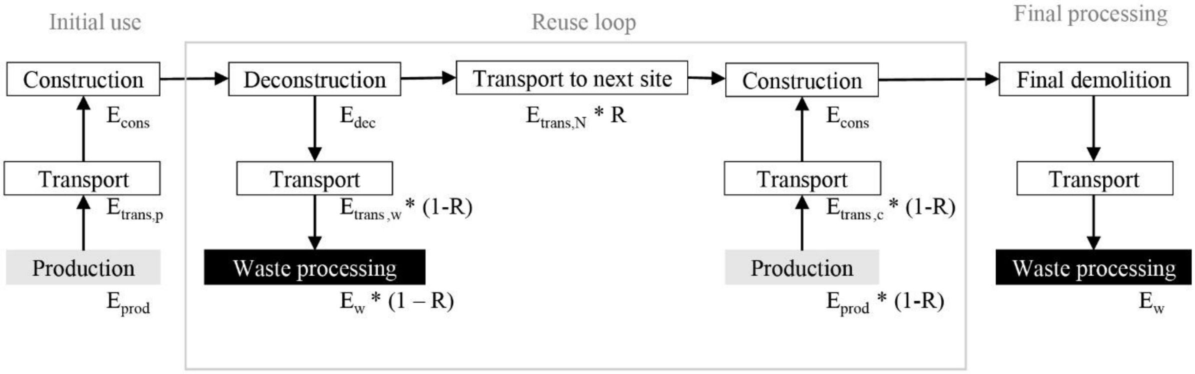

Figure 2. Process and flow model for the life cycle of product with multiple uses.

3. Case study

With the method for a parametric life cycle assessment (LCA) (Section 2), the potential environmental impact of two building products was compared. This section reports the LCA step 1 (goal and scope), step 2 (inventory) and step 3 and 4 (impact assessment and results of the attributional LCA).

3.1. Goal, functional unit and system boundary

The LCA is mandated by the manufacturer of a dry brick veneer available on the Belgian market, called '*Façadeclick*' (FC). The goal is to compare the environmental impact of FC, designed for a circular use of materials, with a '*brick-and-mortar'* (B&M) veneer, its most conventional alternative.

The functional unit (FU) is "a brick veneer, covering one square-meter of external wall with a self-bearing system, including anchors to the load-bearing structure, for 80 years". Both products have similar aesthetical, structural[2] and thermal performances[3], and both act as a rainscreen. Both products can reach a thermal transmittance (U) value of 0.24 W/m²K when combined with 0,14 m masonry wall and 0,11 m EPS insulation. The environmental consequences of a different of product's weight on the dimensioning of the foundations are not included in this illustrative case study.

As for the system boundary, the inventory of mass and energy flows is estimated from cradle to grave (from modules A1 to C4, as defined in the EN15804 norm). It includes the production of the different parts (E_{prod}), their transport between the different production and construction sites (E_{trans}),

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[2] The compression resistance values are 11 N/mm² for the plastics inserts and 5 N/mm² the mortar, according to the product technical documentation.

[3] Thermal conductivity (λ) values are 0.69 W/mK for the reusable brick and 0.59 W/mK for the conventional brick, according to the product technical documentation.

and the waste processing (E_w). Excluded from the analysis are packaging, storage, maintenance of the wall, assembly and disassembly of FC and construction and demolition of B&M.

3.2. Life cycle inventory

The life cycle inventory was carried on with LCA software SimaPro 8 [9], using the process data from the Ecoinvent 3.1 database [10], with default allocation[4]. The impacts of by-products are allocated following the recyclability approach (0:100) with credit for avoided virgin production, as defined by Allacker et. al. [7] who consider this approach valid for the criteria ‘physical realism’ at system level. Following this approach, no credit is given to recycled content (e.g. recycled plastic used in the plastic inserts), but the recyclability at End-of-Life is credited following Belgian conventional recycling rates [12]. The consumption data comes from the product manufacturers. Both FC and B&M products weight respectively 136 kg/m² and 176 kg/m². FC uses 130 kg of hollow bricks and plastic inserts to ‘click’ each brick on top of the other. B&M uses a similar quantity of bricks (128kg) and 48 kg of mortar. FC requires 8 steel anchors to attach to the load-bearing structure, while B&M only needs 5 anchors.

3.3. Modelling assumptions

The final environmental impact (E) score is calculated with the impact assessment method ‘ReCiPe Endpoint (H) V1.12 / Europe ReCiPe H/A – single score’. The parameters value for the baseline scenario are estimated from discussion with the product manufacturers[5], with some modelling simplifications:

- The impact of production (E_{prod}) is calculated based on the inventory of materials and energy given by the product manufacturers.
- FC and B&M are both first installed in Wilsele, Belgium. During each reuse, FC is always relocated at 100 km from the previous site. B&M is installed at 80 km from the brick retailer. The mortar is transported over 5 km to the construction site. At end-of-life, both products are transported to the waste treatment plant over 30 km. All transport distances remain constant for each use cycle.
- Upon recommendation of SETAC [8], two waste treatment scenarios are compared: (1) an “average for Belgium” baseline waste treatment scenario, based on the BE-PCR[6] [12] and (2) an “improved plastic recycling” scenario, in which all HDPE is recycled. Both scenarios are defined as a mix of recycling, incineration, and landfilling per material category.
- In this model, B&M is not reused, therefore $R_{B\&M}$=0% by default. FC is reused with 5% losses over whole product (bricks, inserts and anchors), R_{FC}=95%.
- As for the number of use cycles (N), FC can be disassembled and reassembled up to five times. For the baseline scenario, N varies thus from 0 to 5.
- The service lifespan of all parts of the products is considered higher than the period of analysis (80 years). Consequently, replacements of sub-products are not considered.

3.4. Results

In this baseline waste scenario (FC1) and N=0 (i.e. no intervention), the *Facadeclick* (FC) product has a potential environmental (E_{FC}) impact of 6,0 points, that is 63% higher than the *bricks & mortar*

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[4] Default allocation in Ecoinvent 3.1 considers average supply market, unconstrained, and economic allocation of multiple outputs [11].

[5] The product manufacturers are ‘Snel Bouwsysteem’ and ‘Nelissen’.

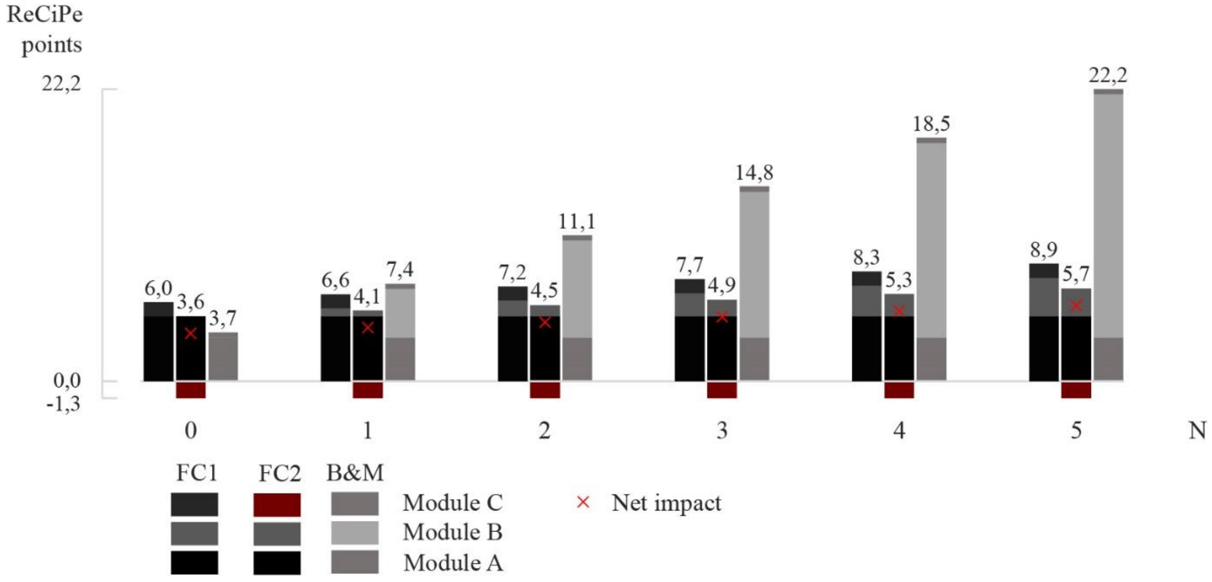
[6] In this BE-PCR waste scenario: Bricks: 5% landfilled; 0% incinerated; 0% reused; 95% recycled; Metals: 5% landfilled; 0% incinerated; 0% reused; 95% recycled; Polyolefins (PP, PE): 10% landfilled; 85% incinerated; 0% reused; 5% recycled.

(B&M) product ($E_{B\&M}$=3,7 points) (Figure 3). When one intervention occurs (N=1), both products have close E (6,6 and 7,4 points). From two interventions (N>1), FC is more environmentally efficient than B&M (7,2 and 11,1 points). In the “improved plastic recycling” scenario, in which the inserts are fully recycled at the end-of-life (FC2), FC has a lower E than B&M already after its first reuse (4,1 and 7,4 points).

As shown in both waste scenarios, when R_{FC} is high (95%), E_{FC} is almost no dependent on a variation of N, because each new cycle does not contribute much to E. Consequently, FC is more resilient to changes than B&M. Therefore, the LCA of reusable products is more robust. A similar conclusion was drawn by Galle for the life cycle costing of reusable products [13].

With the environmental profiles of both products, we can discuss the choice of parameters’ value for the baseline scenario. The demolition of B&M is probably generating environmental impact from the use of building machines and water spraying to control dust emission. If these flows were included in the inventory, it would not invert the interpretation of the results.

The FC’s potential environmental impact for the baseline scenario ($E_{Baseline}$) depends on transport distance for the product relocation and the reuse rate during relocation (R), among other parameters. The sensitivity to those two parameters is assessed for two interventions (N=2). Comparing the impact of a 10% variation of transport distances and R for N=2, we see that $E_{Baseline}$ is especially sensitive for change of R (table 1). When R decreases 10% (R=85% instead of R=95%), $E_{Baseline}$ decreases 15%. E is much less sensitive to the transport distance: a 10% longer transport distance results to only 1% increase of $E_{Baseline}$. When the FC product is relocated twice (N=2), it must be reused at minimum 60**%** to equal the impact of the bricks-and-mortar, as shown by the variation of the E_{FC} to R (Figure 4). Consequently, losses during relocation FC should be limited to 40% (in mass) to perform environmentally better than the conventional system.



LCA single score calculation with ReCiPe Endpoint (H) V1.12 / Europe ReCiPe H/A and Ecoinvent v3.

Figure 3. Environmental impact of FC and B&M brick veneers according to the amount (N) of interventions occurring during the period of analysis. In the ‘average for Belgium’ waste treatment scenario (FC1), the reusable product performs environmentally better than the B&M system from the second reuse (N=2). In the “improved plastic recycling” waste treatment scenario in which the plastic inserts are fully recycled at their end-of-use (FC2), the dry brick system performs environmentally better after the first reuse (N=1).

Table 1. Sensitivity analysis of the parameters influencing the LCA results of the dry brick wall, considering N=2 and $E_{Baseline}$ = 7,08 Points. The most sensitive parameter is the Reuse Rate (R).

Input parameters	Input parameters' value			Resulting E			
	Baseline	$\Delta_{10\%, min}$	$\Delta_{10\%, max}$	E_{min}	E_{max}	ΔE_{min} [relative]	ΔE_{max} [relative]
Transport distance [km]	100	90	110	7,03	7,13	0,56 [1%]	0,05 [1%]
R [%]	95	85,50	/	8,18	/	1,09 [15%]	/ [/]

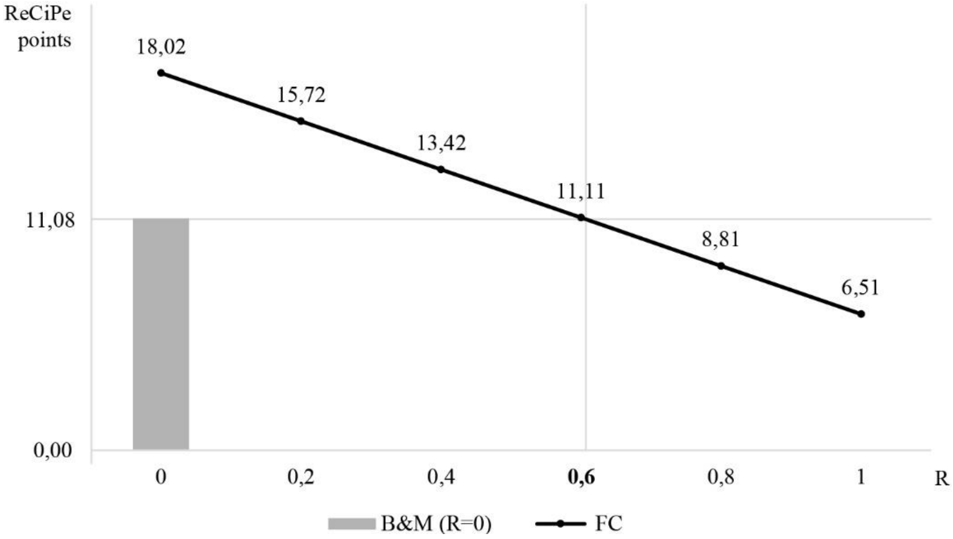


Figure 4. Sensitivity analysis of the Façadeclick's environmental impact to reuse rate (R) value. Considering two interventions (N=2), 60% FC must be reused to equal the impact of the bricks-and-mortar product (11,08 ReCiPe points).

An assumption which is worth discussing is the service lifespan of the sub-products. The service lifespan of all parts of the products is considered higher than the period of analysis (80 years), while the plastic inserts could age faster than the bricks and fail the technical requirement before 80 years. In the model, each time FC is relocated, 5% of the new FC is produced to compensate losses (flows occurring in stage B4 – Replacement of the product life cycle). The remaining service lifespan of these 5% is considered equal to the remaining service lifespan of the other 95%. As a result, the whole product is treated as waste after 5 interventions, although only 75% have effectively reached the end of their technical lifespan and 25% could still be reused.

4. Summary of findings

The case study yields both findings about the environmental impact of the brick veneers and about the parametric life cycle assessment (LCA) method.

4.1. Findings about the environmental profile of the reusable brick veneer

The potential environmental impact of the reusable (FC) product is 63% higher than the brick-and-mortar (B&M) product when the veneer is never altered. It is almost similar to B&M when the veneer is altered once over the period of analysis and lower than B&M when the veneer is altered at least twice. When the plastic inserts are fully recycled, the initial additional environmental impact is always compensated, even without intervention, making both systems almost competitive from the start. These results depend on the simplifications and assumptions detailed in Section 3.

The reusable veneer has an environmental impact (E_{FC}) that is most sensitive for changes in reuse rate (R), while the brick-and-mortar veneer $E_{B\&M}$ is sensitive for changes in the number of interventions (N). When a product is efficiently reused (high R), the product environmental impact is almost not sensitive to N.

4.2. Findings about the parametric LCA method

As shown in the case study, the parametric LCA method proposed in Section 2 allows us to compare reusable and non-reusable products. To assess the LCA of the reusable product, we opt for a system expansion. Therefore, we avoid a complicated distinction of the ‘new reusable’, ‘reused reusable’ and ‘reused non-reusable’ products.

The analysis mixes product and building levels without any problem: the LCA is performed at product level (i.e. the brick veneer), considering use scenarios that are defined at building level. The LCA of the product is made at product level, upon recommendations of the SETAC report [8] and to draw possible use scenarios. For the sake of comparability, reusable and conventional products experience the same amount of use cycles, although this scenario is maybe unprobeable.

The proposed parametric LCA method clarifies how design and use parameters influence the environmental performance of (reusable) products. It shows the potential benefits of Design for Disassembly and Reuse. Thanks to the use of parameters, it also indicates the necessary conditions to realize these potential benefits. With the sensitivity analysis, the importance of the different parameters can be qualified and quantified. Moreover, the parametric LCA can be used to set a specific target value of the E and deduce the parameters values needed to reach that target. Finally, as usual in LCA studies, hot-spots analysis could identify the parts of the product contributing to a large share of E, such as which life cycle module contributes the most to the total environmental impact. These are however outside of this illustrative case’s scope.

5. Conclusion

As designing a product for future reuse is no guarantee for environmental savings, a life cycle assessment (LCA) is necessary. However, the LCA standards remain ambiguous when the product has more than one use cycle. The main difficulties lie in the selection of the right perspective (building or product), the system boundary and the use scenarios. Additionally, considering many different use scenarios can be very time-consuming.

To overpass those difficulties, we proposed a parametric LCA at product level, with use scenarios defined at building level, combined with a system expansion approach to include the largest amount of use cycles as the product can technically withstand. This parametric LCA provides also good insight about the sensitivity of the model to different parameters (e.g. R, N). More than providing a binary ‘*yes or no*’ answer to the question ‘*Does product A perform environmentally better than product B?*’, this method shows how the environmental impact relates to both design and use parameters. Furthermore, the method can be used as target-driven LCA to support decision-making for the design and the use of building product.

The application of the parametric LCA method to the comparison of reusable and brick-and-mortar veneers shows the competitiveness of the reusable veneer. Considering a baseline waste treatment scenario, this product has a higher production environmental impact than a brick-and-mortar veneer but is competitive when the veneer is altered once. The more interventions, the more beneficial the reusable system becomes compared to the brick-and-mortar veneer. When the plastic inserts are fully recycled, the initial additional environmental impact is directly compensated by savings, from the first use cycle. When the reusable product is relocated and reused twice, the material losses should be limited to 40% (in mass) to compete with the brick-and-mortar veneer.

As illustrated by this case study, the proposed parametric LCA is an insightful yet simple method to evaluate the E of reusable construction products. It can provide product manufacturers with useful insight about the environmental profile of their product and the conditions to use it efficiently. However, the method has been developed according to this specific case study. Further research should verify the applicability of the method to other types of reusable products.

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