Evaluating ‘reuse’ in the current LCA framework – Impact of reuse and reusability in different life cycle stages

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Abstract. In the context of circular construction, the (potential) reuse of construction materials and building products is set forward as a general concept to reduce the environmental impact of buildings. But does this really lead to reduced impacts? A standardised framework to calculate the environmental impact of buildings over their life cycle is available through the European standards EN15804+A2 and EN15978 for life cycle analysis (LCA) in construction. The concept of reuse does however intrinsically focus on multiple use or life cycles. A correct quantification of the environmental impacts of reuse in buildings, requires a better understanding of the different mechanisms and issues at play. By means of critical assessment of the LCA methodology, in combination with a simplified case study, this paper provides insights in how different reuse options for products are valorised (or not) when calculating the environmental impact. It is shown that the LCA standard EN15804+A2 allows to quantify the impact related to different concepts of reuse at the beginning or the end of the considered life cycle. In general reused products will lead to larger environmental gains as the production stage (A1-A3) can be avoided. The environmental benefit related to the reusability of a product is typically reflected in a smaller difference in the end-of-life (EOL) stage (C1-C4). Also the relevance of existing concepts, such as module D, is discussed for each of the considered reuse options. Results show that module D can provide insights in the future potential of reuse (at EOL) for virgin products, but that the numbers are difficult to interpret and even misleading for reuse products. The results and discussion show the limitations of the current LCA framework for these types of products and identify the need for the integration of additional concepts to correctly valorise the potential of reusable products using LCA.

Keywords: LCA methodology, reuse, case study, module D

1. Introduction
The construction sector is responsible for 50% of the resource use and produces 35% of the waste in Europe [1]. Several action plans related to the circular economy have been defined and are being developed to move towards a more efficient resource use in construction. The recycling and reuse of existing materials, as well as the reusability of new construction materials are among the strategies that are put forward [1] [2].

Overall, the larger objective is to reduce the impact of construction activities and buildings on the environment, ranging from limiting the impact on climate change to avoiding the depletion of primary resources. Life cycle analysis (LCA) allows to quantify the impact of a product or building over its entire...
life cycle, taking into consideration multiple environmental issues, and thus avoiding pollution transfers. Previous studies focus on the comparison of different environmental assessment methods to quantify the impact of reuse/reusable products and reveals that large differences can occur depending on the selected LCA method [e.g. 3]. More specifically, the end-of-life allocation is shown to play an important role in the impact of products using secondary resources or materials [4]. In general two main strategies can be defined in LCA for assessing the use of secondary materials: (1) one approach is known as the ‘recycled content approach’ (also, the cut-off or 100:0 approach) crediting the recycled content or use of secondary materials in the production stage; (2) the other approach is known as the ‘end-of-life approach’ (also, the 0:100 approach) crediting the recycling rate or use of secondary materials in the end-of-life stage (EOL) [3,5].

The standards EN15804+A2 [6] and EN15978 [7] specify the calculation rules for LCA in construction at product and building level. Specific to these standards is that they are based on a modular approach, attributing the environmental impacts to the different life cycle stages. Moreover, they are based on the “polluter pays principle”, which implies that impacts are fully allocated to the life cycle stage where they occur. Hence these standards follow the 100:0 approach, where 100% of the production impact is allocated to the first life cycle (where the production is actually taking place); and 0% of the production impact is allocated to the subsequent life cycle making use of the secondary resources or product. However, these standards have been developed with a linear life cycle in mind and with a focus on a single life cycle, going from production to end of life treatment.

2. Objectives and approach
A first part of this study focuses on the different reuse strategies (e.g. at the beginning or the end of the life cycle) and what this means from a methodological point of view in LCA. The second part of the study presents a simplified case study of carpet tiles to evaluate the meaning of the different reuse approaches in terms of environmental impacts. This case study provides insights in the potential differences in impact for the different reuse strategies in terms of order of magnitude or uncertainty, but also reveals the limitations of the methodological approach for certain scenarios.

3. Reuse of products in the current LCA framework from a methodological point of view

3.1. Definition of reuse in the study
According to the standards, ‘secondary materials’ refers to both recycled and reused materials. Reused materials are considered to be a special case of secondary materials and represent resources that keep their properties and function from one life cycle to another without being transformed. In this paper, a ‘reused material or product’ refers to the use of a material or product at the beginning of the life cycle that is made from the same materials and with the same composition as in its previous life cycle. A ‘reusable material or product’ refers to a material or product that can be reused at the EOL. The function of the product remains the same during the next, subsequent life cycle and no recycled or virgin materials are added to the product in between its different uses. To avoid confusion, recycling at the EOL of the product is not considered within this study. In all cases, referring to a ‘virgin’ material or product implies that no recycled content is used (so no input of secondary material). Referring to a ‘non-reusable’ product implies that the whole product is disposed off (landfill or incineration) at the EOL (so no output of secondary material).

3.2. Different (re)use cases in relation to the LCA standard
For products, different situations can be identified based on the reuse scenarios at the beginning and the end of the considered life cycle. In this paper, we differentiate between four use cases for the reuse of products:

(a) A non-reusable virgin product
(b) A reusable virgin product
(c) A non-reusable reused product

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(d) A reusable reused product

For each situation, the impacts calculated for the different life cycle modules as defined in EN15804+A2 will be different. The modules defined in EN15804+A2 range from A1 to D and each module is associated with a part of the life cycle of the product. Modules A1 to A3 represent the production stage, A4 to A5 the construction stage, B1 to B7 the use stage and C1 to C4 the EOL. Module D is situated outside the boundaries of the product life cycle and includes the potential benefits and loads related to reuse, recycling or recovery in the next life cycle (also referred to as “avoided impact”).

The environmental “benefits (and loads)” related to the reuse of products (at the beginning or the end of the life cycle) will be visible within the considered life cycle (modules A to C) when comparing them to a traditional non-circular scenario taking into account a new non-recyclable and non-reusable product (scenario (a)). For each scenario, a similar use and life span of the product are considered. Table 1 illustrates the differences that exist between the different reuse scenarios. Each cross shows in which module a potentially significant impact can be avoided compared to the traditional scenario (a).

A non-reusable virgin product (a). This is the non-circular scenario. The product is entirely based on primary resources. The EOL of the product does not consider any recycling, reuse or recovery of the materials making up the product. The materials are sorted and disposed. They either go to landfill or to incineration without heat recovery. According to EN15804+A2, all modules from A1 to C will be taken into account and will have impacts associated with them. As no secondary materials leave the system after the EOL, there are no benefits or loads to be calculated for module D. In case the materials from the product would go to recycling, or energy/heat would be recovered during incineration, some potential loads and benefits could be calculated in module D.

A reusable virgin product (b). The use of a new and reusable product in a building implies that only primary materials or resources are used for the production. Consequently, the production stage of this scenario is similar to the production stage of the scenario (a). The reusability does however lead to changes in the EOL stage. The default hypothesis is that the product is fully reusable in a next life cycle at another building site. This implies that (part of) the building has to be dismantled (instead of demolished) and that the products should be sorted during the EOL phase. As a result, the final disposal will be avoided compared to a traditional, non-reusable product. Therefore, a difference in impact will become apparent for the module C4 (see Table 1). Outside the system boundaries, the reuse potential of the product in a subsequent life cycle, is made visible in module D.

A non-reusable reused product (c). A reused product has been already used during a previous life cycle. The current life cycle is the second (or later) life cycle of the product and thus by definition, the product is composed of secondary materials/resources. As a result, the extraction of primary resources, the transport of these resources and the production process are avoided in comparison with a virgin product. Table 1 illustrates that differences in impact can be found for modules A1-A3 related to the production stage. As the reused product is not reusable, the EOL of the scenario (c) is identical to that of the traditional scenario (a). All the materials that make up the product are disposed off without reuse, recycling or recovery in the next life cycle. Modules A4 to C4 do not represent significant differences compared to the scenario (a).

A reusable reused product (d). This scenario represents a truly “circular” product, implying a multiple reuse potential of the product. Indeed, as the product is reused, it comes from a previous life cycle and its reusable potential shows that it could be also reused in the next life cycle. This scenario creates a combination of the scenarios (b) and (c). The production stage is avoided as the reused product is made of secondary materials which do not need to be transformed. The EOL is identical to the scenario (b), with an avoided disposal of the product. Table 1 shows how important differences might exist for modules A1-A3 production stage and for module C4 disposal. Following the logic of the previous scenarios, module D should highlight the reuse potential of the product in the next life cycle.
However, according to the calculation rules of module D and the specificity of the input flows, module D does not represent a significant avoided impact in this “circular” case. This is discussed later in the text.

In summary, Table 1 clearly shows that the benefits related to a reused product will become visible in the production stages (A1-A3), whereas the benefits related to a reusable product will be seen in part of the EOL stage (C4).

Table 1. Indication of life cycle stages where significant differences in environmental impact are to be found or expected for different reuse scenarios compared to a traditional linear life cycle.

| Product stage | Construction process stage | Use stage | End of life stage | Benefits and loads beyond the system boundary |
|---------------|---------------------------|-----------|------------------|--------------------------------------------|
| A1            | A2                        | A3        | A4               | A5                                        |
| B1…B7        | C1                        | C2        | C3               | C4                                        |
| D             |                           |           |                  |                                           |

Scenarios

- **New product, non reusable (a)**
- **New product, reusable (b)**
- **Reused product, non reusable (c)**
- **Reused product, reusable (d)**

| Scenarios                          | A1 | A2 | A3 | A4 | A5 | B1…B7 | C1 | C2 | C3 | C4 | D                        |
|------------------------------------|----|----|----|----|----|--------|----|----|----|----|--------------------------|
| New product, non reusable (a)      |    |    |    |    |    |        |    |    |    |    |                          |
| New product, reusable (b)          |    |    |    |    |    |        |    |    |    |    | Avoided impact           |
| Reused product, non reusable (c)   |    |    |    |    |    |        |    |    |    |    |                          |
| Reused product, reusable (d)       |    |    |    |    |    |        |    |    |    |    | Avoided impact           |

### 3.3. Difference between in-situ and ex-situ reuse

By default, it is assumed that the reuse of the product takes place in another building (ex-situ reuse). Therefore, at the EOL, the transportation of a reusable product to the sorting facility is needed. However, if the reusable product is reused directly on the building site (in-situ reuse), the sorting takes place on-site and the transportation of the product can be avoided. The impact of transportation to the construction site can similarly also be avoided in the case of reused products originating from reuse on-site. Compared to the linear scenario (scenario (a)) an impact is avoided in module A4 for reused products and in C2 for reusable products (see Table 1, grey crosses).

### 3.4. Calculation rules for module D of reuse

The calculation of the module D for a product is based on the assessment of the net output flows: all the flows of secondary materials leaving the studied system are summed together and all the flows of these secondary materials entering the system are subtracted. In the case of scenario (a), no secondary materials are leaving the system, so the net output flow equals zero and no module D shall be calculated. A similar reasoning exists for the module D in scenario (c) of a non-reusable reused product where no secondary material leaves the system.
For the virgin but reusable product in scenario (b), secondary materials are leaving the system (=output flow) as the product is considered to be fully reused in a next life cycle. As only virgin materials are used in the production stage, the input flow of secondary materials equals zero. As a result, the net output flow equals the output flow. The avoided impact in module D is equal to the impact related to the production of the initial product minus the impact of the processes required to prepare the product for reuse (cleaning for example).

For the reused product that is reusable at the EOL (scenario (d)) secondary materials are leaving the system. As for scenario (b) module D shall thus be calculated to estimate the benefits and loads beyond the system boundary. However, as the product is reused also an input flow of secondary material exists which has to be extracted from the output flow. Given the fact that the product is considered to be fully circular (the product is both reused and reusable), the input flow equals the output flow. As a result, the net output flow equals zero and module D equals zero. The fact that no module D can be calculated for fully circular products (reusable reused products) is problematic for the meaning and interpretation of module D. This issue is discussed into more detail based on the results from the case study.

The reasoning above represents a theoretical exercise only considering either full disposal (incineration or landfilling) or full reuse (complete product reused with reprocessing). In practise, frequently (a part of) the product will be recycled at the EOL. In that case, a net output flow can be calculated for the recycled secondary resources and module D can be calculated for the recycled product. It is possible that the avoided impact (module D) for a recyclable product is more important than the module D of a reusable reused product.

4. Carpet tiles as reuse case study

4.1. Description of the case study

The object of the case study is 1m² of carpet tile flooring, being installed without the use of glue in order to allow for easy dismantling and replacement (so loose-lay application). The service life is set at 10 years. Four scenarios of reuse at the beginning and the end of the life cycle are specified to gain insight in the effects in terms of environmental impact (see also Table 2):

1. Non-reusable virgin carpet tiles, incinerated with heat recovery at EOL;
2. Reusable virgin carpet tiles, with a reuse rate of 70% at EOL;
3. Non-reusable reused carpet tiles, incinerated with heat recovery at EOL;
4. Reusable reused carpet tiles, with a reuse rate of 70% at EOL.

For the scenarios (2) and (4) considering reuse at the EOL the reuse rate is set at 70%. The remaining 30% follows the default EOL scenario of incineration with heat recovery. Theoretically the reuse rate could be 100% at EOL but due to losses related to the different life cycle stages (cutting of the product for installation, stains during service life, damage during deconstruction, …) the actual reuse rate will be lower in practice.

| Table 2. Overview of scenarios of reuse considered for the case study. |
|---------------------------------------------------------------|
| **Virgin carpet tiles**                                      | **Carpet tiles from reuse** |
| Production based on 100% virgin materials                     | 100% reuse of secondary product |
| Non-reusable at EOL                                          |                             |
| EOL: 100% incineration with heat recovery from incineration plant | (1)                        | (3)                        |
| Reusable at EOL                                              |                             |
| EOL: 70% reuse (as carpet tile), 30% incinerlation with heat recovery from incineration plant | (2)                        | (4)                        |
4.2. Methodology, data and assumptions
The various carpet tile scenarios are modelled in SimaPro (version 9.2.0.1) using ecoinvent 3.7 (System model: Allocation, cut-off by classification) as main source of data. The study considers the following life cycle phases, as defined in EN 15804+A2 [6]: production (A1-A3), transport to construction site (A4), installation (A5), replacements (B4), end-of-life (C1-C4) and module D. Results are presented for a reference study period of 10 years, corresponding to the expected service life of the floor finishing. As a consequence no replacements are considered for the study. For the gate-to-grave modules, the modelling is based on scenarios representative for Belgium [8], except for the EOL treatment being specific for each scenario as defined above.

For the calculation of module D of the reusable tiles the end-of-waste point is set after cleaning of the tiles, being ready for reuse. Any transport and storage of the reusable tiles is allocated to the next life cycle. Consequently, the avoided impact of reusable carpet tiles is equal to the production impact of new carpet tiles. As illustrated above, however, the net output flow has to be determined based on the secondary material entering the system.

All the core and additional indicators from the EN 15804+A2 [6], are considered for the analysis. However, to simplify the interpretation, results are also normalised and aggregated to a single score using the Environmental Footprint 3.0 (2019) normalisation and weighting factors.

4.3. Results
In Figure 1, the total environmental impact of each scenario is presented in relation to the life cycle stages. Module D is represented by a negative impact (thus a benefit or avoided impact beyond the system boundary) for each scenario. Given the uncertainty related to module D (as it concerns the use in a future life cycle), the module D impact is represented using a hatching.

The virgin non reusable scenario (1) has the largest impact followed by the virgin reusable scenario (2). The reused and non reusable scenario (3) and the reused and reusable scenario (4) have the smallest impacts in total. The impact of scenarios (3) and (4) with reused products is more than five times smaller than scenarios (1) and (2) with virgin materials. Moreover, the scenario (4) with reused and reusable carpet tiles is three times smaller than the scenario (3) with reused and non reusable carpet tiles. Module D is the largest for scenario (2), followed by module D of scenarios (1) and (3) which are equal.

For the scenarios (1) and (2) the main impact is associated to the production of the carpet tiles which represents more than 80% of the total impact. As the scenario (2) uses reusable carpet tiles, its impact at EOL is smaller than for scenario (1). Indeed, 70% of the carpet tiles are reused in the next life cycle and only 30% of the tiles are incinerated (in contrast to the other case where 100% of the tiles are incinerated). However, the difference in impact between the products is small compared to the total impact (less than 20%). Regarding the module D, the difference in avoided impact between the two scenarios is significant. The avoided impact (production of electricity and heat from fossil fuels) of the scenario (1) is related to the energy generated during incineration (Incineration rate 100%, calorific value for bitumen: 30.06 MJ/kg and calorific value for plastic: 30.79 MJ/kg). While the avoided impact of the scenario (2) is for 30% linked to the usable energy produced during incineration and for 70% linked to the avoided production of new carpet tiles.

The environmental impact of the reuse scenarios (3) and (4) is significantly smaller than the previous scenarios as the production impact of new carpet tiles can be avoided. Thus, the total impact of these reused products is determined solely by the impact of the construction stage (transport) and EOL. Nevertheless, as for the scenario (1) and (2), there is an important difference to be noted in relation to the EOL impact. However, even if the carpet tiles of the scenario (4) are reusable, its module D is smaller than module D of other scenarios. As explained in the section 3.4., this is due to the calculation of the net output flow. As the input flow solely consists of secondary materials (from reuse), the net output flow of the 70% of carpet tiles that can be reused at the EOL results in zero. The avoided impact
calculated within the module D of scenario (4) is solely associated to the 30% of the product that could not be reused but is sent to incineration with heat recovery.

Figure 1. Life cycle impact of 1m² of carpet tiles according to different scenarios of reuse, considering a service life of 10 years.

4.4. Discussion of results

The results show that in terms of impact according to the EN15804+A2, benefits associated to the use of a reused product are more important than benefits associated to the use of a reusable product. Indeed, as the production stage typically has the biggest impact in comparison with other life cycle stages, avoiding the production related impact is more relevant than limiting EOL impact by using a reusable product.

It is frequently stated that the approach taken EN15804+A2 does not stimulate the reuse of products at the EOL [3][4]. The case study shows that the benefit of choosing a reusable product is rather small compared to a product that will not be reused at the EOL. However, it is clear that the EOL impact can be reduced or avoided, and within the considered life cycle this difference in EOL impact reflects the actual difference in impact that will occur by planning a different EOL treatment. Moreover, it is necessary to keep in mind that the reusability of a product is hypothetical and cannot be guaranteed when using the product. The benefit is “potential” while for a reused product, the benefit is certain. This is in line with the “polluter pays” principle that forms the basis for the CEN LCA standards. The use of other calculation methods will also imply benefits and disadvantages. For example, in the case of the “end-of-life approach” (also called 0:100 approach), reusable products will have a smaller impact than reused products that are not reusable. This approach focuses on the potential for future reuse, but does not reflect the impacts at the moment that they are taking place.

To allow showing or valorizing the potential benefits and loads related to reuse, recycling and recovery beyond the system boundary, Module D was introduced in the standard. This case study shows that, for virgin products, module D can effectively be a good indicator for the potential benefits related to the reuse of products at the EOL. Module D of a reusable virgin product (scenario (2)) is significantly larger than module D of a non-reusable virgin product (scenario(1)). However, the case study also reveals that module D is no longer a good indicator to illustrate the potential benefit in the next life cycle in case of a reused product. Whereas scenarios (2) and (4) both consider the reuse of the same amount of tiles in a next life cycle, Module D is very different for both scenarios. Intuitively the same production impact of new tiles can be avoided in the future. However, this benefit is in the scenario (4) already
accounted for at the beginning of the life cycle, and double counting should be avoided. In addition, the results reveal that the avoided impact is even larger in the scenario of a reused carpet tile going to incineration (scenario (3)) than for a reused carpet tile going to reuse (scenario (4)). Therefore, module D only tells part of the story and can be misleading. It becomes clear that module D looses its meaning for a fully circular product, coming from reuse at the beginning of the life cycle and being reused at the end of the life cycle. As a result it is unclear what the actual meaning and significance of module D is. For sure it is not a reliable indicator to assess the environmental (residual) value of circular solutions.

Nevertheless, whereas module D might be misleading in the last scenario, the results clearly show that the reused product that is reusable at the EOL has the lowest environmental impact of the different considered scenarios. In that sense, the methodology developed in the standard seems sufficiently precise to assess the environmental impact of various scenarios applied to reused products.

5. Integration of reuse at the building scale

The discussion and case study above focus on reuse at the product level, where the considered reference study period is lower or equal to the product’s service life. When considering the reuse of products (at the beginning of the life cycle or at the end of the life cycle) in building LCA, other parameters come into play. For instance multiple replacements can occur during the reference study period (RSP) of the building, not only for technical reasons but also for esthetical or financial reasons. Apart from the first use of the product in the building, all the next uses are hypothetical and based on scenarios which increase in complexity when considering reuse materials. Along the specific parameters needed to define these scenarios are: the reference service life (RSL), the replacement strategy and the maximum number of reuses.

Following the standards, the reference service life of a material or product is determined based on the current life cycle. It is not specified how the service life should be determined for reused or reusable products. The service life of the next life cycle is not defined for a reusable product and no specific procedure describes the assumptions that should be made to assess the environmental impact of buildings where reused or reusable products are applied several times during the RSP of the building. If the procedure for new materials is applied to reused or reusable materials, this means that the studied material is replaced by exactly the same material. In that case, a reused product will be replaced by a reused product, and a reusable virgin product will be replaced by a reusable virgin product. These hypotheses and scenarios bring different questions to light, as for example the following. If reused products are always replaced by reused products, who will account for the initial production impact knowing for instance that the product can only be reused once? Will plenty reused product be available to satisfy the market? How can a distinction be made between two “identical” products with a different number of potential reuses? If reusable virgin materials are always being replaced by reusable virgin materials, what is the benefit of using this type of product? Can module D be summed up for all replacements? These questions suggest that a specific approach should be developed to deal with the service life and replacements of reuse materials at building level. In addition to the difficulty related to the frequency of the replacements, the complexity will even increase when considering losses during dismantling and reuse, or when products are partially composed of secondary materials. Further research at building level is needed to understand the full complexity of dealing with reuse and circularity in LCA.

6. Conclusions

In the context of circular construction, the (potential) reuse of construction materials and building products is set forward as a general concept to reduce the environmental impact of buildings. This paper illustrates the different reuse cases for products and relates them to the methodological approach specified in LCA standards. It is shown that the LCA standard EN15804+A2:2019 allows to quantify the impact related to different concepts of reuse at the beginning or the end of the considered life cycle. In general reused products will lead to larger environmental gains as the production stage (A1-A3) can be avoided. The environmental benefit related to the reusability of a product is typically reflected in a
smaller impact in the EOL stage (C1-C4) when landfilling or incineration can be avoided at the EOL. The potential related to the future use of product is reflected in module D which allows to quantify the impact that can be avoided by not having to produce a virgin product. The results of the study show that module D can provide insights in this future potential for virgin products, but that the numbers are difficult to interpret and even misleading for reused products. Therefore module D is not a reliable indicator to measure the circularity of a product or to assess the environmental value of circular solutions. Nevertheless the case study suggests that reused products that are reusable will typically have a low environmental impact if no additional processing is needed. And finally, it is clear that the presented work represents a simplification of the actual situations at building level. Methodological choices that are made (in terms of replacements, RSL, scenarios, …) can have a large impact on the final results and therefore additional work is needed to deal with the complexity of reuse at building level.

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Acknowledgments
This paper was made possible with support from the Belgian Federal Public Service Economy through “Normenanette Milieu-impact en Circulaire Economie” and Innoviris Brussels through “C-Tech: Sustainable building innovation”.