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Relevance of the recycling potential (module D) in building LCA: A case study on the retrofitting of a house in Seraing (Best Paper SB13 Graz)

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Abstract: *Following the European standard concerning the sustainability of construction works EN 15978, the informative module D allows crediting a building for the recycling potential of its materials and the exported energy. Whereas the relevance of this module has largely been associated with the environmental assessment of metals so far, it is not clear to what extent module D is relevant in the life cycle assessment (LCA) of buildings. In this paper a building renovation case study is considered to investigate and discuss the implications of including module D in a building LCA.*

The environmental impacts of the building elements and materials are analysed using a cradle-to-grave LCA, including module D. The impacts related to the different life cycle stages are compared to each other and discussed in relation to the input and output materials. The results initiate a discussion on the controversial module D and illustrate the potential effects of this module compared to the rest of the life cycle.

Life Cycle Analysis (LCA), Recycling, Module D, Renovation, Environmental Assessment, Building LCA, LCA Methodology, System Boundary

1 Introduction

The consideration of recycling aspects in life cycle assessment (LCA) has been a point of discussion for several years. In general there are two contrasting approaches to account for recycling in LCA: (1) the recycled content approach, which considers the benefits of recycling at the input side of the life cycle and (2) the end of life recycling approach, which accounts for the benefits of recycling at the output side of the life cycle [2].

According to the European standards concerning the sustainability of construction works EN15804 [3] and EN15978 [1], a building's life cycle information is organized along three major life cycle stages: (A) the product and construction process stage, (B) the use stage and (C) the end of life stage. The system boundary at the end of the life cycle is set where outputs have reached the "end-of-waste" state, leading to the recycled content approach. However, for the building assessment information, the standard identifies an additional optional life cycle stage (D) describing the benefits and loads beyond the building life cycle. This stage, also called module D, allows crediting a building for the recycling potential of its materials or the exported energy. The calculation of module D thus allows using the end-of-life recycling approach.

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The consideration of module D is argued to be important for metals [2], but it is not clear to what extent this approach impacts the results for building LCA's. In this paper a building renovation case study is considered to investigate and discuss the implications of including module D in an LCA for buildings.

2 Case study

The renovation of a 4-storey high multi-family house located in Seraing (Belgium) is analysed for this study. This building, containing 3 apartments and a commercial space, has been deeply renovated in order to meet the current needs and standards in terms of comfort, space and energy requirements.

The existing building was composed of brick and a sloped roof with ceramic tiles (see Fig. 1). The main structure of walls and floors are preserved during the renovation. The external walls are insulated from the inside, using a system wall with a metal structure. The original street façades are preserved and the façades of the new top floor and south side are covered with metal sheeting. All windows and doors are replaced and new interior walls are assembled using a dry wall system. The entire roof structure is removed and replaced with a steel structure and steel roof covering in order to provide a useable living space on the third floor (see Fig. 1).

Fig. 1: Case study: Multi-family house in Seraing. Representation of the old situation (left) and the renovated situation (middle and right)

3 Methodological approach

LCA is a technique to assess the environmental impact of a product throughout its life cycle, from raw material extraction, via production and use phases to waste management. This study is performed according to the principles of ISO 14040 [4,5], which defines the methodological framework for LCA, and the harmonised European standards EN 15804 [3] and EN 15978 [1], which describe the methodology and calculation methods for the environmental assessment of building materials and buildings. More details on the considered approach (system boundaries, LCI and LCIA) are available in the extended version of this paper [16].

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3.1 Goal and system boundaries

The aim of this study is to evaluate the environmental impact related to specific retrofitting actions performed during the renovation of a building in Seraing and to discuss the potential effects of module D compared to the rest of the life cycle. The functional unit is a 4-storey high multi-family house with three living units and a commercial space, a total floor area of 280 m² and a reference service life of 60 years.

The LCA is a 'cradle-to-grave LCA including module D', with consideration of the stages listed in Table 1. For materials going to recycling, the system boundary between the system under study and the system that will use the waste is set at the gate of the sorting plant.

Table 1: Overview of life cycle stages considered in the LCA, according to EN15978 [1]

Product stage	A1-3	Production of new materials
Construction process stage	A4	Transport of new materials
	A5	Installation of new materials
Use stage	B4	Replacements: Disposal of materials that need to be replaced and production, transport and installation of the new materials
	B6	Operational energy use of building-integrated technical systems, which are covered by the Energy Performance of Buildings Directive
End of Life stage (EOL)	C1-4	Demolition process, transport to the treatment facility, impact of EOL treatment and final disposal
Benefits and loads beyond the system boundary	D	Reuse-, Recovery-, Recycling- potential

Following EN 15978 [1], the informative module D declares the potential loads and benefits of secondary material, secondary fuel or recovered energy leaving the product system. This module is primarily intended to describe in a transparent way the potential benefits of avoided future use of primary materials and fuels – and loads associated with the recycling and recovery processes.

In this study, module D reports on the loads and benefits of:

- the recycling potential of materials
- exported energy generated by photovoltaic panels.

Materials for energy recovery (e.g. through incinerations) are not considered because of the lack of data available on the efficiency of waste incineration installations in Belgium. As a result, the impact of materials being incinerated is fully allocated to the building life cycle).

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3.2 Life cycle inventory (LCI)

The LCA is modelled using Simapro software. Generic data is used from the ecoinvent database v.2.2 [6], harmonized with the Belgian/European energy mix. The study makes use of the transport and EOL scenarios established within the Flemish study OVAM MMG [7], which describe the typical transport distances, routes and transportation modes for different product material groups.

The recycling scenarios considered for this study are based on current average technology or practice (see Table 2). For materials recycled in a closed loop (such as steel), any secondary materials used as inputs for the system are subtracted from the secondary material leaving the system at the end of life, in order to avoid double counting and calculate the net impacts for the net output flow. Recycled content is based on average current production technologies.

Table 2: Scenarios used to determine the recycling potential at the end-of-waste point (to be declared in informative module D)

Material to be recycled	Secondary material
Steel	Secondary steel (closed loop)
Concrete, screed, …	Secondary granulates for roadwork (open loop)
Concrete blocks, bricks, facing tiles, …	Secondary granulates for roadwork (open loop)
Untreated sawn timber, wooden boards (MDF, OSB), parquet …	Wood chips (open loop)
Interior plaster (crushed together with concrete granulates)	Secondary granulated for roadwork (open loop)
Facing tiles, ceramic wall and floor tiles, …	Secondary granulated for roadwork (open loop)
PE-foil, vapour barrier, …	Secondary PE granulates (open loop)
Gypsum plaster board	Gypsum plaster (open loop)
Aluminium in window frames	Secondary aluminium (closed loop)
Glass	Glass cullets (closed loop)

Technical installations for heating and ventilation, sanitary installations and electrical installations are excluded from the study. The life cycle of the building renovation is set to 60 years for the analysis. Building elements with a shorter life span are considered to be replaced

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during this period. Assumptions regarding the probable service life of the materials and components are based on standard values used in the ecoinvent database v2.2 [6] and existing LCA tools, as well as values from literature [e.g. 8,9].

3.3 Life cycle impact assessment (LCIA)

After an analysis of different impact assessment methodologies [10,11], we opted to interpret the LCI results using the ReCiPe method [12]. This method makes use of the state of the art LCIA methodologies and it enables to present the results both at midpoint and endpoint level. Even though the ISO and EN standards do not recommend the weighting and aggregating of different impact categories it allows for an easier comparison and interpretation of the results.

4 Results

First, we discuss the environmental impact of the total building over its considered life cycle stages. Then, the results are broken down according to the different building elements.

4.1 Total impact per life cycle stage

The impact related to the energy use over the building's considered service life (60 years) clearly dominates and represents about 80% of the building's total life cycle impact (Fig. 2). Within this energy use, the largest impact is related to the use of energy for heating. The energy gains from energy generated by the photovoltaic cells are reported in module D, but seem to be insignificant.

The impact of the materials introduced for the retrofitting works is organised according to the different life cycle stages: production, transport, construction, replacement, end of life, and recycling potential (Fig. 2). The largest material impacts result from the production stage. Next, the impacts resulting from module D and the replacements are in the same order of magnitude. Finally, the impacts related to transport, construction and end of life are negligible compared to the other life cycle stages.

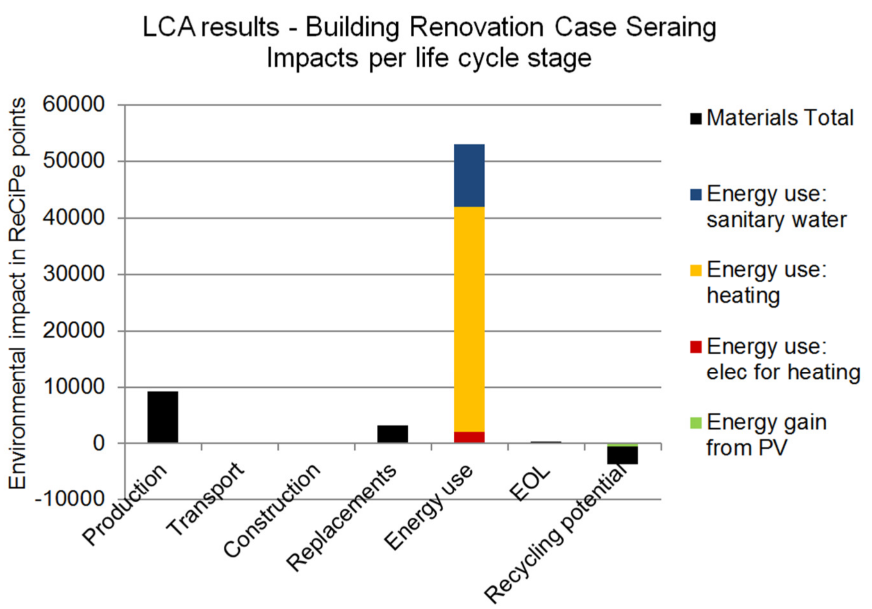

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Fig. 2: Impacts of the total building renovation case per life cycle stage, including module D.

4.2 Production, installation and EOL of materials

When excluding the impacts of the energy use during the use phase, the results can be evaluated per building element (Fig. 3). The highest environmental impact among the different building elements is related to the materials for the roof and intermediate floors. Also the exterior walls, interior walls and windows and doors have a considerable impact. A detailed description of the materials leading to these environmental impacts is available in [16].

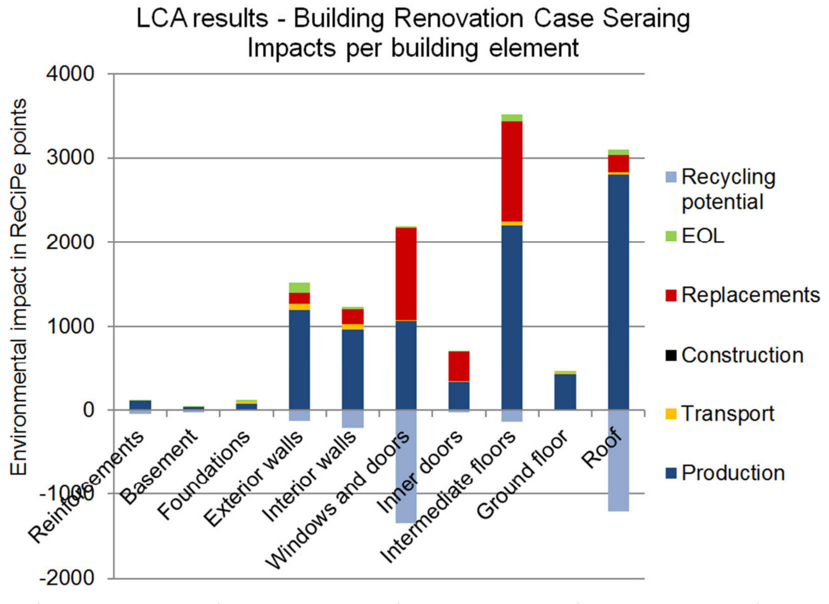

Fig. 3: Environmental impact of the materials over their life cycle, according to the different building elements, with indication of recycling potential (module D).

4.3 Replacements of materials

Fig. 3 shows that the impact of the replacements is significant for the windows and doors, which are replaced once during the considered life cycle. Also the replacements of the wooden floors after 30 years have a substantial impact. Most of the materials used for the building envelope (exterior walls and roof) do not have to be replaced during the reference service life. Consequently, the initial impact of the materials dominates the material impact for most building elements. However, we should note that the study does not account for repairs or partial replacements during the life time, which implies that the calculated impact is slightly underestimated.

4.4 Module D

The environmental impacts related to the recycling potential (module D) are represented in Fig. 3 as negative impacts and can be compared to the impacts related to the other life cycles. This shows that the potential benefits from recycling the materials are considerably high for both the roof and the windows and doors. For the roof, 98% of the avoided impacts are related to the high use of steel, where 95% up to 99% is recycled into new steel (see Fig. 4a for

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network diagram). Also for the windows, the majority of the avoided impacts can be linked to the high recyclability of aluminium (98% of module D impacts). The high recyclability of the glass panes (with 70% recycling rate) represents only a small part of the module D impact (see Fig. 4b for network diagram).

The impacts reported in module D for the other building elements are rather small (Fig. 3) because of the non or low recyclability of the materials (e.g. mineral wool, gypsum board), or because of the low benefits related to the recycling process (e.g. concrete, bricks). For the exterior and interior walls, the potential benefits in module D can be linked to the use of steel for structural purposes (supporting beams and metal frame for dry wall system). In the intermediate floorings, the module D impact is related to the recyclability of the hard wood floors into wood chips.

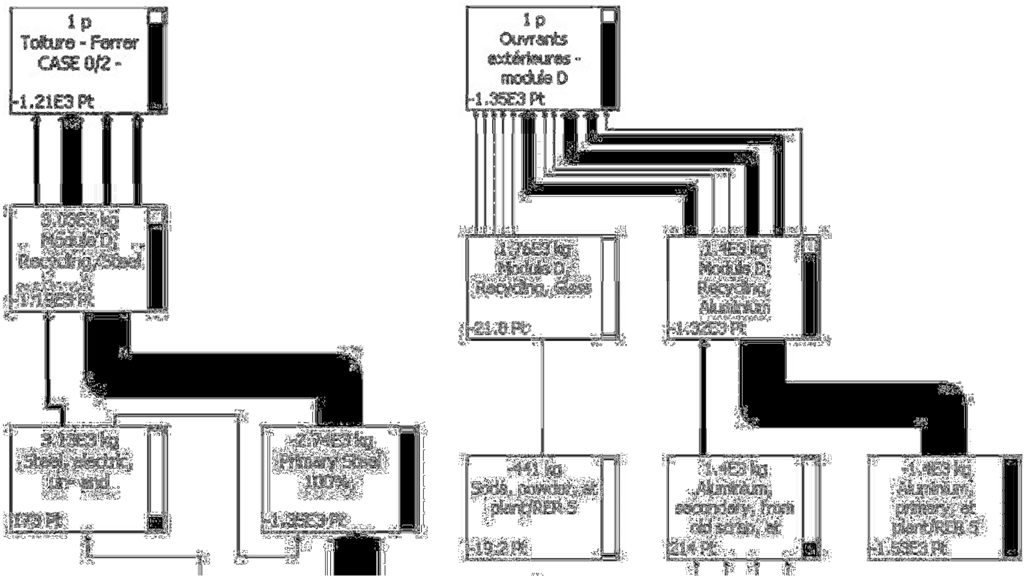

Fig. 4: Network diagram illustrating the materials representing the major impacts in module D for (a) the roof and (b) the windows and doors.

5 Discussion

5.1 Dominance of use phase

Comparing the environmental impacts generated over the different life cycle stages, the LCA results reveal that the highest environmental impacts are related to the energy use during the occupancy phase of the building. This is in line with several other building LCA studies, which illustrate that the building occupation phase is the most important stage in terms of environmental impacts - especially for conventional buildings - and that these impacts can mainly be related to the heating demand [e.g.13-15]. The results of this study confirm that the initiatives to perform better from an environmental point of view, should first be considered from the point of view of reduction of energy during the use phase. Alternative energy production systems, as well as higher insulation levels might lead to a decrease of the building's overall environmental impact.

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However, it should be noted that the relatively high importance of the use phase compared to the impact of the materials is also largely related to the fact that it concerns a renovation project: besides the limitations in terms of thermal performance (e.g. thermal bridges, air tightness), only a limited amount of new materials are being added to the renovated building. Consequently, relatively seen, the impact of the energy during the use phase is likely to be higher for a renovation project than for a new construction.

5.2 Relevance of module D

The results of this case study analysis suggest that the consideration of module D at building level can be significant: the module D impacts are of the same order of magnitude as the impacts of the replacements, and are significantly larger that the impacts related to the transport, construction and EOL of the materials. This suggests that, even though module D is stated to be optional, it can provide some relevant additional information concerning the recycling of materials at the end of life.

However, it should be noted that the case considered for this study contains a lot of metals. Whereas the large amount of recyclable materials was partially the incentive for calculating module D in this LCA study, the results also reveal that the potential benefits reported in module D are strongly - or even almost strictly - related to the use of metals. This confirms the relevance of considering module D for metals [1] but makes it hard to discuss the relevance for other building materials.

It is surprising that certain materials with high recycling rates (like glass or concrete) are hardly visible in module D. Typical Belgian buildings usually use large amounts bricks and concrete materials with high recycling rates (around 95%). In the present case only a small amount of these materials is considered for the LCA as the majority of walls is preserved during the renovation. Nevertheless, the small module D impacts can also be explained by the fact that bricks and concrete are considered to be down cycled into secondary granulates to be used for roadwork (common practice in Belgium). Their avoided impacts thus relate to the mining and crushing of primary granulates, which is far less energy and resource consuming than the production process of the concrete or bricks themselves and therefore will not outweigh the impact related to the production phase. Thus materials with high recycling rates do not necessarily relate to high (avoided) impacts in module D.

In general, one should be conscious of the fact that the impacts reported in module D do not tell the complete story about a material's potential beyond the system boundary. Whereas the module D impact might be relatively small for materials like concrete or bricks, it reveals nothing about issues like avoidance (or production) of waste or market demand for recycled materials.

6 Conclusions

Comparing the environmental impacts generated over the different life cycle stages, the LCA results reveal that the highest environmental impacts are related to the energy use during the occupancy phase of the building. However, for buildings with a better thermal performance (such as passive houses or nearly zero energy buildings) and for new constructions (with a larger of amount of materials used for the building), the relative importance of the use phase will become smaller and the decisions taken at material level will become more significant.

The present study reveals that the consideration of module D in a building LCA is possible and can be relevant. It provides additional information on the potential of materials beyond the building's life cycle and can represent a significant part of the total building impact. For the presented case, the impacts related to module D are larger than those related to transportation, construction and end of life. However, the case also shows that the impacts being reported in module D are strongly related to the use of metals in the building. Based on this study, we can state that module D will show a considerable impact for buildings containing a large amount of metals, but these results cannot be generalized to other buildings without further investigation. Research on the recycling impacts of different types of materials is desirable to get a more holistic view on the value of module D at building scale.

7 Acknowledgements

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