Reuse practices in building construction: proposition of a life cycle assessment methodology and application to a case study in Switzerland

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Abstract. This paper presents a life cycle assessment (LCA) methodology for evaluating the environmental impacts of reuse in building projects and apply it to a case study in Switzerland with 11% of reused components in its total mass. The results show that the life cycle GHG emissions on the construction domain that includes modules A1 to A4, B4, and C1-C4, are 487 kg CO_2-eq./m². In the other hand, the indirect effect of reuse lead to avoided GHG emissions of 76 kg CO_2-eq./m². At the level of a product's supply chain, the analysis demonstrates a significant reduction in the embodied impacts of the reused components compared to newly manufactured ones. The potential benefits from avoided manufacturing and waste management depend on the type of material that is reused.

1. Introduction

The building sector's operation and supply chains consume 88% of material and 34% of final energy flows globally, generate a significant amount of construction and demolition wastes estimated at 461 million tonnes per year in EU-27 of which 84% is from demolition (excluding excavation), and generate a significant 37% of GHG emissions globally [1]–[3]. To address these challenges, circularity and reuse practices are increasingly recognized as effective ways to decarbonize the building sector by extending the lifespan of existing structures and components [3].

However, the assessment of the environmental impact of reuse in building projects is a complex task that poses several challenges. One of the main challenges is how to allocate the environmental burdens and benefits of dismantling and reuse to the appropriate building life cycle, whether it be the prior or the next one [4]. Another one is the lack of data on the activities related to reuse, which are often uncommon or overlooked in standard building practices.

To address these challenges, this paper proposes a building life cycle assessment (LCA) methodology that incorporates reuse practices in today's building projects. The proposed methodology accounts for the environmental effects of reused components by modeling the actual supply chain activities and by allocating the environmental burdens and benefits to the appropriate life cycle.

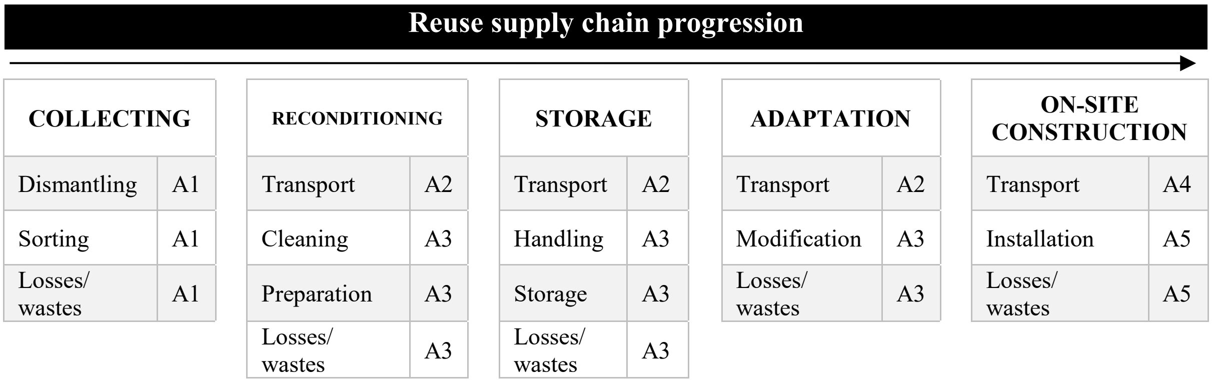
To demonstrate the applicability of the proposed methodology, we present a case study of a new building in Switzerland that incorporates a variety of reused elements, accounting for 11% of its total mass. The effective GHG emissions from the actual construction domain and the avoided emissions due to reuse were calculated.

2. Methodology

2.1. Supply chain of reused components

The systems of study are a building life cycle and the pre-existing components that are reused and supplied from previous deconstruction, dismantling or surplus. The adopted LCA methodology is proposed in the Swiss Federal Office of Energy's (SFOE) project Reuse-LCA as an adaptation of the SIA 2032 and SIA 2040 technical books calculation rules, and the building life cycle stages from EN 15978. The A1 to A5 modules of a building's product stage are adapted to be representative of the supply chain of a reused component from collecting to on-site construction. A component that is qualified to be reusable by a waste audit cannot be qualified as a waste. Therefore, all the following activities (including dismantling) could be attributed to the scope of the building system that reuse the component [5]. However, if the previous owner did not conduct an audit to qualify existing components as reusable, and decided to do a standard deconstruction, all the burdens of deconstruction and waste management activities should be excluded from the scope. In the Figure 1 the potential activities of a reuse supply chain and their corresponding building life cycle modules are depicted. The steps "reconditioning", "storage", and "modification" comprise all potential activities between collecting and on-site transport. These steps are intentionally broad and not exhaustively depicted as their content and their order depends heavily on deconstruction and construction projects' specificities [6].

Along the supply chain from collection to installation of the final product in a construction, a reused component may see losses that end up as waste. Tracing the amounts of material along the supply chain is necessary to avoid the risk of missing burdens from potential wastes treatments. Material flow tracing can be challenging to document because of the diversity of actors involved along the supply chain but is a key aspect to promote material efficiency in LCA results.



Reuse supply chain progression

COLLECTING	
Dismantling	A1
Sorting	A1
Losses/ wastes	A1

RECONDITIONING	
Transport	A2
Cleaning	A3
Preparation	A3
Losses/ wastes	A3

STORAGE	
Transport	A2
Handling	A3
Storage	A3
Losses/ wastes	A3

ADAPTATION	
Transport	A2
Modification	A3
Losses/ wastes	A3

ON-SITE CONSTRUCTION	
Transport	A4
Installation	A5
Losses/ wastes	A5

Figure 1. Reuse supply chain activities and their corresponding life cycle modules according to the EN 15978 building life cycle framework

2.2. Indirect benefits from avoided activities

Besides reducing the impacts of the effective supply chain of a building project, reuse allows extending the service life of an already existing component. Hence, it prevents the waste treatment and the production of a new component that would provide an equivalent function or service during this extended service time. In the proposed methodology, additional LCA indicators are presented to inform about the avoided production and avoided waste management associated to reuse, analogous to the "D module" defined in EN 15978. Tracing the material flows and losses along the supply chain also helps increase the reliability benefits' calculation. This estimate is more representative if it is based on the "installed quantity" of reuse material rather than a potentially overestimated "purchased quantity" which could be adapted and cut up hence producing losses.

2.3. *Case study*

The Primeo Energy Cosmos project is a new exhibition and training building made of wood and surrounded by a steel structure made up of elements of reused electricity pylons, which evokes a Faraday cage. The building is located at Münchenstein (BL), has three floors, and an energy reference area (ERA) of 724 m². The building construction was completed in late 2022.

Figure 2. Architectural view of the Primeo Energy Cosmos building.

The reuse strategy adopted in the Primeo Energy Cosmos project concerns different kinds of reused elements, including steel bars for the exterior steel structure, high pressure laminated (HPL) panels for exterior wall cladding, OSB and medium density fiber (MDF) panels for interior wall cladding, stone slabs on the roof, wood and stone cladding on the floor, PV panels installed on the roof, and individual products such as sanitary elements and furniture. The building has a total material intensity of 641 kg/m² ERA, of which 11% are reused materials and components.

2.4. *LCA hypotheses*

The functional unit for this study is a square meter of ERA of the building construction domain, which has a service lifetime of 60 years. The scope includes the product stage and their transport to construction site (A1 to A4), future replacements of the products (B4), and end-of-life stage (C1 to C4). On-site activities (A5) are excluded considering they are the identical for both new and reused products. However, no specific information is collected to characterize the transport of the new elements in A4 module. Therefore, the LCA impacts of their final transport are calculated using a default scenario, which assumes transportation over an average distance of 50 km by a 16-32 t. truck. Default material losses are assumed to be 0% if the number of items is known, and 10% if expressed in kg or m².

The LCA data of new materials are obtained from the Swiss KBOB 2009/1:2022 recommendation [7]. The LCA of reused products is based on information provided by architects, including relevant data about the supply chain activities illustrated in Figure 1. To create project-specific datasets and to break down existing LCA data that are aggregated at a higher level, the Simapro LCA software (version 9.1.0.11) is used. The GHG emissions' indicator is calculated according to the assumptions of the KBOB 2009/1:2022 recommendation.

To calculate the benefits from avoided activities, certain hypotheses are considered regarding the new life cycle of a reused component. Reused components begin a new life cycle with a reference service lifetime according to SIA 2032 values, which end with a conventional waste management scenario. Their reuse avoids the conventional waste management and production of a new component, as per KBOB's scenarios based on today's technologies. The avoided new production is weighted by functional equivalency, accounting for the degradation and age of the reused component, where relevant data is available. For example, if a reused photovoltaic (PV) installation had an initial power of 4 kWp and is now 19 years old, its guaranteed performance is now 3.4 kWp, according to its technical documentation, and would avoid the production of a new PV installation of 3.4 kWp.

3. Results

3.1. Reused components supply chains

Table 1 summarizes information on supply chains and associated GHG emissions of reused components. Bold text indicates case-specific data; otherwise, default data from the Reuse-LCA SFOE project or KBOB's LCA database are used. The results indicate GHG emissions per kilogram of component ranging from 0.002 to 0.263 kg CO_2eq./kg, with an average of 0.059 kg CO_2eq./kg and a median of 0.016 kg CO_2eq./kg. The difference of emissions between the manufacturing and transport of a new component and the supplying of its reused counterpart is called the “avoided production”. Those emissions are negative for all the components meaning they all bring benefits from being reused compared to using new equivalent products. The emissions from avoided production range from -0.028 to -10.88 kg CO_2eq./kg, with an average of -2.3 kg CO_2eq./kg and a median of -0.084 kg CO_2eq./kg. These components have GHG emissions related to A1-A4 decreased by 40% to 100% compared to their new counterparts, with an average reduction of 90%.

Table 1. Description of the reused components’ supply chains and their GHG emissions per kg

Reused component	Dismantling	Storage	Losses	Modification	Transport (km)		GHG emissions (kg CO_2eq/kg)			
	A1	A3	A3	A3	A2	A4	A1-A4	New eq.	Avoided prod.	Avoided waste
Steel bars	Diesel	**Ext.**	**74%**	**Preparation**	**60**	**5**	0,263	0,740	-0,469	-0,007
Stone cladding	**No, surplus**	**No storage**	**48%**	**No**	**10**	**20**	0,248	0,792	-0,535	-0,231
HPL panels	Electric	Int., 5.5 m^3, 1.2 year	10%	**No**	**87**	**129**	0,174	2,888	-2,735	-1,086
Wood cladding	Electric	Int., 0.5 m^3, 1.2 year	10%	**Oiling,** 22kg/m^2	**14**	**2**	0,056	0,093	-0,028	-0,039
Toilet doors	**By hand**	Int., 2.1 m^3, 1.2 year	0%	*Grinding, painting, handles assembling (not accounted)*	**11**	**8**	0,045	1,089	-1,040	-0,216
OSB panels	Electric	No data	10%	*Cutting (not accounted)*	50	**2**	0,023	0,494	-0,462	-0,080
Ceramic plates	**No, surplus**	Int., 0.5 m^3, 1.2 year	10%	**No**	**102**	**5**	0,048	0,792	-0,737	-0,231
MDF panels	Electric	No data	**0%**	*Cutting (not accounted)*	50	**2**	0,033	0,818	-0,797	-0,100
Stone slabs	Electric	**Int., 0.7 m^2, 0.5 year**	10%	**No**	**11.5**	**11**	0,013	0,152	-0,133	-0,006
PV panels	Electric	**Int.,** 0.5 m^3, **0.75 year**	0%	No	50	**5**	0,012	9,471	-7,843	0,000
Dressing	No, surplus	No	10%	*Manufacturing (not accounted)*	**0**	**5**	0,022	0,865	-0,835	-0,100
WC/urinals	Electric	Int., 9.7 m^3, 1.2 year	0%	**No**	**3.7**	**5**	0,004	2,462	-2,449	-0,014
Washtub	Electric	**No storage**	0%	**No**	**0**	**10**	0,002	4,499	-4,490	-0,007
Kitchen	Electric	**No storage**	0%	**No**	**0**	**10**	0,002	10,889	-10,880	-0,204
Sinks	Electric	**No storage**	0%	**No**	**0**	**10**	0,002	2,348	-2,339	-0,014

Figure 3 illustrates the GHG emissions by type of supply chain activity to analyse their absolute and relative contributions. The dismantling activities based on diesel machinery were found to have a significant impact on the reuse of steel bars and stone slabs, accounting for 10% and 35% of their actual GHG emissions, respectively. Steel bars and wood cladding are the only components concerned by modifications activities and those activities had the highest contribution accounting for 66% and 81% of their respective GHG emissions. The GHG emissions resulting from waste treatment activities varied depending on the type of component. For instance, waste treatment of stone cladding losses resulted in higher GHG emissions per kg of material than waste treatment of steel bars. Transportation impacts are directly proportional to the distance of supply. For half of the reused components (8), transportation was the main contributing activity to GHG emissions. For the other half, either no transportation was required due to *in-situ* reuse, or the impact of transportation was lower than that of modification, storage, or waste treatment activities. Storage was a highly contributing activity for three out of the eight concerned components, and its impact depended on the volume and duration of storage, especially if the component were stored in a building.

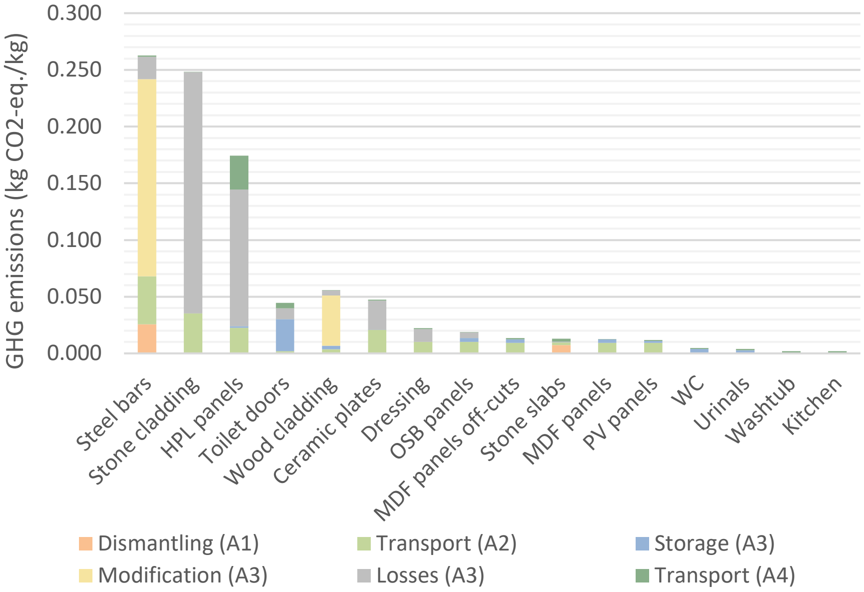


Figure 3. Actual GHG emissions of the supply chains of reused components per type of activity (system boundary: A1-A4 modules)

3.2. *Building impacts*

Table 2 presents for the Primeo Energy Cosmos case study the life cycle GHG emissions (including the actual A1-A4 emissions as well as future emissions related to B4 and C1-C4 modules) and the avoided GHG emissions. The total life cycle GHG emissions are 487 kgCO$_2$eq./m², or 8.1 kgCO$_2$eq./m²/year, which is 8% below the indicative value of 9 kgCO$_2$eq./m²/year set by the prSIA 390/1 for the "construction domain" of an administrative building. The initial construction (A1-A4) accounts for the majority (68%) of the total emissions while the transport of all products to the construction site (A4) represents only a small (2%) of the emissions from the initial construction. The reuse of components resulted in avoided GHG emissions of 76 kgCO$_2$eq./m², with 82% through avoided production of new components, and 18% through avoided waste treatments. These avoided emissions represent 15% of the life cycle GHG emissions of the construction domain. An alternative way of interpreting these results is by considering that the avoided production of new components (avoided waste treatment activities being allocated to their respective systems of origin) would have occurred if the building had the same design but used only conventional products. Under this scenario, the life cycle GHG emissions of the construction domain would have been 549 kgCO2eq./m², or 9.2 kgCO2eq./m²/year, a value 2% higher than the indicative value in the prSIA 390/1.

Table 2. Life cycle and avoided GHG emissions of Primeo Energy Cosmos building per m²-ERA

	Life cycle emissions (including actual + future)				Avoided emissions		
	A1-A4	B4	C1-C4	Total	New production	Wastes	Total
GHG emissions (kgCO$_2$eq/m²)	332	121	34	487	-62	-14	-76

4. Conclusions

The present study introduced a comprehensive LCA methodology for evaluating the environmental benefits of reusing building components. The methodology aims to capture both direct and indirect environmental effects of reuse strategies. It was applied to Primeo Energy Cosmos new construction located in Münchestein, Switzerland, which comprises 11% of reused components in its total mass.

The results of the case study demonstrated that the GHG emissions associated with supplying reused components were less than 300 gCO_2eq/kg, with an average of 56 gCO_2eq/kg. The emissions were 41% to 99.9% lower than the emissions associated with supplying new equivalent products, with an average reduction of 90%. Assuming a full new service lifetime, all reused components resulted in avoided GHG emissions exceeding their actual supply emissions.

The reuse strategy adopted in the Primeo Energy Cosmos building enabled to meet the SIA 2040 target for GHG emissions, whereas an identical building constructed solely with new components would not have satisfied this target. The architects estimated that constructing the variant design with solely new components would have been 3% cheaper than the actual Primeo Energy Cosmos building.

Although the methodology provides a comprehensive approach to evaluating the environmental benefits of reuse strategies, it has practical and methodological limitations. One of the limitations concerns the assessment of effective LCA impacts, which suffers from a lack of data from standard LCA database to evaluate reuse-specific activities. Furthermore, due to the involvement of several actors in building projects, the data required for LCA are often dispersed and challenging to gather. The assessment of avoided LCA impacts also relies on simplified assumptions about the benefits of reuse. More elaborated consequential modelling could improve this kind of assessment while major uncertainties about the future life cycle of reused component is still inevitable. Finally, to promote adaptative reuse and more efficient land use, other LCA impact categories that reflects impacts from land use should also be presented.

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