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LCA supporting the design of circular biobased wall panels

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Abstract. One of the numerous objectives of the European CBCI project is to develop a circular biobased wall element. As part of the design process, the first prototypes are analysed using life cycle assessment (LCA) and compared to a more traditional wood-skeleton element. The results indicate that the prototypes have a significantly higher impact than the reference solution, mainly because of the specific selection of biobased finishing materials. Also, considering an in-use service life of 60 years, the use of metal connectors to enable dismantling and reuse of the structure is not justifiable from an environmental perspective as their impact is about as high as the structure itself. In conclusion, the case study illustrates how LCA allows to evaluate the environmental relevance of specific circular building solutions and can be used to identify optimization strategies.

1 Context

The construction industry is responsible for about 50% of all extracted materials and for over 35% of the EU's total waste generation. Therefore, it is considered as one of the priority sectors in the European circular economy action plan.[1] To set up the bases for a circular biobased construction to become an integral part of the construction industry, the European Circular Biobased Construction Industry (CBCI) project develops an integral approach, considering technical, juridical, financial, and social aspects of circular construction. Regarding technical aspects, the project includes the development of biobased-circular wall elements using an iterative approach. The technical performances of the prototypes are monitored in real life test-setups and life cycle assessment (LCA) is used to evaluate their environmental performance. At first, 2 alternative wooden structures were developed. Those were combined with a selection of biobased circular materials to achieve complete wall elements, including insulation, and exterior and interior finishing materials. The use of metal connectors was considered to facilitate the future dismantling and reuse of the wooden structure. The present article presents the LCA results from this first iteration.

2 Goal and object of assessment

The goal of the LCA was threefold: (1) evaluate the material related environmental impact of the wall prototypes developed within the CBCI project and compare them with a more

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conventional wooden skeleton module; (2) evaluate the impact (or benefit) of using aluminium connectors (**Fig. 1**) instead of screws, to ease the dismantling of the structure for reuse; (3) identify major sources of impact and make recommendations for optimisation.

Fig. 1 Connector to enable the dismantling of the wooden structure (0,14kg aluminium + 0,78kg galvanised steel screws per connector). One connector is needed for each 38x100mm beam connection, two connectors are needed for each 38x200 mm beam connection.

The detailed composition of the 2 prototypes and the reference module, are presented in **Table 1** and **Fig. 2**. Structurally, the frame of the protypes and the reference module are the same (composed of 38 x 200 mm softwood beams). However, the rafters of the protypes are thinner (38 x 100 mm sections), so that they do not cross the whole depth of the frame. Moreover, the second prototype has both horizontal and vertical battens to enable its use also as a floor element.

Table 1 Composition of the wall elements

Components (Fig. 2)	Reference	Prototype 1	Prototype 2
Interior finishing panel (1)	13 mm gypsum board (715 kg/m^3)	22 mm clay-panel (1450 kg/m^3)	
Vapour barrier (2)	Polypropylene/polyethylene foil fixed with an airtight sealant on the wooden structure		
Panel (3,5)	18 mm oriented strand board (OSB) fixed with galvanised steel screws	18 mm bonded straw panel (3% Methylene diphenyl diisocyanate, 97% straw), fixed with galvanised steel screws.	
Structure (a,b,c)	0,13 m^3 softwood (38 x 200 mm) + 0,22 kg galvanised steel screws	0,14 m^3 softwood (38 x 200 and 38 x 100 mm) + 0,29 kg galvanised steel screws or 22 connectors (**Fig. 1**)	0,13 m^3 softwood (38 x 200 and 38 x 100mm) + 0.41 kg galvanised steel screws or 20 connectors (**Fig. 1**)
Insulation (4)	Hemp-cellulose insulation panels (20 cm)		
Waterproofing membrane (6)	HDPE based waterproofing membrane (fixed with staples)		
Substructure (laths) to support the exterior cladding (7)	24 x 36 mm European spruce with 60 cm spacing, fixed with galvanized steel screws	24 x 36 mm Siberian larch with 60 cm spacing, fixed with galvanized steel screws	
Exterior cladding (8)	21 mm impregnated softwood cladding (450 kg/m^3) fixed with stainless steel screws	10 mm composite cladding (1800 kg/m^3), made of mainly (biobased) waste (roadside reed, CaCO3 from drinking water production, polyester resin (for 50% produced out of waste glycol of biodiesel production from animal waste and frying fat)), fixed with stainless steel screws	

(a) (b) (c) (d)

Fig. 2 Schematic representation of the structural concept of the reference (a) and the prototypes (b, c), and the constituting layers of the wall elements (d). The numbering from (d) is explained in **Table 1**

Concerning the finishing materials, on the inside the protypes use clay-panels instead of gypsum plaster boards. On the outside, the prototypes are finished with composite cladding panels, mainly composed of (biobased) waste materials. The latter has a longer service life than the wooden cladding used for the reference module. Therefore, another wood species, with a longer service life (40 years instead of 20 years), is used for the substructure supporting the composite cladding. Finally, the prototypes use bonded straw-panels instead of oriented strand board panels.

3 Methodology, data and assumptions

The wall elements 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 alternative materials selected for the prototypes (cladding, clay-panels, straw bonded panels) are modelled based on product specific information, e.g. technical data sheets and information provided by the producers.

The study considers a reference study period of 60 years and includes following life cycle phases, as defined in EN 15804+A2 [2]: production (A1-A3), transport to construction site (A4), installation (A5), replacements (B4), end-of-life (C1-C4).

For the gate to grave modules, the modelling is based on scenarios representative for Belgium [3]. **Table 2** presents the end-of-life scenarios and service lives considered for the main materials. For the wooden structure, the end-of-life scenario is adapted depending on the connections used (screws or aluminium connectors). Concerning the cladding material, although the producer claims that the material is recyclable, it was not considered a reasonable assumption for the Belgian context as there is only one production/recycling site which is situated in the Netherlands.

Finally, all the core and additional indicators from the EN 15804+A2 [2], are considered for the analysis. However, to facilitate the interpretation, results are also normalised and aggregated to a single score using the Environmental Footprint 3.0 (2019) normalisation and weighting factors.

Table 2 End-of life scenarios and assumed service lives of main materials considered

Components		**End-of-Life scenario (%)**				**Service life (years)**
		Recycling	**Reuse**	**Landfill**	**Incineration**	
Structural Wood (untreated)	/ screwed	75			25	≥ 60
	/ fixed with connectors		100			
Clay panel		100				30
Gypsum board		20		80		30
Hemp-cellulose insulation				5	95	60
OSB/MDI bonded straw panel		5			95	60
Biobased composite cladding		5			95	40
Impregnated softwood (cladding)					100	20
Metals (screws, connectors)		95		5		≥ 60
Membranes (PE/PP)		5		10	85	60

4 Results and discussion

The relative contribution of the constituing components to the total environmental impact of the different modules is presented for a reference study period (rsp) of 60 years (**Fig. 3**). For the prototypes, additional variants are shown where the different parts of the wooden structure are connected using metal connectors (**Fig. 1**) instead of screws to enable the dismantling and reuse of the structure at end-of-life. Given the uncertainty related to the expected service life of materials, the contribution of the replacement phase (B4) is indicated separately (in striped colors) from the production and end-of-life of the components (A1-A3, A4-A5, C1-C4), which are represented in plain color.

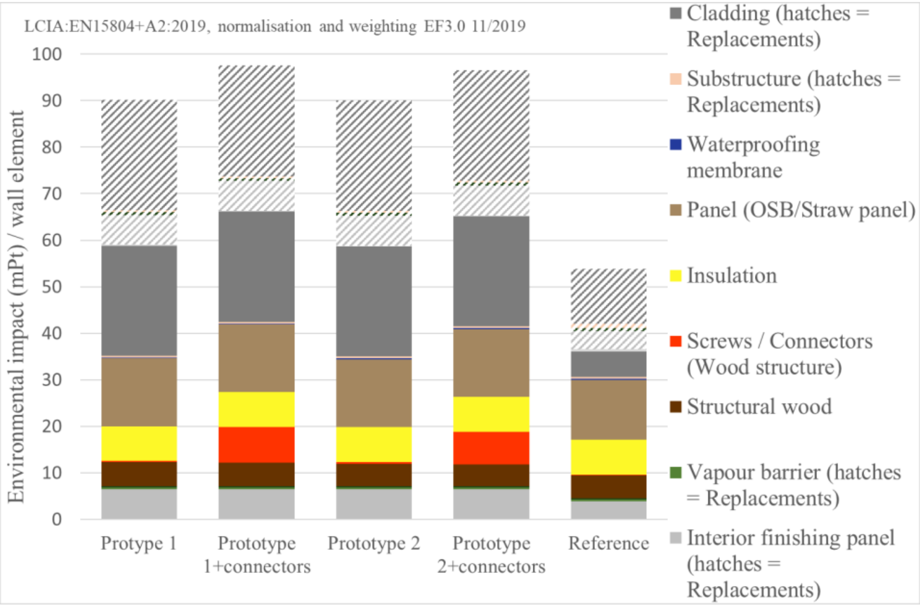

Fig. 3 Life cycle impact per 2,4 m x 2,4 m module, considering a service life of 60 years.

4.1 Prototype wall elements/components compared to the reference

Based on **Fig. 3**, the prototypes have a significantly higher impact than the reference module. The unexpected poor performance of the prototypes is rather due to the choice of the finishing materials, and more specifically the exterior cladding, than to the structural part. Indeed, the latter represents less than 10% of the life cycle impact of the modules. Therefore, although the variation in geometry of the structure induces a small increase in the amount of wood and screws, the effect on the total impact of the module is unsignificant.

The biobased composite cladding from the prototypes has a significantly higher impact than the softwood cladding from the reference module. One of the main contributors to the high production and end-of life impact of the cladding is the polyester resin (50% biobased, 50% fuel based) used as binding agent. Because of this high initial and end-of-life impact, the composite cladding also has a higher replacement impact despite its lower replacement rate (**Table 2**). In theory, the cladding could be recycled instead of being incinerated, and the amount of biobased resin could be increased in the future (when the availability increases). Nevertheless, a sensitivity analysis shows that considering 100% recycling at end-of-life and assuming that only biobased polyester resin is used would only reduce the impact of the cladding by 30%, which is not enough to revert the conclusions.

The impact of the bonded straw panel is about 14% higher than the impact of the OSB panel. However, in this case, the higher impact is mainly due to the transportation phase (A4), which represents about 40% of the life cycle impact of the bonded straw panel. Indeed, the life cycle inventory revealed that the panel, which is commercialised by a European company, is produced in China, and therefore needs to be transported (by boat) over a very long distance. Nevertheless, the bonded straw panel has a lower production impact than the OSB panel as it uses an agricultural residue (straw) instead of primary wood and less binding agent (MDI) than the OSB panel. So, if the production plant would move to Europe, it could be an interesting alternative for the traditional OSB panel.

Finally, the impact of the clay panel used as interior finishing for the prototype walls is about 60% higher than the impact of the gypsum board used for the reference element, mainly because of its higher density and thickness, and the use of jute fibres. The latter represent only 3% by weight of the clay panel, but are responsible of more than 40% of its cradle-to-grave impact. The production of jute contributes especially to the freshwater related indicators of the aggregated score, namely water use, ecotoxicity fresh water and eutrophication fresh water.

4.2 Connectors to enable dismantling of the structure for reuse

The comparison of the prototypes with and without the use of connectors in **Fig. 3** shows that the use of connectors increases the impact of the prototype wall elements by about 8%.

On the other hand, the connectors will enable the reuse of the structure and therefore potentially avoid the production of an equivalent amount of timber in a subsequent life cycle. This potential benefit is not represented in **Fig. 3** as it would normally be reported in module D, outside of the system boundary. Nevertheless, the results indicate that the impact induced by the connectors is about 1.5 times the impact of the wooden structure. Therefore, it can be deducted that the structure needs to be reused more than once to compensate for the additional impact induced by the connectors. However, if the duration of a use cycle is 60 years, it is questionable whether it will be possible to reuse the structure twice. The wood would probably have reached his technical service life after the second life cycle (120 years) and therefore not be available for a third life cycle (second reuse). Also, in practice the structure may even stay in place well after the considered 60 years as the building may be renovated instead of demolished.

4.3 Reflexion on further optimisation

Based on the above results, for the considered use scenario where the modules stay in place for 60 years, the use of metal connectors to ease the dismantling of the structural part is not justifiable from an environmental perspective. Moreover, the selection of finishing materials, and especially the cladding should be optimised. Attention points for further (biobased-circular) material selection are the location of the production site (origin), the impact and quantity of binding agents, and the complexity of the transformation process.

The results also indicate that before any further optimisation, the design team should clearly define the intended use of the module, and more specifically the foreseen duration of the use cycles, as it will strongly influence the composition of the optimal design. For instance, if the module is intended to be moved every 10 or 15 years, the use of connectors and even the choice of the cladding become interesting. Indeed, unlike the softwood cladding, the composite cladding is sturdy enough to be unscrewed and reused, provided that the dismantling takes place before the technical service life of the cladding (40 years).

Nevertheless, seen the relatively small contribution of the structure to the impact of the complete module, if the latter is to be used for more temporary applications, further optimisation strategies should focus not only on the reusability of the structure but rather on the reusability of the module as a whole (including all finishing materials and the insulation).

5 Conclusion

Many stakeholders try to implement circular economy (CE) principles with the aim of saving resources, minimizing waste and ultimately to reduce the environmental impact of buildings. However, the results from the present study show the importance of checking the environmental effects of envisaged circular strategies and materials using life cycle assessment. Indeed, circular or biobased solutions do not always lead to a lower environmental impact. Even products which are composed of mainly biobased waste may have a high impact in the end if they imply a lot of transport or a complex transformation process. In case of design for disassembly and reuse, important parameters that will influence the outcome of the LCA are the intended application of the considered solutions (i.e. foreseen duration of each use cycle), the extra impact induced to enable reuse, and the impact and technical service life of the materials to be reused.

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