



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 642384.



## A greenhouse that reduces greenhouse effect: how to create a circular activity with construction waste?

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**Abstract.** Frontrunner small companies are nowadays developing locally new circular business models with construction resources. This paper presents the genesis, the potential environmental impact, and the business model of producing and marketing greenhouses made of salvaged materials according to the industrial symbiosis principles and the economy of functionality. A designer has recuperated formwork wood on a construction site and glass from reclaimed windows on a demolition site to reuse them in the production of a greenhouse. After cleaning, the wooden elements are calibrated, then assembled to create the greenhouse. Thanks to reversibility and standardization, the greenhouse can be easily repaired, extended and disassembled. In addition to the high recycled content of the greenhouse, all these characteristics make the greenhouse circular by design, and from 3.7 to 8 times potentially more environmental-friendly than a greenhouse in aluminium, as shown by a comparative life cycle assessment (LCA). According to the principle of the economy of functionality, the greenhouse is marketed as a tool to allow its users to reach an objective and not only be sold as a product. In some cases, the greenhouse could remain the property of the producer, while the users receive support to grow fruits and vegetables. The project shows that developing new business activities and reducing the environmental impact of construction sites are goals that can be achieved in parallel in a circular economy approach. We expect that this project will convince other entrepreneurs that innovative construction waste treatment can provide large practical, economic and environmental advantages.

**Keywords:** construction waste, industrial symbiosis, environmental impact, economy of functionality.

## 1. Introduction

Considering that Construction and Demolition (C&D) waste has been identified by the European Union as a priority stream and that raw materials resources are limited, circular economy (i.e. maintaining the value of products, materials and resources in the economy as long as possible while minimizing waste production) has gained interest in the construction sector. The sector has indeed to focus on minimizing raw materials exploitation and waste arising on construction sites. Amongst other principles regarding construction design for flexibility and development of new business models, the circular economy considers waste as resources.

Redefining waste as resource and built stock as a potential source of materials requires a shift in approach across the entire construction and demolition sector. In addition to large manufacturers that emphasize the circular aspects of their products, other smaller frontrunner companies are nowadays developing locally new circular business models.

One of these business models, called industrial symbiosis, is a partnership between two companies: one using as resource the waste generated by the other; and was experimented in an innovative project of circular economy applied to the construction sector in Brussels.

In the last three years in Brussels, thanks to pilot projects in innovative construction waste management practices, formwork wood waste has encountered a high interested [1]. Several projects and economic activities have emerged on the treatment of this waste of construction site. For example, a farm has developed a wood recycling sector and currently employs three full-time employees for the production of garden furniture from wood waste formwork from construction sites in Brussels [2].

Another innovative project is the one of a designer that has recuperated formwork wood on a construction site and glass from reclaimed windows on a demolition site to reuse them in the production of a greenhouse. The assemblies are completely reversible; the greenhouse is thus flexible, reusable and removable. In addition to the high-recycled content of the greenhouse, all these characteristics make the greenhouse circular by design.

Then, a life cycle assessment (LCA) of the process was conducted to estimate the potential environmental impacts of constructing the greenhouse and to compare them to the use of primary materials. This LCA shows the potential environmental benefits of locally reusing materials and also nuances the hypothesis taken for the analysis.

It is planned that the greenhouse would no more be sold to an end-user but will remain the ownership of its producer in accordance with the principle of economy of functionality. The user of the greenhouse only pays for the services obtained with the renting of the greenhouse. The genesis of the project and the business model are explained in Section 2. The evaluation of the potential environmental impact is presented in Section 3.

## 2. Genesis and business model of the project

### 2.1. Industrial symbiosis and circular design

By observing the waste containers on a construction site, a designer realized how few construction waste was valued. The idea of carrying out a circular economy project around recovery and reuse of this type of waste then sprouted in his mind. It was a chance that the site was a pilot site for construction waste management and that the project leader saw the opportunity to give to the designer a large amount of formwork wood, considered as waste for the site and as a resource for the designer. An industrial symbiosis has emerged.

An industrial symbiosis is a collaborative business model in which a producer aims to establish partnerships to replace all or part of its raw materials (from the exploitation of natural resources) with industrial waste from a partner company. This concept is based on collaboration and exchange synergies made possible by geographical proximity and the establishment of short economic circuits [3]. In an industrial symbiosis, environmental and economic costs are reduced by reusing materials and converting waste into economic value. The societal and environmental contribution is positive by reducing the ecological footprint, the production of waste and the exploitation of raw materials [4].

In this case study, instead of being thrown into containers (figure 1), lot of woods were freely picked up on the site and the glass was reclaimed from a renovation site.



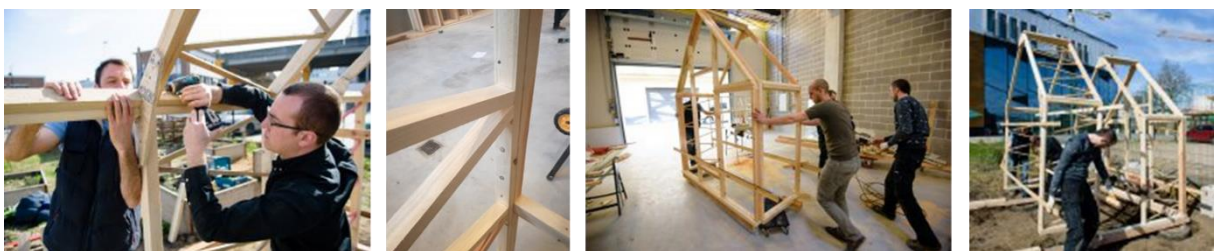
**Figure 1.** Formwork woods were pick up from a construction site

After cleaning, the woods are calibrated and machined to give them the profile necessary for their assembly within the future greenhouse (figure 2). Since the glasses reclaimed from the renovation sites were double glazed windows, it was needed to separate the layers of glass in order to reuse them in the greenhouse.



**Figure 2.** Wood and glass preparation before reuse

The assemblies are completely reversible using no glue but mechanical connectors or interlocking assemblies; the greenhouse is thus demountable, transformable, reusable and removable (figure 3). Moreover, the design of the greenhouse is modular (a module is 65 cm wide) in order to adjust to the need of its user. This also makes the greenhouse easy to transport and to install by only two or three people without heavy handling tools.



**Figure 3.** The greenhouse is demountable, transformable, reusable and removable

In terms of quantity, the amount of materials reused instead of being thrown depends on the size of the greenhouse. A 40 m<sup>2</sup> greenhouse requires 5.25 m<sup>3</sup> (1.2 tons) of salvaged woods and 1.15 tons of reclaimed glasses. For the wooden profiles, 3.05 m<sup>3</sup> (57%) is effectively reused, the rest (43%) is losses (15% in mass for the glass is losses). This is mainly due to the woodworking and the calibrating to the correct width and length as well as the wood planing. There is also waste for parts of wood too damaged or unusable. Nonetheless, this waste is not thrown away but also serve as compost in gardens.

## *2.2. Economy of functionality and sustainable development*

It is planned that the greenhouse would not be sold only as a product. Indeed, accordingly with the principle of the economy of functionality, the greenhouse is marketed as a tool to allow its users to reach an objective. A business model regarding the principles of economy of functionality is a circular business model marketing the use of a good in a mixed solution with a service instead of selling the property of the good. The main aim of a business model in accordance with economy of functionality is to provide services or product-service solutions that meet the demands of users without having to own the services or products. According to the principles of the economy of functionality, the consumer / user pays only for the use of the product-service, and not for the acquisition (ownership) of the product. Product ownership costs are borne by the company and / or partners [3, 4].

In this case study, the greenhouse is not sold, but remains the property of the producer, while the users receive support to grow fruits and vegetables when renting the greenhouse. When the greenhouse is no longer in use (e.g. in winter), the producer recovers the greenhouse to maintain it.

The greenhouse is then a 'product by service' based on the use of the greenhouse and offering its user a lot of services:

- Implementation and sizing advice for the greenhouse
- Customization and 3D simulation
- Start guide to construct the greenhouse by yourself
- Maintenance services in order to keep the greenhouse up-to-date (help of the client in the workshop to learn to paint a layer of wood protection)
- Coaching to grow by yourself vegetables and fruits (permaculture training)
- Help for the group purchase of seeds
- Team building sessions (well-being at work) – Skyfarms (Collaborative vegetable gardens, <http://www.skyfarms.be>. The greenhouse is a tool for Skyfarms for their wellness activity at work, which helps to reduce the burn-out rate.)
- Networking and practical information for disassembly, re-use or recycling at end of life

Despite this business model in transition, nowadays, the circular greenhouses are mainly sold to the customer. Up to now, one of them has been rented for temporary use (one season). On the other hand, customers become co-creators and actors: they are involved in design, the manufacturing and construction process in order to reduce costs and create exchanges with them.

The greenhouse also contributes to the sustainable development of urban cities. The project is based on a collaboration between local small construction and gardening companies. The project integrates a social and professional integration centre to develop employment locally. And finally, the project contributes to urban agriculture growth.

## **3. Comparative life cycle assessment**

Reusing material that is considered as waste is not a guarantee for environmental savings [5]. For instance, reused elements could have a shorter service lifespan and require more maintenance than new elements. To quantify the potential environmental savings linked with the circular greenhouse, we conducted a life cycle assessment (LCA). An LCA is an acknowledged method to evaluate the potential environmental impact generated by a product or a service. This impact is evaluated by taking in account the input and output flows of materials and energy, over the whole life cycle of the product: from raw material acquisition through production, to use, end-of-life treatment, recycling and final disposal, i.e. from cradle to grave [6,7]. LCA measures the environmental impacts that a system generates to deliver a specific function. Attributional LCA (ALCA) focusses on the attribution of these impacts to a specific system, while consequential LCA (CLCA) rather analyses the consequences on the environment due to a certain change [8]. In this case, an ALCA was conducted in order to estimate the potential environmental impact to produce, use and eliminate a circular greenhouse and compare it with the impact attributed to a conventional greenhouse in aluminium.

The LCA consists in four phases, as presented in the next sections: goal and scope definition (section 2.1), life cycle inventory (section 2.2), life cycle impact assessment and interpretation (section 2.3). To evaluate the environmental benefits of reuse, Castellani et al. consider LCA as a more comprehensive hence more suited method than a purely mass-based approach, a carbon footprint assessment, and approaches based on composite indicators such as ecological footprint [9]. However, LCA has also some weaknesses. For instance, there is currently no global consensus on a method to allocate the impacts of reused products. Since allocation methods are not in the focus of this research, we choose (1) to include the impacts of multiple uses of the materials (i.e. the whole ‘cascade’ of the glass panels), and (2) to exclude the production impacts of the reused materials assembled in the circular greenhouse (we only include the impacts occurring after recovering the materials from the waste container).

### *3.1 Goal and scope definition*

The goal of the life cycle assessment (LCA) of the circular greenhouse is to understand whether such greenhouse can generate a lower environmental impact than a conventional greenhouse, and to what extent. The flows of material and energy are estimated from cradle to grave and include the production of the different parts, their transport to the client site, their assembly, the maintenance, and the dismantling and waste processing of the greenhouse. The functional unit chosen is “15 years of use of an 8.5 squaremeter-greenhouse with transparent walls and roof, located in Brussels”. Two aspects of the circularity of the greenhouse described above are assessed in the LCA: the reuse content and the future reusability. Only the glass panels were considered reusable after demounting the greenhouse, since the reusability of the wooden elements is uncertain and probably depends on the maintenance pace. The circular greenhouse is compared to an aluminium greenhouse, of similar dimensions, also from a Belgian retailer. The aluminium greenhouse is not part of a circular business model and is therefore not made from reused materials. In this study, the circular greenhouse is not compared to a greenhouse in virgin wood of similar dimensions for two reasons: (1) no greenhouse in virgin wood is available on the Belgian market and it does not constitute an option from the client’s perspective, and (2) the wooden materiality is not considered as an obligatory characteristic of the greenhouse, unlike its size and shape.

### *3.2 Life cycle inventory*

The lifecycle inventory (LCI) was made using the LCA software SimaPro 8 [10], based on the Ecoinvent 3 (ecoinvent 3.1 – allocation, default) database [11]. The materials needed to produce the aluminium greenhouse are coated aluminium, glass, steel screws, PVC pipes and synthetic rubber. The material quantities needed were estimated using the technical description of the greenhouse given by the retailer (Table 1). In absence of information about the electricity needed to assemble the different parts of the aluminium greenhouse, this flow was neglected, although it was included in the LCI of the circular greenhouse to remain on the safe side. The transport from production site to client was considered. We estimated that no maintenance is needed for the aluminium greenhouse, during 15 years of use.

In conducting the life cycle inventory of the circular greenhouse, the impact linked with the production of secondary materials was neglected, but energy and losses of materials during transport of the secondary materials, calibrating, and pre-assembly were included. We also considered the transport to client and final assembly.

The service lifespan of the circular greenhouse, made of reclaimed wood, is estimated between 5 and 8 years, depending on the maintenance and the climatic conditions. The maintenance (i.e. the application of a protective oil on the wooden parts) is recommended to be done once every three years. To know the importance of the service life (short or long) and maintenance rate (frequent or absent) parameters, we compared four different use scenarios, making each parameter vary (Table 2).

**Table 1.** Life cycle inventory of the production phase of the aluminium greenhouse. Materials and processes are defined based on the “Ecoinvent 3.1 – allocation, default, unit” database. All amounts are displayed per functional unit.

	Materials/Processes	Amount	Greenhouse parts
<i>Production</i>	Flat glass, coated {GLO}  market for   Alloc Def, U	274 kg	Glass
	Aluminium, cast alloy {GLO}  market for   Alloc Def, U	69.02 kg	Structural frame
	Powder coat, aluminium sheet {GLO}  market for   Alloc Def, U	8 m <sup>2</sup>	Structural frame
	Synthetic rubber {GLO}  market for   Alloc Def, U	0.34 kg	Water tightness
	Steel, chromium steel 18/8 {GLO}  market for   Alloc Def, U	2 kg	Screws
	Polyvinylchloride, bulk polymerised {GLO}  market for   Alloc Def, U	1 kg	PVC Pipes
<i>Transport</i>	Transport, freight, lorry 3.5-7.5 metric ton, EURO6 {GLO}  market for   Alloc Def, U	34700 kgkm	Transport of product to client (100km)

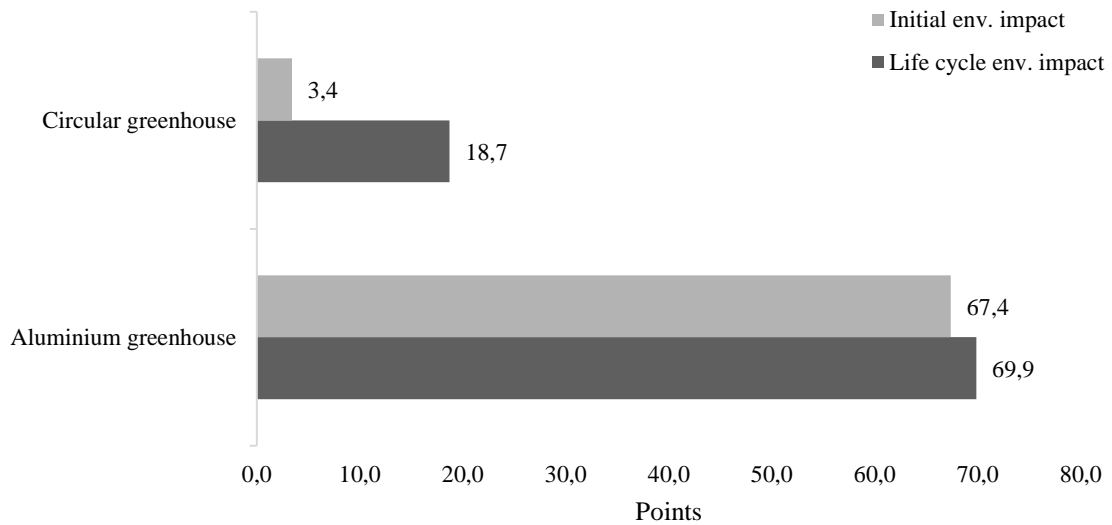
**Table 2.** Four use scenarios compared in the life cycle assessment of the circular greenhouse.

	Service lifespan (years)	Maintenance rate
1	5	Once every three years
2	5	Never
3	8	Once every three years
4	8	Never

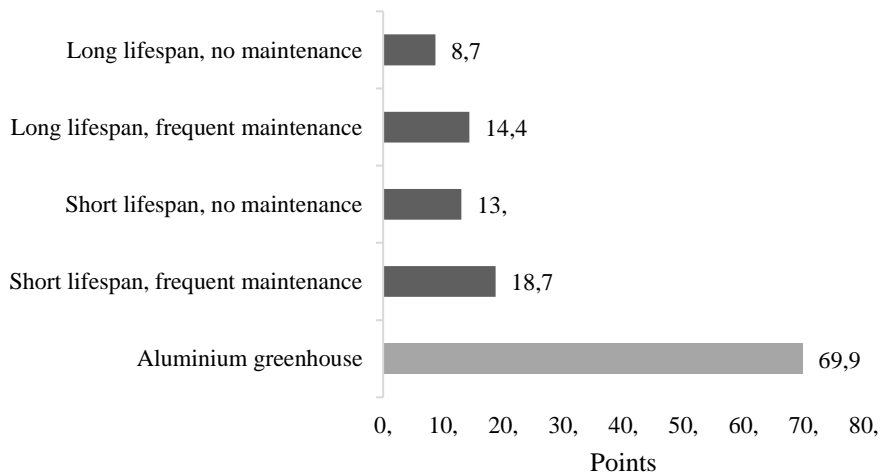
### 3.3 Life cycle impact assessment and interpretation

All material and energy flows identified in the life cycle inventory phase (2.2) were converted into environmental impact according to the impact method ReCiPe Endpoint (H) V1.1, also using the SimaPro 8 software. In this method, the impacts are measured in points, corresponding to damage to human health, ecosystems and resources (Figure 4).

Although the circular greenhouse has a lower service lifespan than the aluminium greenhouse (5 years compared to 15 years), its estimated life cycle environmental impact (18.7 Pts.) is 3.7 times lower than for the aluminium greenhouse (69.9 Pts.). Different use scenarios were tested in order to show the importance of the maintenance pace and the service lifespan (Figure 5). A shorter estimated service lifespan (from 8 to 5 years) increases the potential environmental impact by 49% when maintenance is avoided and by 30% when some maintenance is done. The maintenance increases the potential environmental impact of the greenhouse by 66% in case of a long service lifespan, and by 44% in case of a short service lifespan. Therefore, the length of the service lifespan and the maintenance rate greatly affect the LCA results. Considering a long lifespan and no maintenance, the potential environmental impact of the circular greenhouse are 8 times lower than those of the aluminium greenhouse.



**Figure 4.** Comparison both greenhouses based on their Initial environmental impact and transport to client) and life cycle environmental impact (including production, transport to client, use, and end-of-life). The circular greenhouse has a lower life cycle environmental impact than the aluminium greenhouse, although we considered a shorter service lifespan (5 years) and a frequent maintenance scenario (once every three years).



**Figure 5.** Comparison of different use scenarios, based on the lengths of the service lifespan and the maintenance rate.

According to the life cycle assessment (LCA), the production and use of the greenhouse made of reclaimed materials can have a significantly lower environmental impact than the production and use of an aluminium greenhouse. Yet, some impact is still expected, which means that it is still preferable, from an environmental point of view, to avoid producing any greenhouse. Moreover, LCA analysis doesn't take into account social externalities and working conditions. Nevertheless, this LCA has been simplified, and some environmental savings have been neglected. To avoid double-counting of the environmental savings, the impact of reusing the components of the circular greenhouse (such as the glazing) at the end-of-life phase of the greenhouse has been excluded, since no impact was included in the production phase. Designing the greenhouse for future dismantling, adaptation and reuse could lead

to environmental savings, although these savings do not appear in the LCA. This statement illustrates a weakness in the LCA method as defined in the 2006 version of ISO 14040/44 standards. Additionally, this LCA does not consider the potential environmental benefits of consuming locally grown vegetables, enabled by the use of a greenhouse, because these benefits would be identical for both greenhouse types. Finally, because conventional greenhouses are often sold without service contract for assembly and maintenance, they are often poorly implanted, poorly assembled and they age faster.

#### 4. Conclusion

The project shows that innovative management of construction waste through collaboration between companies enables material recovery for new applications. Moreover, the project also shows that reconsidering waste as a resource can lead to tremendous environmental savings. Finally, rethinking the notion of ownership as proposed by the project allows to create new local economic activities and to develop a thriving business in accordance with circular economy principles. Despite these good results, the project could not have been achieved in this sense without a set of essential factors. The support from authorities, in the form of guidance and subsidies, and the growing attention to the circular economy were two factors for success. The fact that the construction site was close to the designer's studio and the fact that the construction site manager collaborated with the designer were also decisive. Finally, this project required an important phase of preparation, consultation and support, well before the start of the project. This guidance was supported by regional funds for innovation support. We expect that this project will inspire other entrepreneurs and convince them that innovative construction waste treatment can provide large practical and environmental advantages.

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#### Acknowledgments

Action in the framework of the Brussels regional program in circular economy (PREC). Camille Vandervaeren is an SB PhD fellow at Fonds Wetenschappelijk Onderzoek (FWO).