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A Circular and Bio-based Renovation Strategy for Low-income Neighbourhoods

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Abstract. The impact of climate change is expected to increase in the following decade. Possible effects on the built environment are identified as urban heat stress, air pollution, extreme weather conditions, etc. As a result, there is an increase in disease and mortality specifically in the cities among the vulnerable citizens such as elderly people and children. Moreover, many cities worldwide are in the evolution of urbanization which leads to increased carbon emissions as well as a demand for more material production and waste. Consequently, the construction industry embodies great potential for reaching the energy and carbon mitigation goals. For regeneration of the built environment, the European directives requires for the renovation of existing building stock as quick as possible. In Flemish context, cities stimulate renovation projects on a systematic and planned basis, by defining 'urban renovation districts' which received special financial facilities and subsidizing. Consequently, there is a growing demand for affordable housing in combination with a shortage of qualitative and energy efficient housing opportunities. In the last decades, there has been an intensive effort to develop different retrofit strategies, but there is a lack of comprehensive approach that delivers innovative technical solutions such as circular and bio-based construction methods as a solution to the increased housing demand of vulnerable people. For this purpose, this study combines the efforts of two initiatives, (1) Interreg Circular Bio-Based Construction Industry (CBCI) and (2) the innovative financial policy instrument of subsidy retention for low-income groups (refers to citizens living in poor quality houses with insufficient economic means & social skills to renovate). The study has the ambition to explore the coherence between technical, economical, legal, social aspects for circular urban retrofit strategies. Circular building materials and methods were developed and tested in real-life setting with construction of a prototype living lab (LL) in Technology Campus, Ghent. Depending on the results from the LL, an urban renewal strategy for Flemish districts is proposed by using subsidy retention on macro-economic and social level. The scenario is envisaged as a collective approach with the local community in which the vulnerable users also benefit as direct participants to the research.

Keywords: Neighbourhoods, circular and bio-based renovation, revolving fund, reusability

1. Introduction

Transformation of construction sector into a low-carbon industry is a long-term global goal and the point of interest for researchers and professionals. The construction industry embodies great potential for reaching the energy and carbon mitigation goals due to its large share in consumption of energy and material. New ambitions have already been set by European Union (EU), that are categorized under a clear vision for climate-neutral economy that aims to achieve net-zero greenhouse gas (GHG) emissions by 2050 [1]. Following to this framework, the European Green Deal clarifies the targets for such a transformation; increase the EU's greenhouse gas emission reductions target for 2030 to at least 50% and towards 55% and 85% by 2050 [2].

The European directives [3] currently maintain a two-folded approach for transformation of the built environment: create new buildings with highest energy performance and renovate existing building stock as quick as possible. As it was foreseen that around 90% of building stock in EU will remain functional in 2050, this calls for a renovation wave that aims to renovate 35 million inefficient buildings by 2030. This implies that countries should increase the current renovation rates at least double with an emphasis on deep renovations which has an average rate of 0.2% in EU [4]. As a response to EU directives, in the coalition agreement for 2019-2024 (October 2019) the Flemish Government set a goal that requires all homes to have an average of 100kWh/m²/y energy use by 2050 [5]. Moreover, the Flemish Energy and Climate Plan 2021-2030 [6] commits – in addition to the already existing measures related to energy performance and renewable energy – to policies and measures for stimulation of renovation of residential buildings after notarial transfer, encouragement of reconstruction after demolition.

The main bottleneck is considered as the high ratio of old buildings with low performance values in the existing building stock [7]. In this context, a critical challenge is the need for an immense amount of materials for required construction activities. Previous frameworks have focused on operational energy consumption, on the other hand, there is a lack of regulations for the embodied emissions that originate from production and transportation activities. It is put forward that efficient use of construction materials and buildings may save up to 40% of final energy consumption and 50% of extracted materials [8]. In this respect, circularity is considered as a prerequisite for climate neutrality and to conduct comprehensive methodologies such as life cycle assessment (LCA) are advised to be a part of procurement processes [9].

Another bottleneck lies in the fact that most of the low performance buildings may not receive expected renovation due to financial reasons. Especially in low-income neighbourhood, it is observed that there is not enough incentive or motivation for deep renovations due to high initial investment needs or the infamous re-bound effect of such renovation yielding a higher operational costs. There are also studies correlation between the performance of the building and income of the owner. Hence, it is crucial that there are also appropriate funding mechanisms to ensure affordable building renovations that can also be accessed by low-income groups.

In this context, this study aims to introduce a circular renovation strategy that dwells upon two initiatives; (i) Interreg Circular Bio-Based Construction Industry (CBCI) and (ii) Flemish climate revolving fund for low-income groups. In the last decades, there has been an intensive effort to develop different retrofit strategies, but there is a lack of comprehensive approach that delivers innovative technical solutions such as circular and bio-based construction methods and revolving funds as a response to the increased housing demand of low-income people. A case-study approach was adopted in which, sustainable renovation solutions are analysed for the realization of a Living Lab concept (LL) together with possible public and private funding options. In the end of the study, a socio-technical renovation solution for the envelope and technical services of LL in product-as-a-service concept was proposed in combination with a social revolving fund scheme.

2. Literature Review

In this section, the main drivers for renovation such as accommodation demand and building energy performance are discussed together with the analysis of the building stock that is subject to transformation through renovation and new construction. Then emerging concepts such as circular and bio-based construction methods and materials and design-for disassembly were investigated to close the gap for mitigation of embodied energy and emissions. Existing funding schemes are also analysed in this section. Finally, these concepts are then translated into the research methodology of this paper in the following section.

2.1. Drivers for renovation
The renovation wave in the EU has introduced new ambitions for the member states [10]. In the context of given bottlenecks, there is a need to identify the correct drivers for and enhance the impact of renovation activities in order to achieve the mitigation goals.

For the renovation strategies to adequately respond to the increasing housing demand, certain prerequisites should be maintained: (i) achieve the expected (and mandatory) goals for energy consumption levels and (ii) provide affordable good quality housing for all (especially residents living in poor conditions). On the other hand, it is also acknowledged that the building stock has a significant indirect emission and material footprint (embodied impacts), translating in 15-18% of the environmental impact of a building [11]. The ratio of embodied impacts is expected to be higher due to enhanced building codes [12]. The first mandatory requirements on embodied carbon have been implemented in the Netherlands [13]. In the UK, RICS introduced a semi 'mandatory' framework for their members for whole life carbon assessment for built environment in 2017 [14]. A follow-up carbon database was also set up in 2019 [15]. Another requirement for renovation strategies is the increasing demand for accommodation that is expected to be affordable. The need for deeper renovation is currently limiting the access to good quality housing after renovation by low-income groups. This dilemma calls for innovative solutions through technical, economic and social cohesion.

This study adopts a neighbourhood scale approach in the city of Ghent in Flanders, a town with relatively old building stock that provides a great potential for analysing renovation strategies. In order to identity the drivers and challenges regarding the renovation strategy, some of the key factors are reviewed in the next sub-sections; (i) environmental impact goals and (ii) existing funding frameworks.

2.2. Environmental goals in Flemish Context
In Flanders, the building stock has an origin from the large city expansion projects that answered the rising housing demand in the vicinity of large 19th century factory buildings of the industrial revolution. It is heavily dominated by residential buildings (2.3 million residential buildings out of 2.7 million total building stock). The sample results of the Flemish Housing Survey in 2013 showed that 362.000 (13% residential buildings) Flemish houses were of structurally inadequate quality; it concerns problems such as stability, indoor climate and ventilation, electrical installations etc., which require deep renovation work. In most cases these buildings are concentrated in low income neighbourhoods [16].

According to long-term renovation planning in Flanders [17], additional 25.000 dwellings are required to be provided each year with an increase up to 40.000 in year 2040. In this new development, 16% of the dwellings are constructed after demolition and the rest is new development. When the current ratio for building stock is extrapolated, this implies provision of 14.000 single family houses per year. There is also a shortage on social housing in Flanders, with a waiting list for 150.000 dwellings in demand. Specifically in the city of Ghent,. the current status of the housing stock can be seen in Table 1. It can also be seen that more than half of the housing stock dates before 1946.

Table 1. Housing stock statistics in Ghent [18]

Housing Units - Construction date	Number	Ratio
before 1946	49.901	52,9
between 1946 and 1961	11.682	12,4
between 1962 and 1970	7.918	8,4
between 1971 and 1981	7.859	8,3
after 1981	16.980	18,0

In Figure 1, the distribution of EPC levels in Flanders can be seen. When these figures in EPCs by year of construction segment and ratio of residential houses in the same segments are integrated, it is seen that the focus of transformation should be upon the houses built between 1945 and 1981 [17]. Depending on the high ratio in the total housing figures, this study adopts a focus on single-family houses.

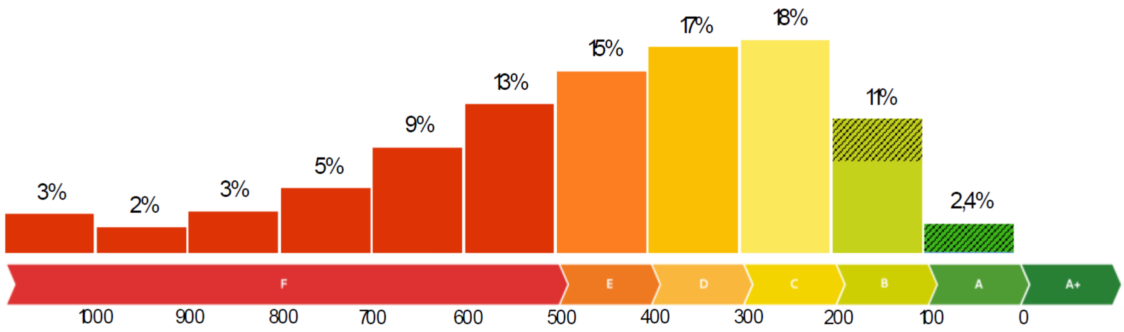

Figure 1. Distribution of EPC levels in Flanders [17]

It is considered that the transformation of the building stock must adopt a more comprehensive framework than only focusing on direct operational emissions in order to deal with the mentioned challenges. A brief of recommendations on developing a built environment within planetary boundaries [19] suggests adoption of a life cycle approach in construction industry for developing a comprehensive framework for achieving carbon mitigation goals. In the context, this study recognizes two critical points of interest that have high potential for mitigation: (i) embodied impact during production and construction and (ii) additional impact avoidance in the end-of-life (EoL) scenarios. In order to achieve mitigation in these life cycle phases, emerging concepts such as circular and bio-based materials and methods are explored in detail in the following sub-sections.

2.3. Circular and bio-based materials and methods

The aim of a circular economy approach to construction is to eliminate waste of valuable natural materials and re-use materials once the initial design life of a construction project has come to an end. Circular construction has been defined as 'the dynamic total of associated processes, materials and stakeholders, led by the owner/user'. Circularity can further be defined as creating value based on *use* (and *re-use*) rather than *consumption* [20].

In their study, Durmisevic discussed the concept of circularity in construction with regards to emerging method such as reversibility, design-for-disassembly and demountability [21]. In order to provide a comprehensive framework for supporting decision-making on circular materials and methods, Kayacetin et al. [22] analyzed existing circularity tools and applied a combination of tools on several design options including circular and bio-based methods.

Another important research topic is the application of bio-based materials for decreased environmental impact and their compatibility with circular construction. Timber is the most established structural and facade bio-based material and structural timber salvaged from previous buildings can be reused in structural applications (in addition to being used for applications such as flooring, partitions and furniture) [23].

2.4. Revolving fund for low-income owners

For sustaining a circular renovation strategy, there is also a need for a 'circular' funding mechanism. Several funding and subsidy frameworks exits in Flanders, on the other hand, a new concept that is depending on revolving fund based on subsidy retention [24,25] is considered suitable for this study. The principle of subsidy retention is based on an allowance that is recurring over time to the public authorities. This instrument was developed to improve the living conditions of low-income neighbourhoods in Ghent by introduction of a revolving fund which aims to renovate low quality houses in order to generate additional value for the resident when the building ownership is changed [26]. In the case of an ownership change, the homeowner has to pay back the initial allowance increased with a part of the realized added value of the property (see Figure 2).

On the other hand, two drawbacks were observed in this study: (i) low budget cannot guarantee the renovations ensure the expected performance (ii) it was significantly difficult to maintain the value of the initial investment to the low quality house as long as circular methods are not conducted. As the investment is 'embedded' to the building irreversible, the new owner of the house after the ownership change has no other option than renovating-by-demolition in case that the renovated quality of the house does not satisfy the needs and expectations (in comfort, aesthetics or environmental performance) of the new owner. Therefore, it is considered that this model can further be improved by utilizing building components that are circular, reversible and bio-based. Moreover, there is also a need to explore the possibilities of new approaches for the ownership of these circular building components.

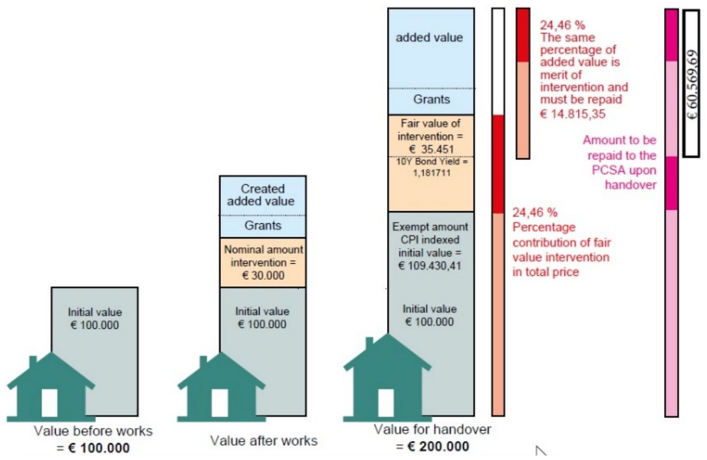

Figure 2. Funding strategy for a low-income neighbourhood renovation [25]

3. Methodology

The methodology depends on the combination of technical and financial frameworks: (i) living lab (LL) approach with circular and bio-based construction methods and (ii) the revolving fund. By this integration, it is aimed to integrate an circular impact to the revolving fund and maintain the investment even after the EoL of the renovated buildings. The steps of methodology can be seen in Figure 3.

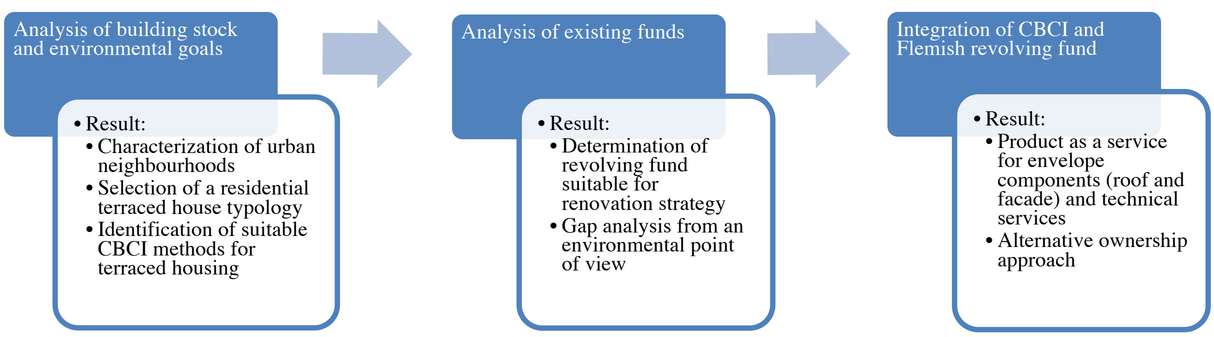

Figure 3. Methodology for developing a circular renovation strategy

In this methodology, a case-study on a terraced house typology was selected depending on the building stock analysis in the neighbourhoods. Then, an assessment on circular and bio-based methods and materials was conducted to develop an optimal prototype for new construction and renovations to achieve environmental goals. On the other hand, in order to sustain the impact of the proposed solutions, a suitable funding scheme was determined among existing options. Then, the combination of both methods was explored which yields a circular funding scheme that requires an alternative ownership approach which benefits from products-as-service.

3.1. Circular and bio-based living lab approach

A design research methodology was conducted in order to facilitate coherence between environmental, social and legal aspects (see Figure 4). The research findings were applied on a real life application with realization of LL concept in Technology Campus Ghent. Several preliminary design options (PDs) for the LL were created by utilizing circular and bio-based materials and methods. As a result, 9 PDs for envelope and 5 scenarios for technical services were generated including heavy weight masonry, light weight steel framework and bio-based materials. Each PD were compromising of 6 components (front and side facades, roof, internal wall, floor and floor-on-soil). The essence of research lies in the exploratory approach that aims for an optimum solution for the LL.

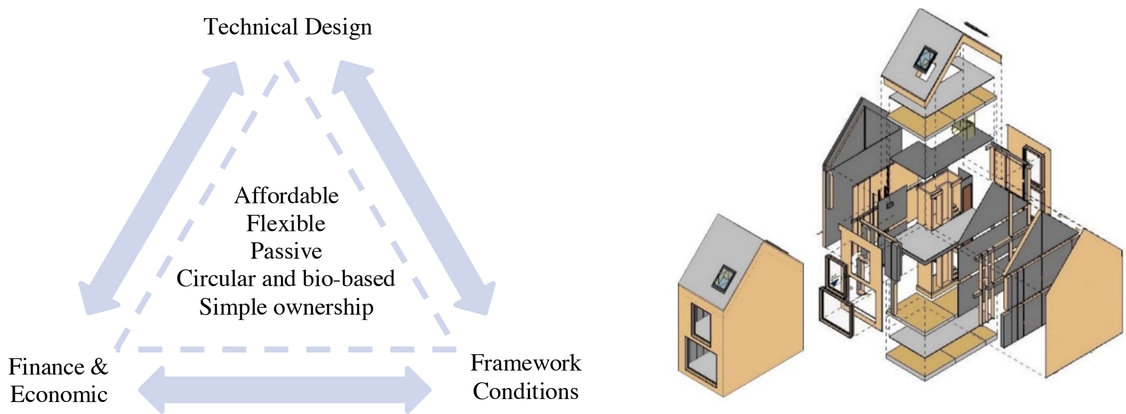

Figure 4. Design research approach for LL Ghent and final outcome

In the study of Kayacetin et al. [22], 9 distinct PDs were analyzed in a multi-criteria approach with a focus on DfD and demountability. This previous study provided a general perspective on available construction materials and methods and laid the basis for development of a demountable envelope (façade and roof) component that is reusable after the lifetime of the initial building. In a comparative analysis, it was seen that there is a gap between initial economical cost and future cost through environmental impacts for some PDs (See Figure 5). A similar assessment was also conducted for the technical services that achieved circularity from the technical (demountable) and legal perspective (product as a service) [27]. In both of the studies, it was seen that specific administrative and financial schemes are required to achieve the expected environmental impact mitigation through reuse of envelope and technical components in the end-of-life of the building lifetime.

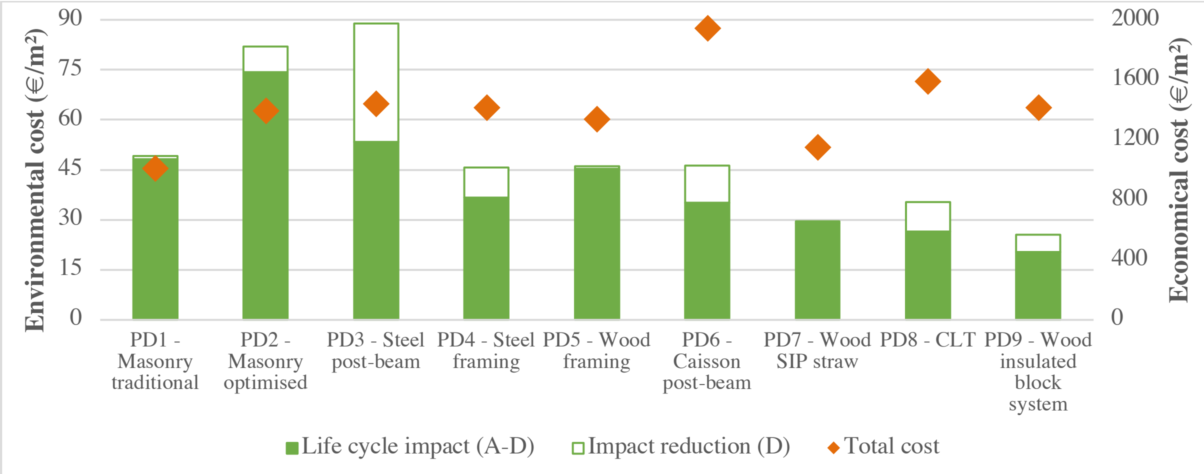

Figure 5. Environmental and economical assessment framework

3.2. *Integration with Revolving Fund*

This study attempts to close the gap in the existing revolving fund by integration of a circular perspective. The main essence of this integration focuses on revolving the circular building components rather than only focusing on the monetary value of the renovation investment. It is observed that in each change of ownership, there is a high possibility that the material and energy embedded in the renovation would be lost in the conversion to monetary values that revolved back to the fund. In this proposal (see Figure 6), the building investment maintain its current form as 'building components' rather than being converted to monetary values in order to initiate the next renovation. On the other hand, it was also recognized that the current initial costs and lack of integration with private funds renders this approach inaccessible by low-income groups. In this context, there is a need for alternative ownership approach for maintaining the building components during change of building ownership.

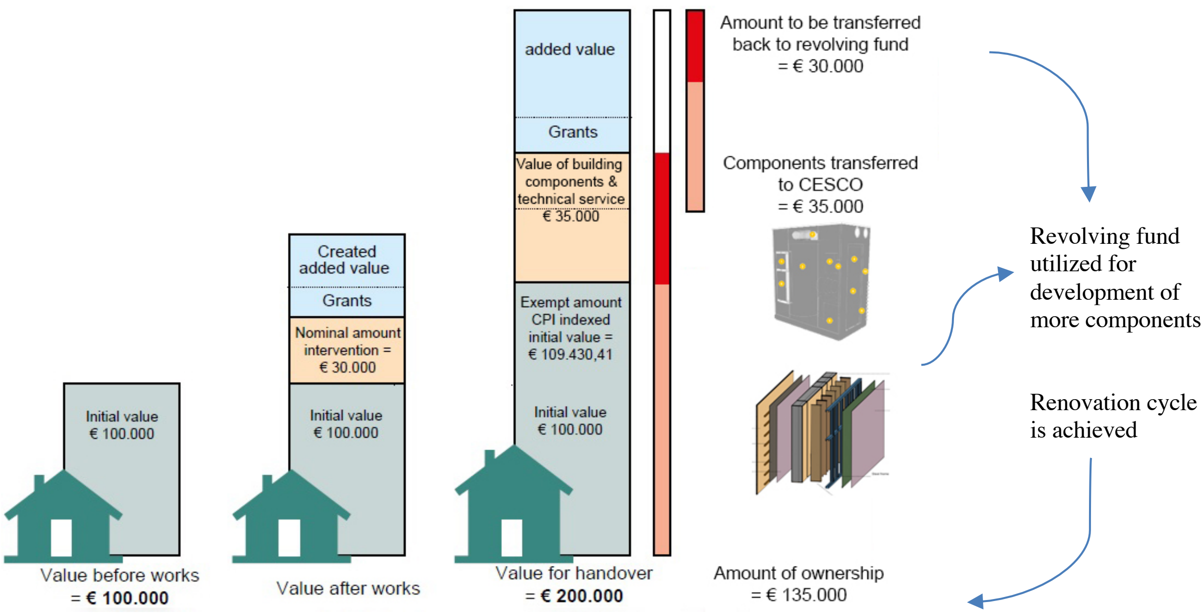

Figure 6. Circular funding strategy for a neighbourhood renovation

3.3. Alternative ownership concepts

The integration of a circular and bio-based approach with revolving fund yields the necessity for an entity that is similar to a circular economy service company (CESCO) concept. Some of the basic characteristics of such an entity was previously analysed by Alaerts et al. [28]. For this specific study, the CESCO concept is proposed for maintaining and re-using the building components that are generated by the initial investment through revolving fund.

In the existing revolving scheme, the revolving fund is utilized for additional renovation projects in the future. But in the proposed funding scheme, the revolving fund will also be utilized to develop more reusable building components. As the example in Figure 6, a certain amount of investment is used to renovate a building and the total value of the building after works is more than the sum of the investment and the value of building before works due to additional value created by increased overall performance. At the time of ownership change, the homeowner needs to:

- pay back the initial allowance with a part of realized added value of the property to the fund.
- return back the reusable buildings components that are owned by the CESCO.

In the end of the ownership change; the homeowner yields a larger value of building ownership than the initial value, has benefit from a better performing house with less consumption. The fund receives back an increased amount of monetary value for more renovations and/or development of building parts and the CESCO takeovers the reusable building components for repair and reuse in the next renovation project. By each cycle, the amount of fund and the number of reusable building components increase.

The increased number of reusable building components are proposed to be considered under product-as-service concept to avoid high initial costs and better management of the stocks. On the other hand, these services are only applicable to measures with a limited technical lifetime of 25 years [29]. In this study, this applies for (i) building envelope and (ii) technical systems. Moreover, in order to provide accessibility of the renovations to low-income groups, a collective renovation strategy for the CESCO is proposed. Then, the concept of CESCO is considered under the scope of a community building trust (CBT) in which public authorities, private sector, civil society and owners/users become a partner.

4. **Results**

As a result of the LL approach, a demountable terraced housing prototype in line with passive house criteria was realized in the Technology Campus Ghent. The environmental assessment of the prototype displayed a significant potential for impact mitigation around 20% through reuse in EoL scenarios. This potential was unlocked by a very high demountability index of 0.74 (from 0 to 1). On the other hand, it was seen that the initial cost of the current prototype is significantly above the average cost for housing. In order to ensure that the expected impact mitigations are realized in the EoL, certain administrative and financial mechanisms are required. Then, two proposals as product as a service for building envelope and technical systems are introduced and further discussed under the concept of CBT:

4.1. Community Building Trust (CBT) concept

The most significant contribution of a CBT in this framework is the fact that, they have both the technical and economic capacity to maintain the ownership of the building component while being able to repair and reuse these components in the end of the component use. Moreover, the link to the private sector partners provides new possibilities to cope with affordability problems being experienced by low-income partners. As the ownership of the building component may continue with CBT despite several obstacles such as sale, change of tenant or renovation, there are two important characteristics that are relevant for CBT's consideration: (i) technical service duration and (ii) takeback obligation.

4.2. Product as a service: building envelope and technical systems

A prefabricated and demountable steel frame panel component which is integrated with bio-based insulation and façade finish was developed. It was designed according to passive house criteria and has a U-value of 0.15 w/m^2K. The weight and environmental impact of the component is minimized by use of steel frame and bio-based materials. The panels are connected to each other and to floor by bolts that allows for easy (dis)assembly. The component itself is also dismantlable so that the bio-based insulation material can be repaired or replaced (by a better product) when needed. A standard technical service duration for external components is around 25 years. After this period, there is a need for repair or maintenance. In this way, the technical service duration for the component is increased, repair processes are standardized and enables for utilization of the component for several lifetimes.

In the end of technical service duration (that depends on included material's lifetime), the CBT has an obligation to take back the components. This obligation provides an opportunity for the new owners to be able to conduct further renovations on their building without damaging previous renovations. In this context, the panel possesses good potential for optimizing for transportation and storage. The amount of time and labour for on-site construction is significantly decreased by prefabrication, which allows an easy transition of the component from a building site to the CBT. As the component is dismantlable, there are several means of storing the component as a whole or in standardized parts. On the other hand, there are uncertainties about the performance in disassembly after long-periods of usage (which cannot be tested for exact durations).

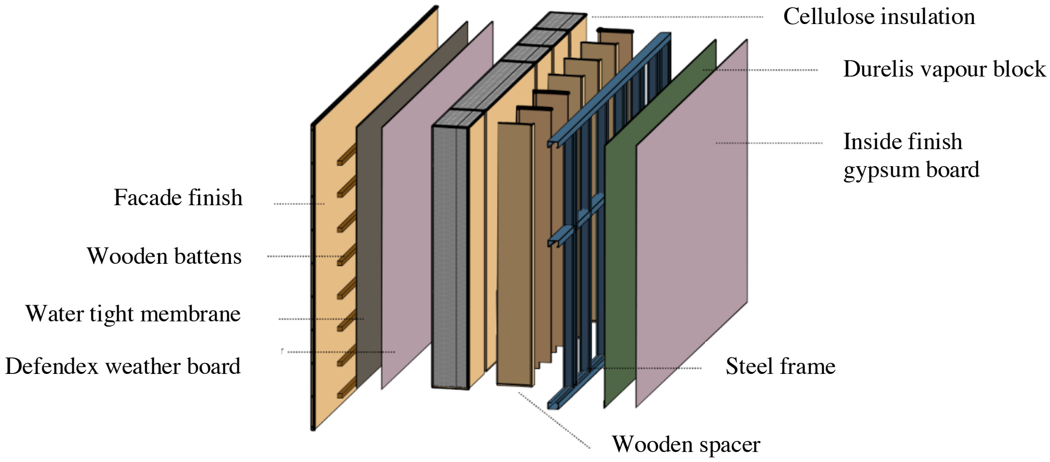

Figure 7. Demountable envelope component

For achieving a comprehensive demountability for LL Ghent, a stand-alone technical service component was adopted. This technical box acts as a compact, prefabricated technical room that includes all necessary systems for the LL to function; an air-to-water heat pump, a water storage for consumption and heating, electricity system connected with solar panels. It is placed in the top floor and attached to a vertical shaft that enables connection with other floors (See Figure 8).

The technical box itself is not demountable, but due to its standardized parts it is significantly easier to repair and maintain the component. When it is considered with distribution system, the box provides direct access to production and storage components and the technical shaft is open on one side for maintenance and the integration of the piping in the subfloor is managed with a demountable floor finish, make the whole technical system easily maintained. This allows for a longer technical service duration, with possibility to upgrade the systems when or if needed.

The technical box was the last component that was placed in the LL Ghent just before the roof was enclosed. Due to its location and independent connection with wall or floor components, the technical box can easily be demounted with minimum intervention to the roof structure. As it combines all systems in a single location, it also allows for easy monitoring. As the ownership belongs to the CBT, they are also responsible from monitoring of the energy and water consumption. Being a standard unit, it is considered that the reusability after a deep renovation is also possible in another low quality housing.

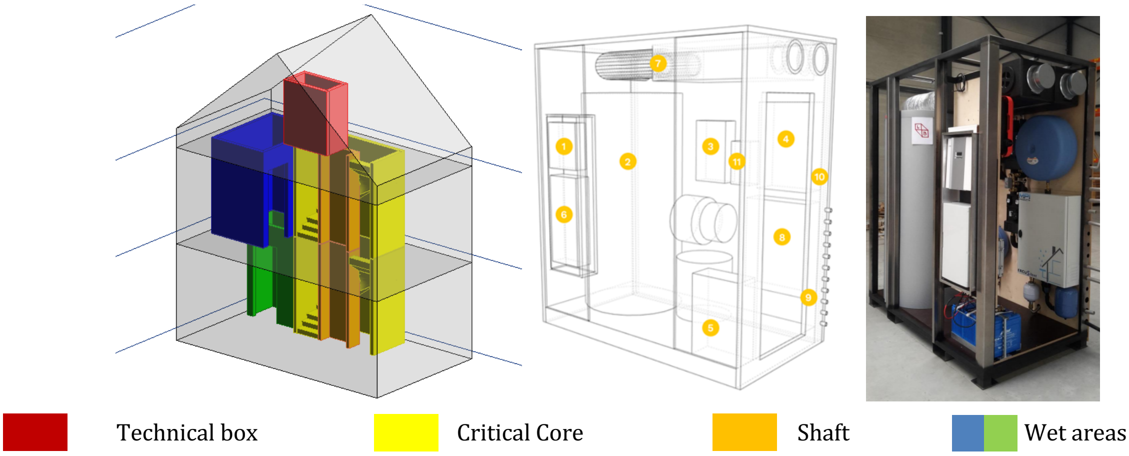

Figure 8. Demountable stand-alone technical services

5. Conclusions

The study focuses on the need for innovative solutions that address several issues regarding the renovation wave that is required for achieving environmental mitigation goals. The results of the study provided a selected combination of possible solutions for a complex problem. It must be emphasized that the combination of subsidy retention funding and emerging circular and bio-based solutions should be tested by real-life renovations. On the other hand, it is clear that a renovation strategy must include certain socio-economical concerns especially about access to the high-quality accommodation and sustainability of the funding schemes.

The research study scope is regional (Two Seas Region) on the other hand, the methodology can be replicated globally. The focus should be on the material selection for reusability and means of achieving demountability should be sought. Even in the current regional context, the proposed envelope panel demonstrates a hybrid system with integration of steel and bio-based materials which allows a larger geographical utilization.

There are several uncertainties regarding the application of the renovation strategy as it includes long-term planning for re-use and maintenance. The performance of demountability of component would have a direct impact on feasibility of the strategy for an CBT. Currently, there is a lack of data on demountability of components which hinders the design and implementation processes with circular materials. Furthermore, there is also a need to validate the theoretical demountability data with real-life monitoring specifically for the EoL scenarios. In this respect, the number of case studies on the topic should be increased.

Another limitation of the study lies with the logistics of the CBT system. A revolving system for components would require increased transportation and storage. Even though the proposed envelope and technical components were designed with such concerns (lighter components that are easily dismantled for transportation and maintenance), there is a need for further exploration for determining feasibility of such an application. It is currently not clear when or at which capacity such a business model would be profitable (than a conventional construction company).

It was also acknowledged that existing funding amounts are limited to compensate for the costs of emerging concepts of circular and bio-based methods and materials. The proposals in this study depends on a prototype of which the costs are assuming to decrease when the solutions are standardized in time. On the other hand, it is clear that the approach would decrease the amount of raw material use, labour and time for implementing the renovations. Especially when the circular and bio-based components increase in quantity (after each successful renovation) and a material bank is achieved, then the profitability and efficiency of the strategy would also incrementally increase. Moreover, existing urban mining potential should be analyzed as a complementary and further study.

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