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DEMOLITION VERSUS DEEP RENOVATION OF RESIDENTIAL BUILDINGS: CASE STUDY WITH ENVIRONMENTAL AND FINANCIAL EVALUATION OF DIFFERENT CONSTRUCTION SCENARIOS

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Abstract

In a context where buildings are required to be and become very energy efficient – also for the existing housing stock – the question arises whether a thorough retrofit really is a better alternative than demolishing the building and re-constructing a new one.

This paper presents a building case study where the environmental and financial impact of different construction scenarios (renovation versus demolition/new construction) are evaluated. It concerns a single-family house, located in Brussels, deeply renovated up to the passive standard by using a box-in-box system. For the analysis, two additional scenarios were defined: one considering more commonly used renovation techniques (installing an external insulation), the other considering a demolition of the existing building and the construction of a new building within the same volume. Life cycle analysis (LCA) and life cycle costing (LCC) are used to gain insights in the environmental and financial impacts of the different retrofitting (or new built) strategies.

The results reveal that the environmental impact of the new building is about 20% higher than that of the box-in-box renovation and that the total life cycle cost of demolition and re-construction is about 30% higher. However, when taking the considerable difference in useable floor space into account, the results also show that the new construction performs significantly better per square meter of heated floor space than the box-in-box renovation – both financially and environmentally. In an urban context where space is scarce, the option of demolition and re-construction thus might be valuable.

Keywords:
LCA; Life Cycle Assessment; Construction; Renovation; Case study

1 INTRODUCTION

In the context of sustainable development, and more specifically the targeted reduction of CO2-emissions, buildings are required to be and become very energy efficient. For the existing housing stock, a deep energy retrofit step is needed in order to meet the required energy standards. Considering the magnitude of such renovations, the question arises whether a thorough retrofit really is a better alternative than demolishing the building and re-constructing a new one.

A building case study is selected and different retrofitting scenarios are defined for the analysis. The scenarios all consider the current standards in terms of comfort and energy consumption. In addition to the “as-renovated” situation, two alternative scenarios are defined: one considering some commonly used renovation techniques, another considering a complete demolition of the building and the erection of a new building. The different alternatives are compared to each other from an environmental point of view by use of life cycle analysis (LCA).

Naturally, the costs related to the retrofitting or demolishing of the building might strongly influence the feasibility of these different scenarios. Therefore, also a life cycle costing analysis (LCC) is performed for the different scenarios. As a result, the feasibility of retrofitting versus demolition and new construction can be discussed from both an economic and an environmental point of view.

2 CASE STUDY

2.1 Building case study

The project in scope is a single-family house with three floors, located in Schaarbeek, Brussels. The house was going to be demolished, until the owners decided to keep it for deep renovation up to the passive house standard. External insulation was not possible due to city regulations, so the building had to be insulated from the inside. As a result, a completely new wooden structure was erected within the existing structure (box-in-box). The building was renovated within the context of the call 'BATEX – Voorbeeldgebouwen -Bâtiments Exemplaires', which promotes the construction and renovation of buildings with good environmental and energetic performances in the Brussels Capital Region. The very low energy use (passive house standard), reuse of rain water, use of ecological construction materials, reuse of waste materials, attention to soft mobility and use of solar energy for the production of sanitary hot water and electricity all contributed to this award.

2.2 Investigated scenarios

The main differences between the considered scenarios are represented conceptually in Fig. 1 (i.e. box-in-box renovation (BB), ETICS renovation (ET) and new construction (NC)).

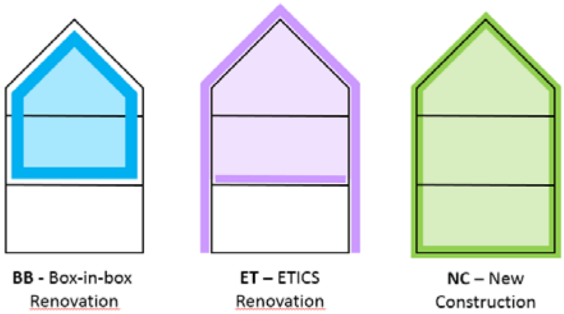

Fig. 1: Conceptual representation of the investigated scenarios.

In the **Box-in-Box renovation** (BB), the building is insulated from the inside. The ground floor is kept for (unheated) storage because of the limited available free height of the spaces. The heated area consists of a living space on the first floor and bedrooms on the second floor, with a total of 110m² of useable (heated) floor area.

In the **ETICS renovation** (ET), the building is insulated by use of an ETICS (External Thermal Insulation Composite System) on the outside of the building. This is a hypothetical scenario, as adding insulation from the outside was restricted through urban regulations. As in the BB-scenario, the ground floor is kept for (unheated) storage. The heated area consists of a living space on the first floor and bedrooms on the second floor, with a total of 127m² of useable (heated) floor area.

In the **New Construction** scenario (NC), the original building is demolished and a new building is erected within the same volume. The complete building is insulated. The heated area consists of a living space on the ground floor and bedrooms on the first floor. The attic on the second floor is also insulated so can be considered within the heated volume. This leads to a total useable (heated) floor area of 196m².

Table 1 provides an overview of the most important dimensions and summarizes the main differences between the different scenarios in terms of material use.

3 METHODOLOGY

3.1 Energy consumption

Even though the different scenarios all strive for a high thermal efficiency of the building, some differences in energy use will exist due to the differences in conception of the buildings (e.g. type of insulation, used floor space). To account for these differences over the building's life time, the energy consumption is calculated for all scenarios using the PHPP-software (PHPP2007). The energy consumption includes the energy consumption for heating, for cooling, for warm water and auxiliary energy (for ventilation system and for circulation pumps for the heat distribution).

3.2 LCA approach

The environmental impact of the different scenarios defined earlier is determined by the use of life cycle analysis (LCA). The cradle-to-grave LCAs carried out within this study take into account the principles described within the ISO 14040 international standards series and the European harmonised standards on the environmental evaluation of buildings (NBN EN 15978) and construction products (NBN EN 15804) [1], [2].

As a functional unit for this study, the whole building is taken into account. The reference study period is set to 60 years, corresponding to the expected service life of the building (after renovation or new construction). Materials or components with a shorter service life have to be replaced during the considered reference period. All newly applied construction materials are taken into account; materials that are being reused are not considered as they fall outside the system boundary. Technical installations for heating and ventilation (boilers, radiators, photovoltaic panels, ducts, fans, etc.), sanitary installations (kitchen and bathroom) and electrical installations (wiring, lighting, etc.) are excluded from the study.

Two sets of life cycle impact assessment methods are used to interpret the environmental impact of the considered scenarios: 1) ReCiPe Endpoint (H) v1.10, Europe ReCiPe H/A represented by use of

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a single score per scenario (expressed in Points) [3] and 2) the CEN indicators (CML Baseline) as described in EN15804+A1 [2]. The results for the CEN indicators are given on a relative scale (expressed in %).

For this study, the generic Swiss LCI database Ecoinvent v2.2 is used [4], [5]. Most data within this database is representative for Switzerland or Western Europe. In the current LCA, data for Western Europe is used when available. For Swiss data, the electricity mix is replaced by the European mix. Furthermore, data is harmonised to the Belgian context by considering transportation and end-of-life (EOL) scenarios representative for the Belgian situation [6].

		BOX-IN-BOX RENOVATION (BB)	ETICS RENOVATION (ET)	NEW RECONSTRUCTION (NC)
Building footprint		83 m²	93 m²	89 m²
Total floor area (level 0+1+2)		177 m²	194 m²	196 m²
Useable (heated) floor area		**110 m²**	**127 m²**	**196 m²**
Use	Level 0	Storage space, ceiling insulated	Storage space, walls and ceiling insulated	Living area
	Level +1	Living area	Living area	Bedrooms
	Level +2	Bedrooms	Bedrooms	Attic, insulated
Basement		/	/	/
Exterior walls	Structure	Construction in wood on inside	Maintain existing structure	Construction in wood
	Foundations	Reinforcement using concrete pillars for back façade / reinforcement using I-beams for front façade	Existing foundations	New foundations
	Insulation	cellulose 40 cm + 4 cm hemp insulation	EPS 30 cm	cellulose 40 cm + 4 cm hemp insulation
	Finishing	Cedar wood, only front façade, levels +1/+2	Plaster, all facades, levels 0/+1/+2	Cedar wood, all facades, levels 0/+1/+2
Interior walls		Wooden structure, gypsum panels	Wooden structure, gypsum panels	Wooden structure, gypsum panels
Roof	Structure	Wooden structure	Wooden structure	Wooden structure
	Insulation	cellulose 40 cm + 2 x 6 cm wood fiber panels	glass wool 40 cm	cellulose 40 cm + 2 x 6 cm wood fiber panels
	Covering	Ceramic roof tiles	Ceramic roof tiles	Ceramic roof tiles
Floors	Ground floor / floor level 0	Existing floor	Existing floor	Concrete, PUR insulation, finishing cork
	Floor level +1	New wooden structure, cellulose 40 cm, finishing cork	Existing floor, PUR 12 cm, finishing cork	New wooden structure, finishing cork
	Floor level +2	New wooden structure, finishing cork	Existing floor, finishing cork	New wooden structure, no finishing
Windows	Openings	Existing + new openings	Existing + new openings	More/larger windows
	Frames	wood	wood	wood
	Glass	triple glazing	triple glazing	triple glazing
Stairs	Outside	existing stair	existing stair	none
	Interior	1 new stair +1/+2, wooden	1 new stair +1/+2, wooden	2 stairs, from 0/+1 and +1/+2, wooden

Table 1: Summary of the main differences (surface and materials) between the scenarios considered in this study.

3.3 LCC methodology

The Life Cycle Costing (LCC) calculations are executed according to ISO 15686-5 on life cycle costing [7]. Construction costs, operational costs (energy, cleaning, etc.), maintenance costs (preventive maintenance, curative maintenance, replacements, etc.) and the end-of-life costs are taken into account. The following costs are excluded from the LCC-analysis: externalities (costs caused by the building, but at the expense of a third party), non-construction costs, income (rental income, subsidies, etc.), acquisition costs, water consumption, regular cleaning costs and

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energy consumption for lighting and housing appliances.

The Life Cycle Cost will be described using the Net Present Value (NPV) as economic indicator. All cash flows occurring during the period of analysis are discounted back to their present value, after which they are summed up. A reference study period of 30 years is considered for the LCC. A nominal discount rate of 3.5% is used for the study (including sensitivity analysis).

4 RESULTS LIFE CYCLE ASSESSMENT (LCA)

4.1 Comparison total building cradle-to-grave (ReCiPe)

A first comparison of the environmental impact of the different scenarios is made using the ReCiPe methodology. Results show that the total environmental impact of the NC-scenario is larger than the other two scenario's (BB and ET), which are comparable in terms of total life cycle environmental impact (see Fig. 2).

The distribution of the impacts over the different life cycle phases is similar for the different scenarios, with the highest impacts related to the production phase and the energy consumption during the use phase. These phases represent 82-85% of the total life cycle impact for all scenarios. For the BB-scenario and NC-scenario the impact of the production phase is slightly higher than the impact related to the energy consumption. For the ET-scenario the impact related to the energy consumption is significantly higher because of the lower thermal efficiency of the building. The construction phase (1%) and EOL phase (5-6%) are small for all scenarios. The impacts related to the replacements are slightly higher (9-11%) but still small in comparison to the production and energy use phase. The impact of replacements is the highest for the NC-scenario where more windows have to be replaced, as well as the complete wooden cladding on all 4 facades.

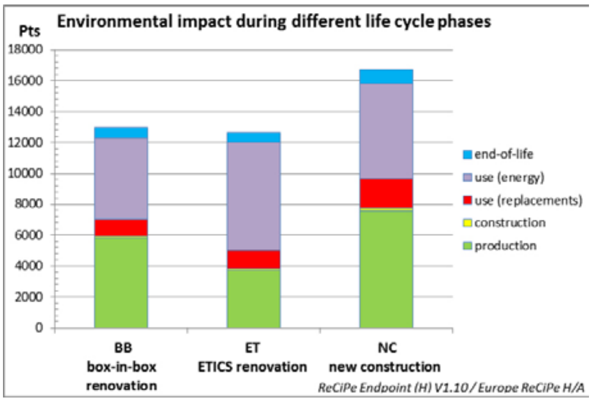

Fig. 2: Comparison of the environmental impact of the different scenarios over the building's complete life cycle (cradle-to-grave).

In the discussion above it should be noted that the installations themselves have not been modelled but would lead to a significant contribution in the production, use (replacements) and EOL phase. This would thus alter the comparison of the different phases for each scenario, with higher impacts for all phases except the energy consumption phase.

4.2 Comparison in relation to floor area (ReCiPe)

As seen in the results above, the new construction results in higher environmental impact for almost all life cycle phases and building elements. However, the new construction (NC) also has a larger potential in terms of useable floor space as the contained (heated) volume houses three floor levels instead of only two in the other scenarios (BB and ET). Therefore it seems useful to compare the total impacts of the buildings in relation to the useable floor space (see *Table 1*).

Looking at the environmental impact in relation to the floor area provides some valuable and interesting nuances in the results (Fig. 3). First of all, the comparison per m² leads to a lower environmental impact for ET than for BB. Whereas the total life cycle impact is similar for both scenarios when considering the total building impact (see Fig. 2), the impact per square meter of useable floor space is lower in case of the ET-scenario (Fig. 3).

The discussion of these results is more difficult for the new construction. When considering the complete heated floor area, the NC-scenario scores significantly better than both the ET- and BB-scenario (see Fig. 3). However, the second floor is not finished for the NC, and given the significantly larger total floor space one could state that the functional unit does not allow for a correct comparison. Nevertheless, the wish for as much useable floor space as possible remains very important, especially in an urban context.

The results where only two floors of the new construction are considered as useable floor area (129m²) reveal that the environmental impact of the new construction is slightly higher than the box-in-box renovation when considered per m² of useable floor area (see Fig. 3).

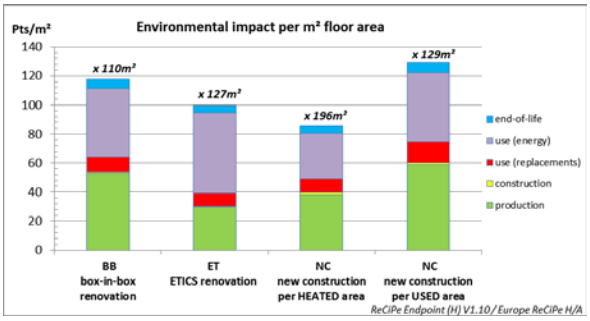

Fig. 3: Environmental impact for the three scenarios per m² of floor area.

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4.3 Comparison of scenarios for individual impact categories (CEN indicators)

The consideration of individual impact categories according to the 7 CEN indicators (see Fig. 4) allows for a more nuanced comparison of the scenarios. The impact represents the impact for the complete renovation and does not take into account the differences in useable floor area (m²). The results show that the NC-scenario has the highest environmental impact for all categories. The impact of the BB-scenario is about 20% lower for each indicator. Finally, the impact of the ET-scenario varies according to the indicator. For Photochemical oxidation the impact of EC is the same as for the new construction NC. For Abiotic depletion (ADP) and Eutrophication (EP) the impact of EC is significantly lower than that of BB (-20%). For the remaining indicators, the impact of the ET-scenario is comparable to that of the BB-scenario.

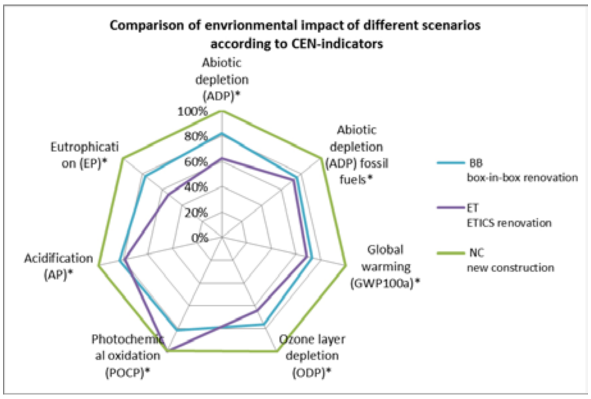

Fig. 4: Environmental impact of the different building and renovation scenarios according to the 7 CEN-indicators.

5 RESULTS LIFE CYCLE COSTING (LCC)

The life cycle costs are summarized in Fig. 5, together with the resulting total Life Cycle Cost. The end-of-life costs, calculated as residual values (via linear depreciation), are included as negative costs.

The ET-scenario has the lowest Life Cycle Cost, but the difference with the BB-scenario is small (3.5% difference). The LCC of the NC-scenario is significantly (34%) higher than the ET-scenario.

The energy cost (operation cost) represents only a minor part of the LCC for these nearly passive buildings. Especially for the BB and NC-scenarios (1.8% and 2.1% of the total LCC respectively), but also for the ET-scenario with an operations cost of only 3.8% of the total LCC.

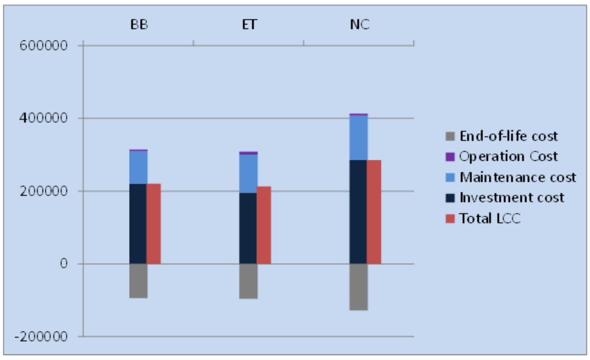

Fig. 5: Total life cycle cost.

In the calculations above, the total life cycle costs are represented without consideration of the differences in useable floor space for the different scenarios. Comparing the costs in relation to the useable floor space reveals that the NC-scenario has the lowest life cycle cost per square meter – being 27% lower than for the BB-scenario (see Fig. 6). Also between the BB and ET-scenarios (with comparable absolute life cycle cost) a difference of 16% is found when considering the cost/m².

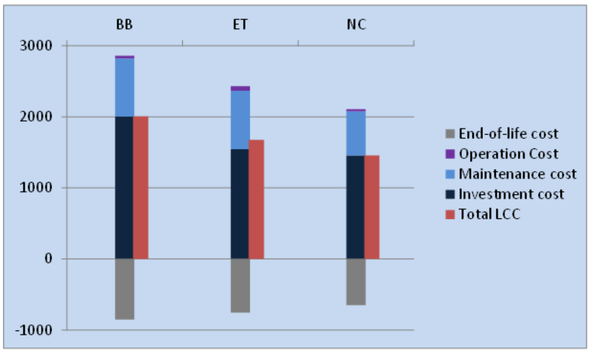

Fig. 6: Total life cycle cost per square meter.

6 DISCUSSION COMBINATION LCA/LCC

As both environmental indicators and economic indicators have different units of measurement it is difficult to compare results from the LCA and LCC analyses. However, Fig. 7 shows a relative comparison of the scenarios, where the scenario scoring the worst for an indicator is used as the 100% reference. For the LCA, the Initial impact of production and the Total life cycle environmental impact are considered (both using ReCiPe). For LCC, the Investment cost and the Total life cycle cost are included.

The graph shows that the new construction (NC) scores about 20% worse than the box-in-box renovation (BB) for the main LCA and LCC indicators. The ETICS renovation (ET) has a similar scoring to the box-in-box renovation (BB), except for the LCA Production impact where it scores significantly better. The latter can be explained by the fact the ET-scenario consumes significantly less materials than the other scenarios. The resulting lower thermal efficiency,

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however, compensates any gains over the considered life cycle of 60 years.

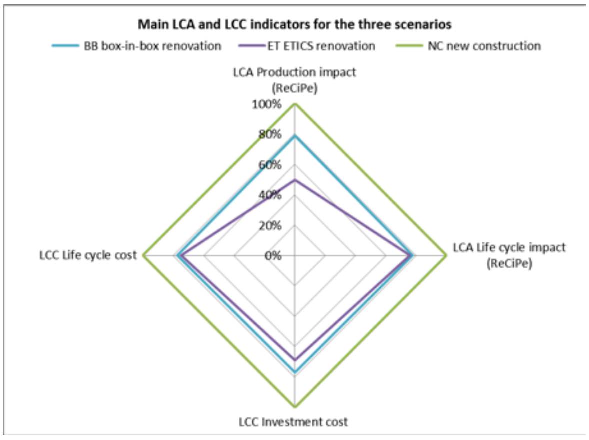

Fig. 7 : Main environmental and economic indicators for comparing the three scenarios BB, ET and NC.

7 CONCLUSIONS

For the present case study, the results reveal that the NC-scenario (new construction) has the largest overall environmental impact and the highest life cycle cost: the environmental impact of the new building is about 20% higher than that of the box-in-box renovation (BB-scenario) and the total life cycle cost of demolition and re-construction is about 30% higher. However, when taking the considerable difference in useable floor space into account, the results reveal that the new construction (NC) performs significantly better per square meter of heated floor space than the box-in-box renovation (BB) – both financially and environmentally. The higher total environmental impact and higher total costs generated during the demolition/new construction are thus compensated by a gain in useable floor space.

Considering the total environmental impact and total life cycle cost, the ETICS-scenario performs similar to the BB-scenario. The environmental impact of the materials used for the ET-renovation is lower than that of the BB-renovation. However, this difference is compensated by the higher impact for energy during the use phase in the ET-scenario. In terms of costs, the ET-scenario has the lowest Life Cycle Cost, but the difference with the BB-scenario is only 3.5%. When considering the impacts per square meter, the ET-scenario performs better than the BB-scenario because of the larger useable floor space (related to insulating from outside instead of inside).

To conclude, the scenario considering the demolition and new construction leads to the highest total environmental impact and the highest life cycle cost. However, considering the additional floor space that can be created in a new construction, this option might be a valuable one, especially in an urban context where space is scarce.

8 ACKNOWLEDGMENTS

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