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Office to housing conversion: estimating life cycle environmental and financial performance

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Abstract. Renovating existing building is often touted as having an improved environmental performance as compared to demolition and construction. However, very few studies have quantified the life cycle environmental benefits resulting from such renovations. The aim of this research is to provide a benchmark based on a real and representative case study building to estimate life cycle greenhouse gas emissions and financial costs of redeveloping an office building by considering different scenarios: (1) renovation as an office building; (2) conversion as a residential building; (3) demolition and construction of an office building and (4): demolition and construction of a residential building. Results show that the demolition-construction scenarios are undoubtedly the most environmentally impactful, but the difference between offices and housing is less significant and depends greatly on the assumptions made. On the other hand, from a tax point of view, the demolition-construction scenario is favoured by the real estate industry because it allows for the recovery of VAT in the operation and thus maximizes the value of the real estate asset as well as the financial return. There is also a significant difference between the profitability of a housing and an office project. The latter is favoured by market values. The tendency to favour offices in the European district could be reversed in the current post covid situation and solutions exist to encourage the development of housing projects through office conversion.

Keywords: Office to housing conversion, life cycle assessment, financial performance, multicriteria renovation, adaptive reuse, construction costs analysis, scenarios of reconversion.

1. Introduction

While many cities are currently facing the challenge of converting offices to housing, Brussels can be considered a forerunner, with the first conversion dating back to the early 1990s. Since then, the pace of conversion has steadily increased. In 2018 and 2019, it is estimated that some 20% of annual housing floor area built in Brussels result from converted office buildings. Since the records began (in 1997) more than 1 million m² have been transformed into housing (more than 1,6 million m² in total, including other functions than housing, compared to approximately 700 000 m² in Paris over the same period, but with a much more significant built stock and population) [1].

The aim of this paper is to quantify the life cycle greenhouse gas emissions and financial performance of different renovation and demolition-construction scenarios for office buildings.

2. Method

A case study approach [2] was chosen due to the lack of data. The representative case study captures the most common construction assemblies used in new buildings and in renovations in the European District of Brussels, Belgium.



Firstly, an analysis (including financial, technical, environmental and legal aspects) of the case study (rue d'Arlon 104 in 1000 Brussels) is conducted, using available documentation and on-site visits. This enables an assessment of the current status of the building. Secondly, four scenarios are defined, namely: (1) renovation as an office building; (2) conversion as a residential building; (3) demolition and construction of an office building and (4): demolition and construction of a residential building. These scenarios have been arbitrarily defined by public authorities as those most often encountered in office building redevelopment projects. Thirdly, data from comparable projects is collected to ensure that material and construction choices, as well as cost, are representative for all four scenarios. This ensures that they are a realistic representation of the current state of the market. Finally, each scenario is evaluated according to three dimensions: economic, fiscal and environmental.

The tool used to quantify life cycle greenhouse gas emissions is TOTEM [3]. It was chosen because it quantified environmental impacts of construction materials, at the level of elements (wall, roof, floor...) and buildings. TOTEM was developed for Belgium by integrating the European standards and directives on the matter. It has been demonstrated that it is preferable to use methods, tools and databases in line with the geographical situation [4]. The embodied flows database has been developed on the basis of generic data from the established Ecoinvent database (Switzerland), adapted to the Belgian context.

The criterion that seems to be the most impactful and representative of the carbon footprint is "climate change". It represents the increase in the average atmospheric concentration of various substances of anthropogenic origin (CO_2 , CH_4 , CFC...). In other words, it evaluates the emissions of gases contributing to the greenhouse effect, which notably increases the average temperature on Earth. The sub-indicator "climate change - fossil", expressed in $\text{kg CO}_2 \text{ eq.}$ represents 40% of the weighting proposed by TOTEM for its aggregated environmental indicator. This aggregates the different environmental impacts considered in the tool into a single score via the Product Environmental Footprint (PEF) method, expressed in Milli Points [5]. Thus, interpretation and decision making are facilitated by this multi-criteria result. Therefore, these results for these two indicators will be compared.

3. Case study description

The case study (Figure 1) is an office building of approximately 11,000 m^2 located on rue d'Arlon, 104 in Brussels, in the European district, built in the 1960s. It presents several specificities, both typological and constructive (load-bearing facade) and, having been empty for nearly 20 years, it is currently bare, without any finishes, nor any technical equipment.

Distributed over 9 floors above ground and 2 floors of underground parking (2,800 m^2). The basements as well as the ground and second floors occupy almost the entire plot (except for a strip set back from the sidewalk) and have a floor area of approximately 1,400 m^2 each. The second through sixth floors are identical and have an "L" shaped floor plan.

The facade elements are made of prefabricated reinforced concrete and are self-supporting. This is probably the most particular constructive fact because they are cast in one piece and are therefore integral with the structure. They play a load-bearing structural role. This results in a very low flexibility of the structure and a real difficulty in case of dismantling or demolition of the building. The frame of these elements is 1.80 m wide. The street facade of the last three floors is set back about 1.80 m from the lower floor (i.e. the width of a facade module), resulting in smaller floor areas (1,000 m^2 , 850 m^2 , 700 m^2) on the last three floors and the existence of flat roofs.

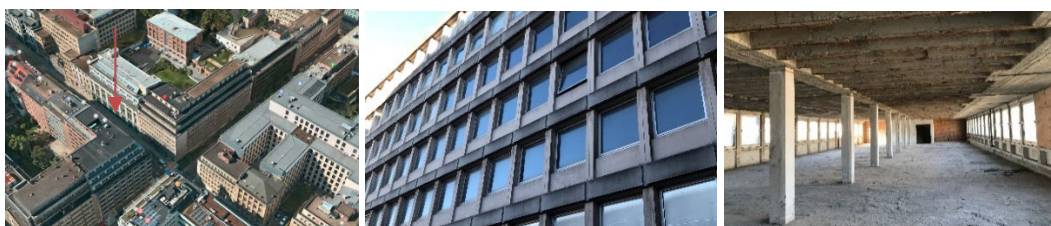


Figure 1. Photographs of the case study, rue d'Arlon 104 in Brussels

The geometry, quantities and materials of the case study were used, but slight adaptations and simplifications were made to make it as representative as possible of the existing Brussels office building stock. Wall compositions (materials and thicknesses) were chosen from the TOTEM library and then adapted to the case study in order to simplify the process. To complete this work, typical elements were sometimes slightly modified to get closer to other research results on the materiality of Brussels office [6]. To test several alternatives, the TOTEM walls are chosen according to their environmental score [mPt/m²]. The insulating materials were selected according to their representativeness on the market, but a more ecological alternative is also proposed [7].

The idea being to reach buildings close to Net Zero Operational Energy, the wall compositions are influenced by their thermal transmission coefficient, U-value. To maintain the same standards between scenarios, the walls of the same element have the same (or very close) U-value in compliance with Energy Performance of Buildings Directive requirements [8].

4. Scenarios of reconversion

The key element in determining the scenarios and the main differences between them (in the metrics and the wall compositions) is to focus on what differentiates the scenarios, so that only what is specific to a renovation/conversion versus a demolition-construction and an office building versus housing is considered. Thus, the rest must be identical, both in the metric and in the composition of the elements, to make the comparison possible. To differentiate renovation/conversion from demolition-construction, the ceiling height of the first floor is increased by one meter and that of the upper floors is increased to 3.3 meters, with one floor less in the demolition scenarios. The height of the building in renovation/conversion is thus 27 meters (3+3×8) is then comparable to that of the demolition-construction which is 27.1 meters (4+3.3×7).

Moreover, the insulation is placed on the inside in renovation/conversion and from the outside in demolition-construction (this is mostly the case, but the opposite has also been tested as a variant). This assumption creates an inaccuracy since the finishes are not taken into account in any case. In the case of interior insulation, the exterior finishes are maintained, although they have a significant effect on the environmental balance.

According to the recommendations of the 'Good Living' expert commission [9], terraces are added to the dwellings, which implies that they would be added to the volume for conversion, while they would be included in the volume for demolition-construction. The partitions are also different for the offices (light structure: glass or steel with stone wool) and for the units (solid structure: concrete or sand-lime). A concrete circulation core is also added for the residential units. The walls (amount of concrete) will be accounted for in the balance sheet.

5. Benchmark on costs

From a financial point of view, rather than doing a theoretical exercise of establishing a fictitious price list of development projects for each scenario, the analysis consisted in gathering information on costs of recent and comparable real estate operations (construction costs, project fees, etc). Most of the benchmark projects were selected in relation to their location in the European district in Brussels (in comparison with the case study's location) and to their recent topicality (projects completed less than 5 years ago).

By choosing this methodology, we have tried not to bind ourselves to the specificity of the case study Arlon 104 in order to remain generic in the approach and coherent in relation to real costs from operations already carried out. Each real estate operation remains specific, and it is therefore not possible to generalize. Nevertheless, we have obtained sufficient data on costs to define orders of magnitude in the distribution of construction items (demolitions, structure, techniques, finishing, fittings) for cases comparable to each of the scenarios considered. It was easier to obtain a sufficient amount of information on office developments than on housing redevelopment projects, simply because there are very few housings redevelopment projects in the European district in Brussels to date.

6. Results

6.1. Life Cycle Performance

Following the assumptions determined above, the four scenarios were evaluated according to greenhouse gas emissions indicator. It was decided to study phases A1 through A5, since the assumptions TOTEM made regarding building occupancy are not known.

Results (Figure 2) show that the demolition-construction scenarios are undoubtedly the most environmentally impactful, but the difference between offices and housing is less significant and depends greatly on the assumptions made. The office renovation scenario has the lowest impact (only 13% of the impact of the housing demolition-construction scenario (which is the most impacting scenario, per m² of gross floor area), followed by the housing conversion (22%) and office demolition-construction scenario (82%). These are not surprising results given that this is also the order in which more changes occur from the baseline, except for the floors. The impact is higher for offices than for housing, because false ceilings are added to the composition. Numerical results are only valid if they are compared as several elements have not been taken into account (such as techniques and finishes).

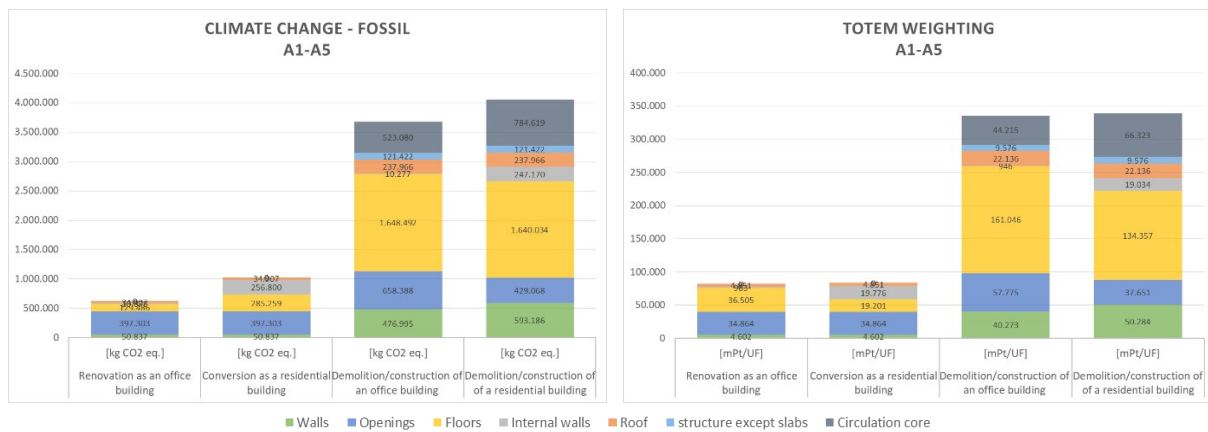


Figure 2. Results for four scenarios according to greenhouse gas emissions and TOTEM weighting.

Given that the climate change - fossil indicator represents 40% of the TOTEM weighting, it is not surprising that these two indicators tend towards similar results, but the difference between offices and housing is smaller. Regardless of the indicator, it can be seen that floors have a significant environmental impact and results for openings are constant.

Due to the complexity of life cycle analysis (LCA) studies, simplified methods that focus on certain phases of the building's life cycle or on a reduced number of indicators are frequently used, as in this case A1 to A5 (product manufacturing phase). The results of a full and a simplified LCA (building use phase and product manufacturing phase) have shown that the simplification can be sufficiently accurate to facilitate decision-making for building energy refurbishment. The other phases of the building life cycle related to product transportation, on-site construction, deconstruction, or end-of-life represent a generally negligible part of the total life cycle impact, both in terms of resource use and environmental impacts [10]. In this case, the analysis was performed only for the product manufacturing phase (A1 to A5). To test the hypothesis that there is not much difference, the TOTEM weighting index was also tested for a complete analysis, from A1 to C4. The results are relatively proportional, but the residential demolition-construction scenario has a better environmental impact than the office scenario. The openings have, in all scenarios, a much greater impact for the longest LCA (Figure 3).

6.2. Financial performance

The benchmark clearly showed a variable distribution of the proportions of the various building components (demolitions, structure, techniques, finishing, fittings) for each of the different scenarios.

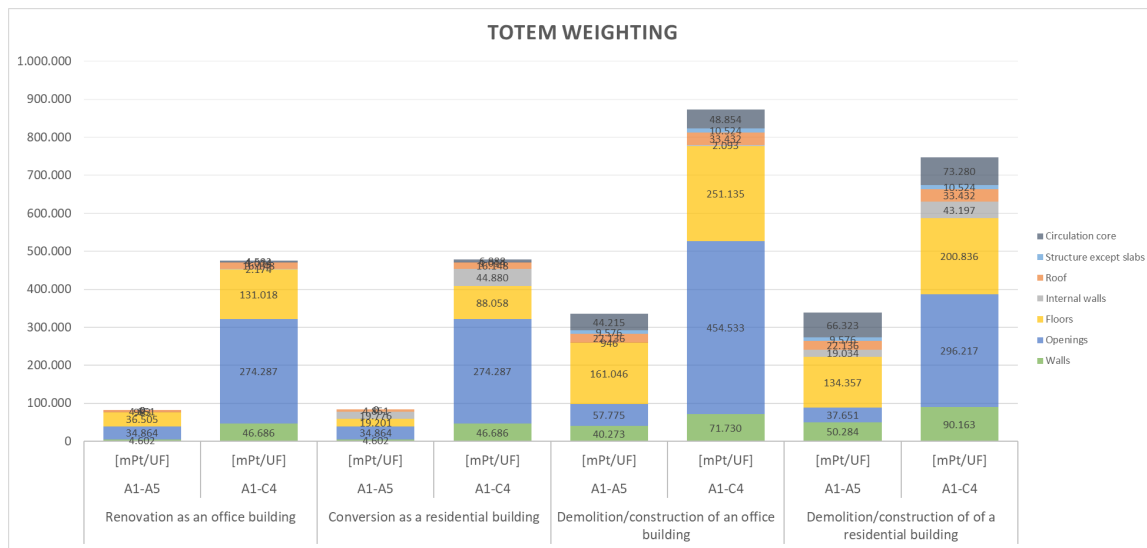


Figure 3. Results for four scenarios according to TOTEM weighting indicator from A1 to A5 and from A1 to C4

However, the total cost of operations (comparing demolition-construction and renovation) did not vary significantly (except in the case of so-called "light" renovations and when there is no change of use). The range is set between 1.800€/sqm and 2.200€/sqm. The exact costs vary from one project to another and is also linked to the context and the date of the operation (recent inflation impacts the construction costs significantly); In financial terms, therefore, renovation with a change of use is not attractive. Moreover, it is more complicated for non-financial related reasons: a slower project planning, an increased complexity in the project's implementation and an inherited existing structure that comes with all its "defects" and irregularities. Therefore, it clearly emerged from the benchmarked study that converting old offices buildings into residential use is not an answer to the need for affordable housing.

The market analysis highlighted the fact that for reasons linked to the valuation of office projects (market values, rental amounts, yields, land values), it is clearly more interesting from a financial point of view for a developer to transform or rebuild an old office building into offices than to transform it into housing. The valuation can double, specifically in a central business district such as the EU district in Brussels where land values remain very high, and the attractiveness still is very much in favor of recent office developments.

For an office building valuation at the time of the study (end of 2022), with a mean rent of 230€/sqm/year and a forecasted yield of 4%, a 10.000sqm of lettable office space could be valued at 57,5 million €. For a housing building, the valuation would be based on an average 180€/sqm/year for the rent, which for a similar yield of 4% would end up at a value of 45 million € for 10.000 sqm building.

The developers would clearly favor office use in that case. Housing would only be implemented by constrain (local urban planning regulation) or with the support of public authorities (e.g. subsidies).

7. Discussion and conclusion

The interest of this research lies mainly in the approach used and the questions raised. It was difficult to determine the differences between the scenarios according to the size and composition of the elements, but these initial results are convincing. Simplifications had to be made in order to make the case study as representative as possible and to achieve a certain degree of extrapolation. The results obtained have value only by comparison. The assumptions for differentiating the four scenarios could be further improved and the finishes and systems could be integrated, as the new update of the TOTEM tool allows it. Other elements, such as balconies, stairs or lifts, are not yet included in the tool.

Case study research, as such results are valid for the case study and can be extrapolated to similar buildings, allows some deviations. Reliance on process-based life cycle inventory approaches, as such,

there is a truncation error which underestimates embodied environmental flows [11]. Crawford, Stephan and Prideaux [12] have demonstrated that this truncation error can vary significantly between material groups, as such, comparisons which rely on different material pallets are subject to potentially significant variations in their embodied environmental flows, which could affect the results.

On the financial aspects, the benchmark analysis highlighted a set of factors that can help public authorities to better understand the market logics and define strategies:

- the relative loss of floor space when converting office space to residential (simply because marketable office space is gross and residential space is net). We have estimated this loss at between 15 and 18%.
- the relative loss of surface areas during demolition-construction operations: the ceiling heights in the new regulations (Good Living - in progress) are higher than previously (2.70m vs. 2.50m previously), which often leads to the loss of a floor in a building with more than 8 floors above ground.
- the current difficulty in comparing the costs of recent operations given the rapid evolution of the construction cost index and the evolution of the returns expected by investors (linked to the evolution of bank financing rates).
- from a fiscal point of view, the developer will always try to requalify his operation as a "new" development because he will be able to deduct TVA costs at the time of the resale. He can achieve this in two ways, either through demolition-construction, or by maximizing the work done (the operation can be considered as "new" when the cost of the work exceeds 60% of the market value of the building).

Although current standards (such as ISO 21931-1) and certifications (such as LEED) do not propose limit values for greenhouse gas emissions at building level, they do encourage the reduction of these emissions through methods and tools. At national level, many countries are introducing regulations to help achieve this, and will hopefully soon be proposing legislation along these lines (as some pioneering countries have done).

The tax and financial logic which always seeks the optimum is at odds with the technical and environmental desire to preserve the existing building. These findings could form the basis for a strategy to increase housing projects through conversion in Brussels European district.

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