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Building Upcycling *vs.* Building Reconstruction: a Life Cycle Valuation for investment decisions

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Abstract

Decision-making processes concerning investments in building upcycling vs. building reconstruction of the existing stock involve environmental aspects besides the economic-financial ones. For example, material and energy preservation, waste management, Embodied Energy (EE), and Embodied Carbon (EC) management in construction processes are crucial aspects that concern different scales: material/component/system, whole building, urban scale, and civil engineering works and infrastructures. In the perspective of more restrictive norms on the displacement of materials with residual energy potential, EE and EC should be considered as hidden components of building value and, thus, internalized into investment decision-making processes under a circular perspective. Therefore, this contribution aims to present the first simulation of a methodological proposal to evaluate two alternative investment projects (a residential building upcycling vs. a reconstruction scenario) by internalizing environmental components in the financial Discounted Cash-flow Analysis (DCFA). From a life cycle perspective, the global cost and the «global benefit» are modeled using the NPV indicator calculation. The results highlight the weight of the environmental cost items from a financial perspective and the capability of environmental input (EE and CO_2 emissions) to influence the results, thus orienting investment decisions and public policy-making towards sustainable design.

Keywords: Discounted Cash-flow Analysis; Embodied Energy; Embodied Carbon; Global Cost; Global Benefit

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1. Introduction

The European regulatory framework, with the purpose of achieving zero-impact buildings by 2050, regulates environmental policies in the construction sector. Attention is paid to waste production from building construction activities. Among the others, the EU Clean Energy Package (European Commission, 2020) and the EU Circular Economy Package (European Commission, 2019) promote building refurbishment and decarbonization, reduction in energy and resource consumption and waste production, and the recycling of material/product to maintain their value. Waste elimination implies material recovery, recycling, reuse, etc., while maintaining the maximum possible efficiency level (Azcarate-Aguerre et al., 2022), with a crucial impact on the economic sphere. Precisely, construction waste recovery/recycling (at the material, component, system, and building levels) implies EE calculation, aiming at exploiting residual technological performance to achieve an economic-environmental surplus value, according to the "add value-maintain value" model, theorized by the circular economy. Analogously, EC in recycled products can be considered a result of avoided atmospheric emissions.

Thus, the EE and EC can be conceived as implicit components of the real estate asset value (Monsù Scolaro, 2018), even more so in the perspective of future more restrictive norms on waste management. This reasoning is particularly appropriate in the presence of new constructions, demanding eco-compatible design and production processes, and even more in the existing building heritage, focusing on retrofit interventions (Thormark, 2002). Even more so considering the potential impact on housing real estate market pricing processes of new built assets and upcycling of the existing stock. This last is largely represented in Europe: as (Arcarate-Aguerre et al., 2022) underline, about 25 billion m^2 belongs to existing spaces. In Italy, about 85% of the building stock belongs to residential buildings, prevailing realized after the Second World War without binding norms on building energy consumption, highly impacting our urban areas (Becchio et al., 2002. Lo Curcio et al., 2022).

With these premises, in this work, we assume the Global Cost concept and the "Global Benefit" concept proposed as the 'life cycle value' of existing buildings, as formalized in a methodological proposal illustrated in previous research (Fregonara, 2023). Global Cost and Global Benefit are internalized into the DCFA to calculate the NPV synthetic indicator for investment decisions. Thus, the work aims to illustrate a first simulation of the previously mentioned proposal according to the methodological steps presented in the next section.

Two alternative project scenarios are assumed and compared – a residential building retrofitting vs. a demolition and reconstruction – considering the EE in the construction process and the CO_2 mean emissions in the use-maintenance-adaptation stage. The results show the capability (and weight) of EE and CO_2 to influence the project's financial valuation results and, thus, to orient investment decisions at different scales toward sustainable design and building production activities. Therefore, this research would contribute to the growing literature on the topic and support decision-making processes in both the private and public sectors, as well as in PPP interventions.

The work is articulated as follows. In the next section, 2, the methodological background is illustrated. In section 3, after synthesizing the hypothetical case study assumptions, the simulation results are presented and briefly commented on. Finally, section 4 concludes the work by highlighting future research perspectives and issues to be further explored.

2. Methodology

The methodology explored in this work originates from the proposal illustrated in (Fregonara, 2023). This proposal founds on three main assumptions.

Firstly, the Global Cost concept formalized in the EN 15459:2007 Standard and Guidelines accompanying Commission Delegated Regulation (EU) No 244/2012.

Secondly, the synthetic economic-environmental indicator formalized through the Life Cycle Assessment (LCA) in ISO 14040:2006, and the Life Cycle Costing (LCC), as standardized in ISO 15686:2008, encompassing recycled materials, dismantling, and waste produced, presented in (Fregonara et al., 2017). In that work, the Global Cost is rewritten as in equation (1):

$$C_{GEnEnv} = C_I + C_{EE} + C_{EC} + \sum_{t=1}^{N} (C_m + C_r) \,.\, R_d(i) + (C_{dm} + C_{dp} - V_r) \,.\, R_d(i) \qquad (1)$$

where: C_{GEnEnv} is the Life Cycle Cost encompassing environmental and economic indicators; C_I is the investment cost; C_{EE} is the cost related to EE; C_{EC} is the cost associated with the EC; C_m is the maintenance cost, C_r is the replacement cost; C_{dm} and C_{dp} the dismantling and disposal cost respectively; V_r is the residual value; t is the year in which the cost occurred and N the number of years of the analysis; R_d is the discount factor.

Thirdly, the centrality of the end-of-life stage and the building's final value which can be positive or negative.

Starting from these assumptions, the Global Benefit is proposed as the sum of the incomes from investment in a building reconstruction/retrofitting, incorporating the energy-environmental value components of the existing building as implicit or 'hidden' values. The environmental impact on the value can be monetized through the embodied residual energy, potentially reused in a building's upcycling process, and through the quantity of CO_2 embodied in material/component/system production and operation, potentially saved/avoided by building recycling in place of a building dismantling and reconstruction. Thus, the Global Benefit can be formalized in the following equation (2):

$$B_{gEnEnv} = V_{tr} + V_{en} + V_{env} + \sum_{t=1}^{N} (R_{Revenue}) \,.\, R_d(i) + V_r \,.\, R_d(i) \qquad (2)$$

where: B_{gEnEnv} represents the economic-energy-environmental Global Benefit, V_{tr} is the market value of the asset under transformation, V_{en} is the residual energy value, and V_{env} is the environmental value (avoided EC). $R_{Revenue}$ is the income from the market, t the year in which the income occurred, and N is the number of years considered for the analysis; V_r is the residual value, and R_d is the discount factor.

The Global Benefit can represent support in decision-making processes involving reconstruction vs. retrofit investment decisions at the building scale. In fact, as a second step, the methodology assumes the NPV calculation as conceptualized in the DCFA, which, according to the Global Cost and Global Benefit concepts, can be reformalized by including externalities throughout the life cycle as in equation 3:

$$NPV = \sum_{t=1}^{n} \frac{B_{gEnEnv} - C_{gEnEnv}}{(1+r)^n} \qquad (3)$$

Thus, assuming the set of costs/value input in a DCF model for the retrofit scenario and for the demolition and reconstruction one, equation (3) can be reformulated as in equations (4) and (5), respectively:

$$NPV = \sum_{t=1}^{n} \left[\left(\frac{B_{gRetrofit}}{(1+r')^n} \right) - \left(\frac{C_{\mathrm{gEnEnv}Retrofit}}{(1+r'')^n} \right) \right] \qquad (4)$$

$$NPV = \sum_{t=1}^{n} \left[\left(\frac{B_{gReconstr}}{(1+r')^n} \right) - \left(\frac{C_{\mathrm{gEnEnv}Reconstr}}{(1+r'')^n} \right) \right] \qquad (5)$$

This work explores the methodology – according to a first simplified operative modality - through the simulation illustrated in the following section.

3. Simulation and results

The simulation is conducted concerning a hypothetical case study by implementing a data set based on literature and according to the following workflow:

(1) alternative scenarios definition;
(2) EE and CO_2 quantification and monetization for both scenarios;
(3) internalization of the environmental components into the DCFA;
(4) implementation of the Global Cost and Global Benefit into the NPV calculation;
(5) results interpretation.

As a first step, two options – a residential building retrofit (upcycling) scenario and a demolition and reconstruction scenario - are defined. A residential building with an overall gross floor area of 500 square meters is hypothesized. Indicatively, a double-storey building with four apartments is foreshadowed. For the first scenario, a retrofit intervention is hypothesized, with demolition and reconstructing about 2/3 of the existing building. For the second scenario, the complete demolition and reconstruction of the existing building is foreshadowed. As mentioned before, for this first application, some results and conditions of a study by (Gaspar and Santos, 2015) are assumed, considering the research particularly interesting for the aim of this work.

As a second step, EE and CO_2 are quantified and monetized. Precisely, the EE is quantified about the construction activity, and the data related to EE is adopted, as in the before-mentioned study by Gaspar and Santos, considering analogous energy efficiency measures. The related costs adopted for the EE monetization are taken from the market (energy market price by ARERA). Contextually, the data related to the product CO_2 during the management stage (use, maintenance, and adaptation activities) are taken from (ENEA, 2023). These data are related to the mean consumption of Class A1 residential buildings. The CO_2 emissions are monetized by adopting 44,49 euros as the reference value, extrapolated by Europe's carbon tax mean values (The World Bank, 2023).

In the third step, a DCFA is implemented by internalizing the EE in the construction process, and the CO_2 mean emissions during the management stage (spreading, for simplicity, a constant mean value over the entire lifespan).

In the fourth step, the two scenarios are compared by calculating the respective NPVs, which are calculated according to equations (4) and (5), simplified.

The simulation assumptions are summarized in Table 1.

Table 1. Simulation assumptions.

Input Drivers	**Unit of measurement**	**Upcycling scenario**	**Reconstruction scenario**
Investment cost	€	900,000	900,000
Incomes (rent)	€ per year	68,600	68,600
Maintenance cost	€ per year	686	686
Replacement cost	€ per year	13,500	13,500
Operation costs (heating + electric power)	€ per year	12,836	12,836
End-of-life costs (dismantling + disposal)	€	30,000	30,000
Embodied Energy (in investment cost)	MJ/m^2	5,666	7,271
Embodied Energy (in investment cost)	€	157,401	201,988
CO_2 (in operation costs)	kg/m^2 per year	14.90	14.90
CO_2 (in operation costs)	€ per year	331	331
Discount rate	%	6.50	6.50
Period of analysis	years	30	30

More precisely, a construction cost of 1,800 €/m^2 is hypothesized for new construction and retrofitting of the existing building. Retrofit interventions are assumed to be equivalent in terms of costs to the new construction ones even if, generally, retrofit interventions require lower costs than the new construction in Italy. Analogously to (Gaspar and Santos, 2015), the same value is adopted in this simulation to emphasize the impact of the solely environmental components on the cash-flow analysis results. As said, a Class A1 is adopted concerning the Italian Energy Performance Certificate labeling system for buildings and housing units. This last is deeply analyzed in the recent literature on the potential impact of energy performance capability over housing pricing processes (Barreca et al., 2021). Further, maintenance and replacement costs are derived from the experience and calculated as a percentage of the revenues. Running costs are calculated based on the standard mean consumption for A1 residential buildings. In contrast, the end-of-life costs are dimensioned, assuming the dismantling and disposal costs are at the end of the building service life.

Conversely, the incomes are quantified by market rents for the rental segment in Turin (Northern Italy).

Finally, the financial data were defined by assuming a discount rate referred to the rental market condition in Northern Italy, conscious about the limits of this assumption as discussed in a contribution correlated to this work, presented in this Symposium (Fregonara and Ferrando, 2024). A lifespan of 30 years is assumed as a time horizon for the analysis.

The simulation results are synthesized in Table 2:

Table 2. Simulation results.

Indicator	Unit of measurement	Upcycling scenario	Reconstruction scenario
NPV	€	46,316.40	4,450.77
IRR	%	6.80	6.53

The Analysis results, expressed through the synthetic indicators NPV and IRR, show the preferability of the upcycling scenario. This result is expected, considering the equal conditions for all the other input assumptions. Further, even in the presence of a different construction/retrofit unit cost in the reconstruction or upcycling scenario, the retrofit would be preferred due to the lower cost entity in the generality of the cases. Nevertheless, according to the aim of this work, the simulation highlights the weight of the environmental cost items, even from the financial perspective.

Moreover, the reconstruction activity implies EE losses with the dismantling and disposal of the building, beyond that of Embodied Carbon (CO_2 in our case) avoided by recycling materials/components/system. In our case, the CO_2 impacts the results with a less significant incidence, partly because the CO_2 produced in the construction/retrofit execution stage is not included in the calculation.

Summing up, upcycling is preferable, even from an environmental-financial viewpoint.

4. Conclusions

The operative modality illustrated in this work aims to support buildings management activities, considered in a life-cycle perspective, by considering the environmental impacts implied in renovation, upcycling and reconstruction interventions, besides the financial ones. Particularly, the application of both economic and environmental criteria in public/private decision-making processes can represent a substantial step toward the ecological transition. Furthermore, it can support private investors' or public policy-makers decisions by considering the potential increase in property value due to the decreasing energy cost and CO_2 emissions, giving a contribution to growing the efforts toward the implementation of environmental and energy policies, normed by the regulatory framework at the European and international level. Moreover, it can promote the use of materials with a high impact on quantifying the asset's residual value at the end-of-life stage, growing its residual energy potential. Thus, the proposed methodology can generate managerial and policy implications, supporting urban and territorial governance activities and public administrations in decision-making processes, at different scales: in public, private, and PPP interventions.

This last reasoning opens the way to further research and advancement towards quantifying the impact of environmental components on the value, according to a life cycle viewpoint and operatively from the Global Benefit formalization perspective. This address will be explored in a future piece of work.

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