An approach for handling environmental and economic conflicts in the context of sustainable building

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Abstract

When striving for sustainable buildings, the focus is often set on the optimization of the building environmental impact. In that perspective, the Life Cycle Assessment (LCA) method is widely used to calculate the environmental impact and through comparative studies, the preferred design options are chosen. As costs are however a very important issue in decision making, it is important to include costs in the analysis too. Although decisions are often only based on investment cost, we recommend considering also the life cycle cost (LCC) to guarantee long term affordability. This paper illustrates the importance of considering both aspects by discussing the optimisation of 16 representative residential buildings in Belgium from both an environmental and financial perspective. The question raises how to handle contradictions between the results of an LCA and LCC study of a building. The paper discusses and illustrates the promising approach of monetary valuation of environmental impacts. Recommendations are formulated based on the experience in the Belgian context.
Keywords: life cycle assessment, life cycle costing, monetary valuation, Pareto optimisation, weighting.

1 Introduction

There is a general consensus on the definition of sustainable development as defined by Gro Harlem Brundtland "*development that meets the needs of the present without compromising the ability of future generations to meet their own needs*" [1]. It is furthermore broadly recognised that sustainable development

enhances three important pillars: the environmental, economic and social pillar. Despite this general consensus, there is less agreement on how to quantify each of these or assess these in a qualitative way. Neither is there a widely supported approach on how to combine the three pillars into an overall assessment.

To date, we see a proliferation of sustainability assessment methods and certification labels for buildings. Each of these uses its own specific approach for assessing one or more of the three sustainability pillars. Within this large set of available methods/certification systems we can distinguish (category 1) methods that focus in detail on one of the three pillars (most of the time in a quantitative way) and (category 2) methods that address the three pillars in an overall but more subjective way (most of the time semi-quantitatively, i.e. based on a multi-criteria analysis).

Within the *first category of quantitative methods* focusing mainly on a single sustainability pillar, most often a life cycle approach is followed. The *assessment of the environmental impacts* is most advanced. A life cycle assessment (LCA) is often used. The wide recognition of this method by the scientific committee is clear from the international standards ISO 14040 [2] and ISO 14044 [3]. In the specific context of sustainable construction, this is reflected in the European Standard EN15804 [4]. Many LCA studies of construction products moreover prove the applicability and viability of the method, amongst others by Aktas and Bilec [5], Blengini and Di Carlo [6], Jönssen *et al.* [7], Li *et al.* [8] and Stazi *et al.* [9]. Also for the assessment of the *economic issues* a life cycle approach is possible by using the well-established life cycle costing (LCC) approach. As defined by the building and construction assets standard ISO 15686, it enables the calculation of "*the total cost of a building or its parts throughout its life, including the costs of planning, design, acquisition, operations, maintenance and disposal, less any residual value*" [10]. The LCC method is also used in the European Standard prEN 16627 (current status: under approval) concerning the economic performance of buildings. The assessment of the *social aspects* is less advanced, but attempts are being made for a social life cycle assessment (S-LCA). This is for example reflected in the handbook '*Guidelines for Social Life Cycle Assessment of Products*' of UNEP/SETAC [11].

Within the environmental and social pillar there are typically several indicators assessed, expressed in different units. In consequence equilibrium needs to be found between comprehensiveness and simplification (for communication and decision taking reasons). Attempts are therefore made to combine the different indicators into a single score (index). Several approaches are followed. Two important ones in the terms of their wide application are normalisation combined with weighting on the one hand and monetary valuation on the other hand. Through normalisation the different indicators are compared to the impact of a common reference and hence are expressed in a dimensionless unit. Weighting means each of the indicators is assigned an importance and a single score is calculated based on the sum of the weighted normalised values. The single score is typically expressed in Ecopoints. Monetary valuation is an approach that expresses all indicators in a monetary unit (e.g. EURO). The environmental impacts are then expressed in external environmental

costs. Several methods exist for the calculation of these external environmental costs. An extensive overview of possible approaches is given by Huppes *et al.* [12]. The advantage of monetary valuation compared to normalisation/weighting is that these are expressed in the same unit as financial costs and hence environmental impacts and economic issues can be assessed simultaneously: these can be added up and decisions can be taken based on total costs (i.e. sum of environmental and financial costs). The approach of monetary valuation could furthermore be extended for the social pillar, by expressing social impacts in social external costs. This would hence allow taking straightforward decisions in case of contradictions based on the three sustainability pillars.

The second category of methods comprises of certification systems such as LEED [13], BREEAM [14] and the German DGNB [15]. These methods cover a broad range of indicators which are then translated in a single score via a (subjective) multi-criteria analysis.

Because the approach of monetary valuation seems promising in terms of a consistent approach for the three sustainability pillars, this method was explored for the assessment of buildings in the Belgian context. In the first phase, the method was limited to the environmental and economic issues through a combination of LCA and LCC. The approach used is further discussed and illustrated in this paper.

2   Objectives

One of the objectives of the research presented here was to search for the most preferred technical solutions for 16 representative dwellings in the Belgian context from both an environmental and financial perspective. It was investigated if decisions based on both criteria, were identical. If not, how decisions can be taken considering both criteria. A method is proposed combining both environmental and financial optimisation criteria, based on the Pareto principle. The methodological steps and insights are described in section 3 of this paper. Section 4 summarises the results of the implementation of the methodology to the 16 representative dwellings and the final, fifth section, summarises the main conclusions and formulates recommendations for an integrative assessment and further research.

3   Methodology

3.1 Environmental impact assessment

For the assessment of the life cycle environmental impacts of the 16 residential buildings, the LCA method was used. For a further explanation of the LCA methodology, we refer to the international standards and previously mentioned papers reporting LCA studies of building products and buildings. We will limit this section to a summary of the most important methodological decisions in our

study in order to allow for a correct interpretation of the results. The Swiss Ecoinvent database was used for the inventory of the environmental data. The data were moreover adapted to improve their representativeness for the Belgian context (i.e. by adapting the Swiss electricity mix and transport means to the European ones, done by VITO (Flemish Institute for Technological Research)). Several scenarios are needed when conducting an LCA study of a building. The main assumptions can be summarised as follows: building life span equals 60 years (with a sensitivity analysis of 30 and 120 years), the impacts during the construction phase were limited to material loss with an assumption of 5% on average for the different materials, the cleaning, maintenance and replacement activities differ for the different technical solutions and were determined based on a literature study (i.e. activities, frequencies) and the transport and end-of-life scenarios were determined based on surveys (by the Belgian Building Research Institute (BBRI)). More detailed data on each of the assumptions can be found in Allacker [16]. For the impact assessment we refer to the subsequent section.

3.2 Monetary valuation

The environmental external costs were mainly based on the willingness to pay approach and were retrieved by combining different existing methods. A detailed discussion on external costs, monetary values and an extended justification of the selected methods was elaborated in Allacker and De Nocker [17]. In summary, the environmental external cost referred to in this paper covers the impacts due to the emission of CO_2-equivalents, SO_2, NO_x, PM2.5, NH_3, VOC; human health effects due to carcinogens, respiratory effects, radiation and ozone layer depletion; impact on ecosystem quality (acidification, eutrophication, ecotoxicity and land use); and finally depletion of resources (minerals and fossil fuels).

3.3 Life cycle costing (LCC)

Life cycle costing (LCC) is a well-known and broadly accepted method to assess the life cycle costs of products in general, and buildings in specific. An LCC study takes into account the costs of a building over its entire life span. These costs obviously occur at different moments in time and hence their present value is calculated in order to determine the total life cycle cost of a building (i.e. sum of the present values of all costs). As it is unknown how costs will evolve in time, assumptions are needed regarding several economic parameters. For a further explanation on all sources used and assumptions made we refer to a previous paper by Allacker [18] and Allacker and De Troyer [19].

3.4 Pareto optimisation (2 dimensions)

As the aim of the study was to search for the most optimal technical and constructive composition, several alternatives were defined for each building and a comparative analysis was made. The alternatives for each dwelling ranged in insulation level, air-tightness, construction technique (i.e. solid versus

skeleton) choice of building materials and choice of technical services. For each of the dwellings, about 23,000 variants were analysed.

For each of these variants, the external environmental cost and financial cost were determined for both the construction phase (initial cost) and life cycle (life cycle cost) of the building. In a subsequent step a Pareto optimisation was made based on minimum life cycle cost and minimum investment cost. This allowed searching for these options which led to the highest reduction in life cycle cost for the lowest increase in investment cost. For each of the dwellings a set of Pareto optima were defined for the environmental impact, financial cost and total cost (i.e. sum of the environmental and financial cost). This is illustrated in figure 1 for the environmental cost for one of the detached dwellings. The Pareto optima were determined for the two construction techniques separately. The absolute optimum on both Pareto fronts was defined as the option with the lowest life cycle cost (assuming there was no budget restriction). As it was however noticed that the "end" of the Pareto front very often had a weak slope (i.e. nearly horizontal), also a sub-optimum was defined. This is the option on the Pareto front at the end of the steep slope (i.e. still a high reduction in life cycle cost for a relatively small increase in investment cost). This is elaborated in more detail in a previous publication by Allacker [18]. In the remaining of this paper only the sub-optima of the dwellings will be discussed. For the most important options in the cloud of solutions, the most relevant data are mentioned as well (i.e. initial financial cost, life cycle financial cost, K-value (reflecting insulation level and compactness) and E-value (energy performance).
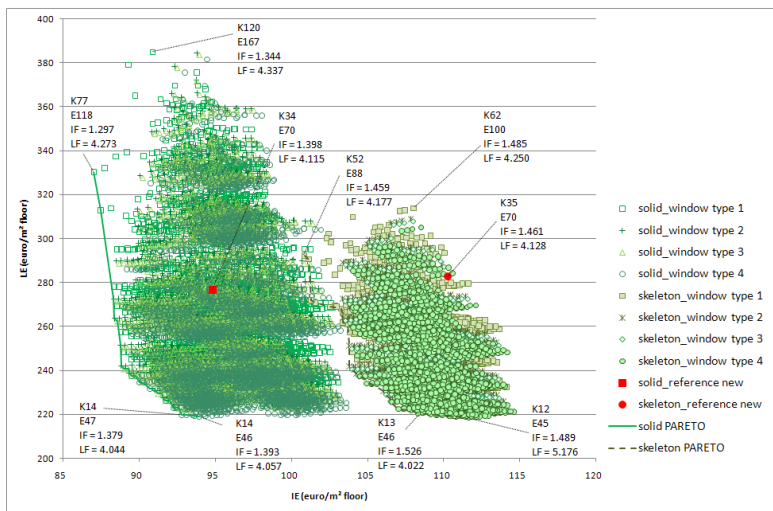

Figure 1: Detached dwelling type 1: Initial environmental (IE) and life cycle environmental cost (LE) of the analysed variants, indicating the Pareto optima [16].

3.5 16 case studies

A selection of 16 representative residential buildings was made based on a national statistical socio-economic survey conducted in 2001 [20]. The selected dwellings cover four types: detached houses, semi-detached houses, terraced houses and apartments. For each of these, representative dwellings were selected for four construction periods: before 1945, 1945–1970, 1971–1990 and 1991–2001. For each of the 16 buildings, a wide range of new-built dwellings were investigated (see previous section) and the Pareto optima were determined based on environmental, financial and total cost.

4 Results of case studies

The tables 1 to 4 represent the sub-optima from an environmental (EC), financial (FC) and total (TC) cost perspective for the 16 buildings. For the three sub-optima of each dwelling the technical solution for the different building elements (i.e. floor on grade, outer wall, flat roof, pitched roof, window) are shown in the columns 3 to 7. These are indicated by their symbol (i.e. GRFL, OW, FR, PR and WIN respectively) and a number. The different numbers indicate different technical solutions. The aim here is only to show different choices, the exact representation of each of the numbers is not elaborated here, but can be found in Allacker [16]. Columns 8 and 9 represent the K-value and E-value respectively. The lower the K and E values, the lower the thermal losses and the lower the net energy demand. Columns 10 to 15 represent the initial (IE, IF, IT) and life cycle cost (LE, LF, LT) from an environmental, financial and total perspective.

The results illustrate that for all dwellings, the sub-optima from an environmental perspective differ from the financial sub-optima. We furthermore see that for 8 of the 16 dwellings, the sub-optima based on total cost differ from the financial sub-optima. For these dwellings, the internalisation of the environmental external cost hence has an influence on decision taking.

A detailed analysis of the Pareto optima moreover revealed that environmental and financial priorities differ. Measures which lead to a reduction in life cycle external cost do not always imply a reduction in life cycle financial cost. Despite this difference in priorities, the analysis also showed that for most dwellings, the environmental sub-optima led for 10 of the 16 dwellings to a reduction in life cycle financial cost. Moreover, only a small increase (6% on average) in financial investment cost was noticed.

5 Conclusions and recommendations

In the analysis, within the hypotheses mentioned above, of the 16 representative residential buildings in Belgium discrepancies are noticed between the importance of the different life cycle phases and processes in terms of environmental and financial costs. While a reduction in the heating demand is the highest priority from an environmental point of view, reducing the cleaning and maintenance cost should be primarily reduced from a financial perspective.

Table 1: Detached houses: sub-optima based on environmental cost (EC), financial cost (FC) and total cost (TC).

		floor on grade	outer wall	flat roof	pitched roof	window	K	E	IE	LE	IF	LF	IT	LT
											€/m² floor			
Dwelling 1	EC	GRFL3	OW9	FR3	PR5	VAR4	14	47	93	220	1379	4044	1472	4264
	FC	GRFL3	OW2	FR1	PR11	VAR2	21	54	98	235	1398	3949	1496	4184
	TC	GRFL3	OW2	FR3	PR5	VAR2	19	51	96	228	1408	3945	1505	4173
Dwelling 2	EC	GRFL3	OW9		PR5	VAR4	16	48	85	205	1408	4244	1493	4449
	FC	GRFL3	OW2		PR10	VAR2	26	55	87	252	1399	4150	1486	4402
	TC	GRFL3	OW2		PR11	VAR2	25	54	87	219	1402	4147	1489	4366
Dwelling 3	EC	GRFL3	OW9	FR3		VAR3	24	60	74	187	1109	3447	1184	3634
	FC	GRFL3	OW8	FR1		VAR2	31	63	81	205	1041	3373	1121	3577
	TC	GRFL3	OW8	FR1		VAR2	31	63	81	205	1041	3373	1121	3577
Dwelling 4	EC	GRFL3	OW9		PR5	VAR4	16	30	89	169	1579	4349	1668	4518
	FC	GRFL3	OW2		PR10	VAR2	26	54	87	209	1294	3783	1381	3992
	TC	GRFL3	OW2		PR10	VAR2	26	54	87	209	1294	3783	1381	3992

Note: IE = Initial Environmental cost, LE = Life cycle Environmental cost.
IF = Initial Financial cost, LF = Life cycle Financial cost.
IT = Initial Total cost (IT = IF+IE), LT = Life cycle Total cost (LT = LF+LE).
K-value = indication of the building insulation level, E-value = indication of the building energy performance.

Table 2: Semi-detached houses: sub-optima based on environmental cost (EC), financial cost (FC) and total cost (TC).

		floor on grade	outer wall	flat roof	pitched roof	window	K	E	IE	LE	IF	LF	IT	LT
											€/m² floor			
Dwelling 1	EC	GRFL3	OW9		PR5	VAR4	15	22	90	149	1746	4631	1836	4780
	FC	GRFL3	OW2		PR10	VAR2	22	53	87	199	1319	4191	1406	4390
	TC	GRFL3	OW3		PR11	VAR2	19	43	89	176	1352	3857	1440	4033
Dwelling 2	EC	GRFL3	OW9	FR3	PR5	VAR4	13	49	65	155	1020	3070	1085	3225
	FC	GRFL3	OW3	FR3	PR11	VAR2	18	53	68	161	1026	3009	1094	3170
	TC	GRFL3	OW3	FR3	PR11	VAR2	18	53	68	161	1026	3009	1094	3170
Dwelling 3	EC	GRFL3	OW9	FR3	PR5	VAR4	15	51	68	169	1136	3494	1204	3662
	FC	GRFL3	OW2	FR1	PR10	VAR2	23	59	70	182	1133	3425	1203	3607
	TC	GRFL3	OW2	FR3	PR5	VAR2	20	56	70	177	1141	3421	1211	3598
Dwelling 4	EC	GRFL3	OW9	FR3	PR5	VAR4	14	49	76	190	1096	3294	1172	3484
	FC	GRFL3	OW2	FR1	PR10	VAR2	21	56	79	204	1092	3228	1171	3433
	TC	GRFL3	OW3	FR3	PR10	VAR2	16	51	79	195	1107	3221	1186	3416

Note: IE = Initial Environmental cost, LE = Life cycle Environmental cost.
IF = Initial Financial cost, LF = Life cycle Financial cost.
IT = Initial Total cost (IT = IF+IE), LT = Life cycle Total cost (LT = LF+LE).
K-value = indication of the building insulation level, E-value = indication of the building energy performance.

Table 3: Terraced houses: sub-optima based on environmental cost (EC), financial cost (FC) and total cost (TC).

	floor on grade	outer wall	flat roof	pitched roof	window	K	E	IE	LE	IF	LF	IT	LT
										€/m² floor			
Dwelling 1 EC	GRFL3	OW9		PR5	VAR4	12	40	79	152	1223	3587	1302	3739
FC	GRFL3	OW2		PR10	VAR2	19	56	73	167	1139	3460	1212	3627
TC	GRFL3	OW2		PR10	VAR2	19	56	73	167	1139	3460	1212	3627
Dwelling 2 EC	GRFL3	OW9		PR5	VAR4	11	64	51	113	937	2769	989	2881
FC	GRFL3	OW2		PR10	VAR2	20	71	52	123	921	2716	973	2839
TC	GRFL3	OW2		PR11	VAR2	19	70	52	123	923	2714	975	2837
Dwelling 3 EC	GRFL2	OW9	FR4		VAR4	13	59	42	95	810	2597	851	2691
FC	GRFL3	OW2	FR1		VAR2	21	62	44	106	786	2542	830	2648
TC	GRFL3	OW2	FR1		VAR2	21	62	44	106	786	2542	830	2648
Dwelling 4 EC	GRFL3	OW9	FR3	PR5	VAR4	13	52	54	125	845	2534	899	2659
FC	GRFL3	OW2	FR1	PR10	VAR2	20	57	55	133	836	2501	891	2634
TC	GRFL3	OW2	FR1	PR11	VAR2	20	57	55	132	837	2500	892	2632

Note: IE = Initial Environmental cost, LE = Life cycle Environmental cost.
IF = Initial Financial cost, LF = Life cycle Financial cost.
IT = Initial Total cost (IT = IF+IE), LT = Life cycle Total cost (LT = LF+LE).
K-value = indication of the building insulation level, E-value = indication of the building energy performance.

Table 4: Apartments: sub-optima based on environmental cost (EC), financial cost (FC) and total cost (TC).

		floor on grade	outer wall	flat roof	window	K	E	IE	LE	IF	LF	IT	LT
										€/m² floor			
Apartment 1	EC	GRFL2	OW8	FR3	VAR4	14	59	72	190	1093	3703	1165	3892
	FC	GRFL2	OW8	FR1	VAR2	20	62	74	198	1067	3679	1141	3877
	TC	GRFL2	OW8	FR1	VAR2	20	62	74	198	1067	3679	1141	3877
Apartment 2	EC	GRFL1	OW8	FR3	VAR4	20	69	72	189	1336	3929	1408	4118
	FC	GRFL1	OW1	FR1	VAR2	33	76	73	202	1287	3814	1361	4015
	TC	GRFL0	OW8	FR1	VAR2	32	76	71	202	1256	3856	1327	4058
Apartment 3	EC	GRFL1	OW9	FR3	VAR4	14	66	97	210	1342	4144	1439	4354
	FC	GRFL0	OW2	FR1	VAR2	25	70	99	220	1330	4064	1429	4284
	TC	GRFL2	OW2	FR3	VAR2	23	69	98	217	1334	4062	1432	4279
Apartment 4	EC	GRFL0	OW8	FR3	VAR4	28	74	92	162	1608	4156	1700	4318
	FC	GRFL0	OW8	FR1	VAR2	42	83	92	174	1564	4109	1656	4283
	TC	GRFL0	OW8	FR1	VAR2	42	83	92	174	1564	4109	1656	4283

Note: IE = Initial Environmental cost, LE = Life cycle Environmental cost.
IF = Initial Financial cost, LF = Life cycle Financial cost.
IT = Initial Total cost (IT = IF+IE), LT = Life cycle Total cost (LT = LF+LE).
K-value = indication of the building insulation level, E-value = indication of the building energy performance.

This difference in priorities confirms the need for an overall assessment of both environmental impacts and financial costs.

The analysis furthermore clarified that the optimum insulation level and optimum energy performance level differ from an environmental and financial point of view. From an environmental perspective we should strive for higher insulation levels and a better energy performance of our buildings than from a financial perspective. The net energy demand of the optima from a financial perspective equals on average 41 kWh/m² floor, year. From an environmental perspective it equals 28 kWh/m² floor, year.

Sensitivity analysis of the life span confirmed the importance of this parameter as different results were obtained for a building life span of 30 years compared to a building life span of 60 years. Lower optimal insulation levels were identified when considering a shorter building life span. The results were however approximately identical for a life span of 60 and 120 years.

The analysis finally revealed that the environmental cost represents only 5 to 10% of the total life cycle cost. The highest contribution of the environmental cost was noted for heating (approximately 30% of the total cost). Based on this result we can conclude that adding the environmental external cost to the financial cost would not lead to unaffordable housing, except for dwellings with a high energy demand.

We would like to conclude that environmental external costs is promising because (a) it is an easy communication tool (i.e. EURO is easy to understand) and (b) it allows to make overall decisions based on environmental and financial costs. However, we would also like to stress the importance of considering environmental and financial costs separately as environmental costs (calculated with our approach) proved to be relatively low compared to financial costs. They hence only play a minor role in decisions based on total costs. Considering both separately allows checking the priorities from both an environmental and financial perspective and hence allows gaining insights in both issues.

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