Interreg North-West Europe
FCRBE
European Regional Development Fund

EX-POST ANALYSIS OF 32 CONSTRUCTION AND RENOVATION WORKS

RESULTS AND DISCUSSIONS

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https://vb.nweurope.eu/fcrbe

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Interreg North-West Europe FCRBE
European Regional Development Fund

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TABLE OF CONTENT

1° METHODOLOGY

1.1 Context

This document details the approach used to analyse the reuse rates achieved by 32 construction and renovation projects that have successfully reused building materials and elements. A particular feature of this analysis is that the reuse rates were calculated post facto, i.e. for projects that had already been completed.

It is one of the four reports produced within the FCRBE project as part of the work on reuse (and reclamation) rates. The four documents are as follows:

1. *Set, monitor and report on reclamation and reuse rates in construction projects. A common approach.* This document sets out the necessary definitions and presents the main methodological aspects for dealing with the issue of reuse and reclamation rates.

2. E*x-post analysis of 32 construction and renovation works. Results and discussions.* This is the present document. It sets out how we calculated and analysed the reuse rates achieved in a sample of 32 recently completed projects.

3. *32 detailed project sheets. Projects info, reused rates and reused elements.* This document complements the analysis presented here below. It details the results achieved in each project with regards to their specificities. It also provides a detailed overview of the quantity and nature of reused elements.

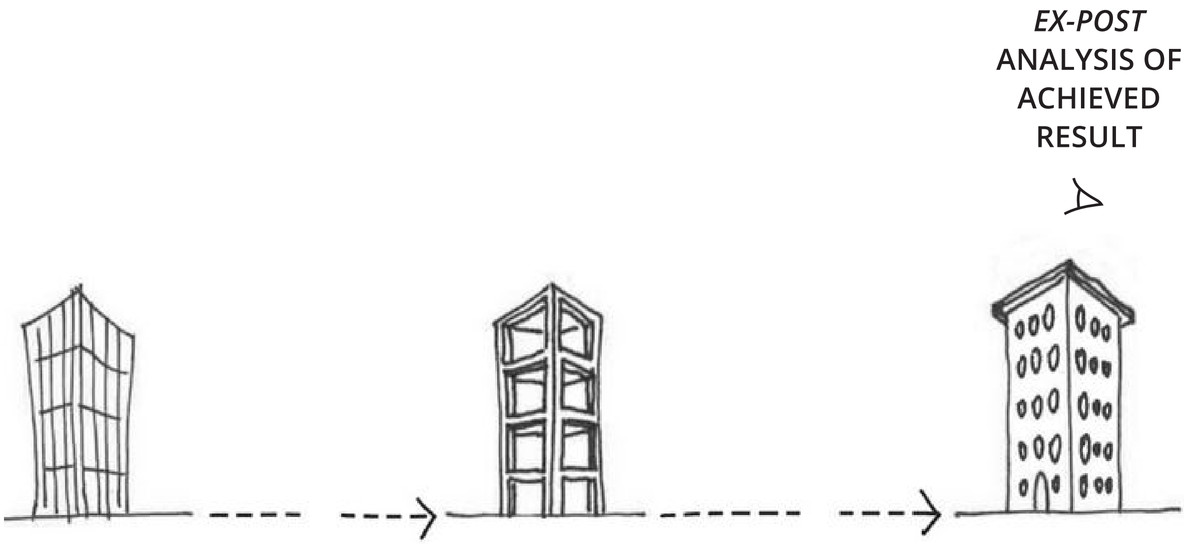
4. *Live tests. Report on 4 operations using reuse targets.* This last document reports on live tests which explored how to implement reuse rates in various procurement procedures.

Most of the projects we analysed here had not explicitly set a reuse rate as an objective to be achieved at the start of the project (as set out in *Set, monitor and report on reclamation and reuse rates in construction projects*). However, most of them had formulated qualitative and open-ended reuse targets, which our ex-post analysis makes it possible to quantify[1].

Our aim in analysing these 32 projects was to learn about the reuse rates achievable in different contexts and to see whether it was possible to infer from them indicative rates that would be useful in supporting the formulation of quantitative targets in future projects.

Our analyses focus only on the reuse rate. This corresponds to the fraction of materials reused in relation to all the materials needed to carry out the work (see chapter 2 of *Set, monitor and report on reclamation and reuse rates in construction projects*). According to the stock-flow model developed in our general method, our analyses therefore focus only on the flow in. We have not analysed the reclamation rate (related to the flow out) or calculated the preservation rate (related to the retained stock, i.e. the part of the original buildings that has not been demolished) for the projects we have analysed. This is not to say that no effort has been made in these areas. Quite the opposite, in fact! However, our objective was to provide input into the way in which construction and renovation work can foster the adoption of reuse practices. This explains the focus of our approach.

1- Some of the projects analysed had already carried out a quantitative assessment of their reuse efforts. Where available, these assessments were a valuable source of information for our own analysis. However, to ensure a consistent approach across our 32 projects, we generally had to repeat this analysis.


EX-POST
ANALYSIS OF
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RESULT

1.2 Collect the data

The first stage of the analysis consisted in identifying a sample of completed projects that had applied reuse (see below chapter 2). The next step was to gather data on the material flows that had been used in the project. We wanted to know the nature and quantity of these materials.

In theory, this type of information can be deduced from an as built file, containing in particular :

- The bill of quantities for the project.
- The specifications, which detail the type of materials required and how they are to be installed.
- The final plans, which complete the information on quantities.
- The technical data sheets for the equipment installed, detailing the characteristics of the elements actually used.

In practice, for several projects, we were only able to collect part of these documents, but this did not prevent us from carrying out the analyses on the basis of a few clearly formulated working hypotheses (see below Appendix 1).

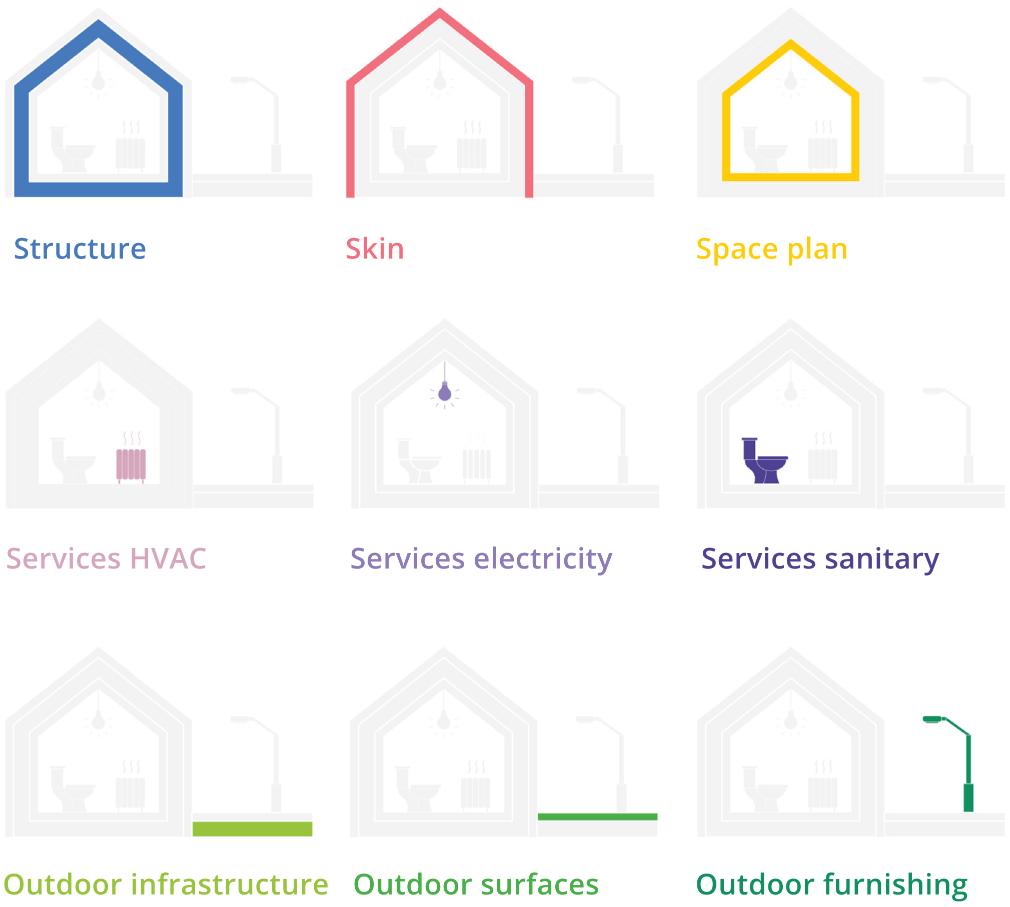
1.3 Subdivision into layers

In our approach, we have chosen to work with a re-use rate expressed per layer[1]. We used the following layers:

- Structure.
- Skin.
- Space plan.

1- Stewart Brand, *How Buildings Learn: What Happens After They're Built* (Viking Press, 1994).

- Services - HVAC.
- Services - electricity.
- Services - sanitary.
- Outdoor infrastructure.
- Outdoor surfaces.
- Outdoor furniture.



In our analysis, we have left out furniture, which corresponds to the Stuff layer in Brand's model (in *How Buildings Learn: What Happens After They're Built*, Viking Press, 1994).

This enabled us to ensure, for the most recurrent layers, greater comparability between projects despite a relatively small sample. It was also a way of focusing on the most relevant parts of the projects – those that had actually been reused – thus making the analysis work somewhat easier.

In practice, for each project, we relied on the bill of quantities. For each line, we specified:

- Whether the element was new or reused.

- To which layer the element belonged.

In some projects, the initial subdivision of the bill of materials corresponded fairly well to the layer structure we had adopted. In other cases, it was necessary to reorganise the bill of quantities according to our layers – a division that necessarily involves making choices (some elements being open to interpretation) and then being transparent and consistent with these choices.

☞ Only layers containing reuse were analysed in detail. This is why, with a few exceptions, we cannot express the rate of reuse achieved at the scale of an entire project.

Example: let's imagine a new-build project where all the effort comes down to reusing 10 interior doors and 10 washbasins. In this case, we concentrated our analysis on the following layers: space plan and services sanitary. However, for each of these layers, we analysed the entire flow of materials involved (i.e. new and reused materials).

The other layers were not analysed in detail, as we already knew that their reuse rate was 0%.

1.4 Calculation of the total mass of materials per layer and calculation of the reuse rate

Once the bills of quantities had been adapted according to our layers, we proceeded to calculate the reuse rate. To do this, we assigned a weight to each line of the bill of quantities belonging to a layer concerned by reuse.

We chose to work on a mass basis in order to have a homogeneous unit that would allow us to compare elements that are otherwise very diverse. Although this choice is not without bias[1], these are largely mitigated by the subdivision into layers. It avoids mixing elements with masses of too dissimilar orders of magnitude (100 m^3 of poured concrete screed with a dozen nylon door handles, for instance).

In practice, it turns out that the mass of materials is rarely indicated as such in bills of quantities. Quantities are generally expressed in various units (mc, m^2, m^3, pc, etc.). A conversion is therefore necessary to obtain the mass of the materials, which is used to calculate reuse rates.

In our analysis, we have made the conversion as follows:

1. For homogeneous materials, we have obtained the mass by multiplying the volume by the density (kg/m^3) (or, more rarely, the surface area by the mass per unit area (kg/m^2)). When it is not expressed as such, the volume is generally easy to calculate if the specifications of the materials concerned can be found. For example, a masonry structure expressed in surface area, where the thickness of the bricks is also known.

2. For composite materials and/or materials with volumes that are difficult to measure, the mass is obtained by multiplying the number of units by their unit mass.

Density and unit mass are also information that does not always appear as such in quantity surveys. We therefore have to look

1- These are detailed in the document describing the general method for setting reuse rates.

elsewhere for this information. To do this, we used the following elements, in order of preference:

1. Technical data sheets for the components concerned. An investigation into the plans, pictures, technical data sheets, as-built documents, etc. generally (but not always...) enabled us to find precise data.

2. If this specific information was not available, we relied on reference databases in which the density of materials is expressed (in most cases, these were databases designed to express the environmental impact of materials, see appendix 1 below).

3. Specific assumptions. Where specific information was not available, nor was it possible to rely on standard data, we made assumptions, usually relying on data from comparable items. These assumptions are mentioned and sourced in our reference database.

Once we had identified all the elements making up a layer concerned by reuse, we calculated its total mass, including the mass of the reused elements. A simple division then allows us to establish the rate of reuse achieved within a given layer.

Example :

ID	Description	Data	Unit	Quantity	Reuse or new?	Layer	Mass (kg)	Source
N	Application N							
N.1	Component 1	Thickness = 0.01 m, ρ = 1000 kg/m³	m²	100	Neuf ▼	Space plan ▼	1.000	Thickness = technical sheet from the manufacturer. Volumic mass = idem..
N.2	Component 2	Thickness = 0.01 m, ρ = 1000 kgm³	m²	100	Reuse▼	Space plan▼	1.000	Thickness = project specification book. Volumic mass = database XYZ.
Total Mass Space Plan (kg)							2.000	
Total Mass Reuse for Space Plan (kg)							1.000	
Reuse rate (%)							50	

2° CORPUS OF PROJECTS

2.1 Projects selection

From a shortlist of around sixty projects, we have selected 32 on the basis of various selection criteria.

The first criterion was whether these projects had successfully reused building materials and elements. To identify them, we used several sources of information:

- Websites listing reuse projects (e.g. Opalis.eu).
- Pilot operations carried out in the first phase of the FCRBE project[1].
- Literature on the topic of reuse.

In addition, we made sure that these projects were evenly spread across the different countries of the FCRBE project area. In total, 14 projects were selected in Belgium, 9 in France, 8 in the Netherlands and 1 in the United Kingdom.

1- FCRBE, FCRBE Pilot Operations. 37 case studies on reclaiming and reusing building elements. Novembre 2021. Available online: https://vb.nweurope.eu/media/15788/37-po-summary-report_cv_low.pdf

Next, we focused on diversity in terms of programmes. The selected projects cover a wide range of functions (see section 2.3). We felt that looking exclusively at office projects, for example, would not be sufficiently representative. In addition, we sought to strike a balance between new builds and renovations (which we will see later is a very significant factor in the reuse rates that can be achieved). However, we have tried to obtain a certain number of projects for the different types of work envisaged, in order to have some points of comparison.

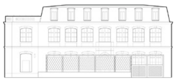
Another criterion was the conditions for replicability of the selected projects. As far as possible, we opted for projects that fit into relatively common contexts, avoiding projects carried out in somewhat exceptional circumstances (a student workshop, for example) or those with exorbitant budgets. Our aim was to give priority to projects that were as close as possible to current practice (although this point is open to discussion, see section 4.2).

We have also focused on relatively recent projects.The oldest, Bedzed, was completed in 2002.

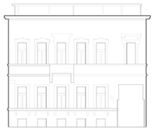
Finally, we have sought to diversify the scale of the projects, ranging from buildings of just a few square metres to work with a total surface area of several tens of thousands of square metres, or even outdoor developments covering several hectares.

It should be pointed out that our overall selection was somewhat constrained by issues of access to information. Some pre-selected projects did not respond to our requests.

2.2 The projects


Maison des Canaux


Grande Halle Colombelle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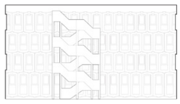
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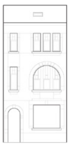
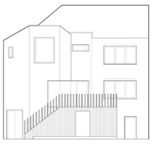
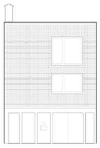
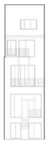
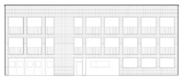

Warland

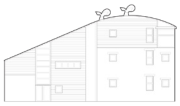

Clos Dupont

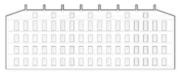

Maison Vignette


Rue de l'est

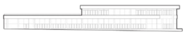

Dethy


Cohousing De Schilders

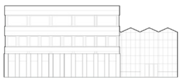

Bedzed

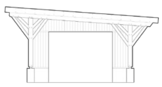

Caserne de Reuilly


Clinic of Emergis child & youth

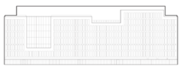

Circl' Pavilion


Mundo Madou


Biopartner 5


Déchèterie de Kaysersberg


Botany institute Liège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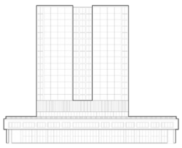
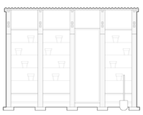
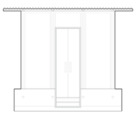
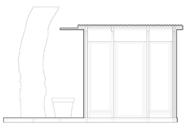
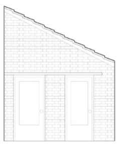
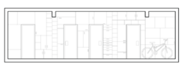

Multi


Green house


Circular Pavilion

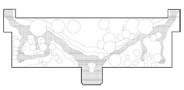

Tree house

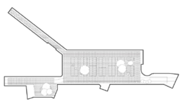

Bloc sanitaire Chiro

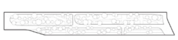

VLA office


Local Droits et habitat

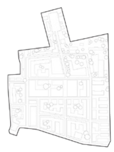

La Fabrique Ressourcerie


Caserne de Reuilly


Place communale de Molenbeek


Croeselaan


Cremerstraat


Caserne Mellinet

2.3 Projects clusters

In order to improve comparability between projects and to refine the analysis of the results of the 32 projects, we have grouped them into 5 clusters:

1. Renovations for social and cultural facilities.
2. Housing.
3. Tertiary buildings.
4. Micro-projects and demonstrators.
5. Outdoor spaces.

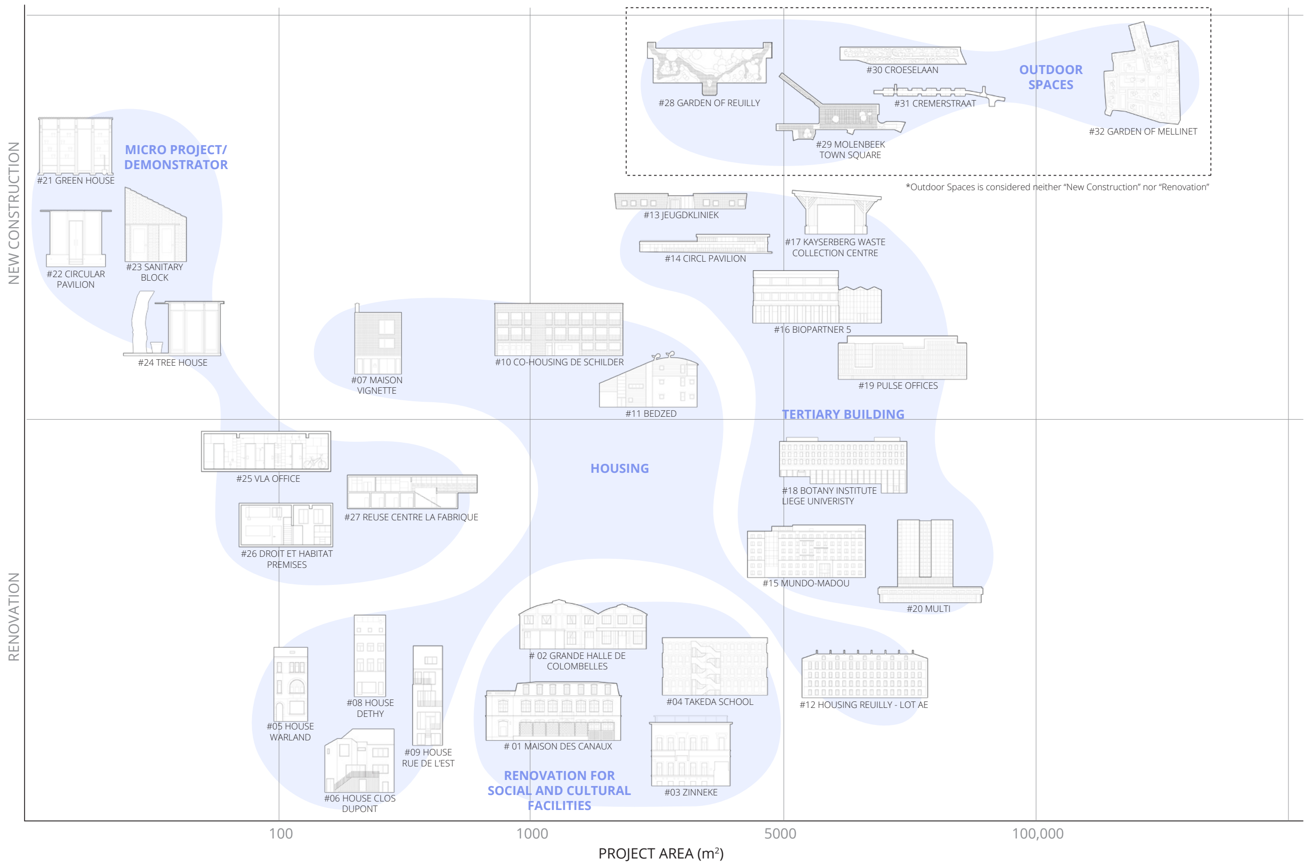
These clusters were defined on the basis of the initial selection of projects. They were developed during a participatory workshop involving several of the FCRBE project's partners. After a presentation of each project, the participants used various factors to bring the 32 projects together. The factors were as follows:

- Programme.
- Nature of the work.
- Scale of the projects.
- Architectural approaches.

Some of these factors were decisive for certain clusters and less so for others. For example, the question of the scale of the projects (approached through their floor area) was decisive for category no. 1 (conversion of existing buildings to house socio-cultural activities), which groups together projects of a similar scale, but less so for category no. 2 (housing), which includes both small detached houses and collective housing.

These categories are neither fixed nor entirely exhaustive. They are, however, useful for analysing and interpreting the reuse rates actually achieved.

FCRBE CASE STUDY ANALYSIS



Classification of the 32 projects according to surface area and whether they are new builds or renovations.
Projects involving the development of outdoor spaces are classified according to surface area but not according to whether they are new or renovated, which does not apply to these projects.

3° RESULTS

3.1 Table of the reuse rates

This table (see next page) shows the overall reuse rates in the 32 projects analysed. The columns (vertical) correspond to the projects. The horizontal lines correspond to our different layers.

The columns are grouped by cluster and, within each cluster, the projects are sorted in ascending order of surface area.

We used a five-colour gradient to highlight the reuse rates achieved:

The application of this colour code highlights a number of general observations:

- For example, it is very clear that projects in the Micro Projects and Demonstrators cluster achieve high reuse rates in several layers.

- Or that the category of outdoor facilities / public spaces only concerns 3 layers.

	Maison des Canaux	Grande Halle de Colombelles	Zinneke	Takeda school	House Warland	House Clos Dupont	House Vignette	House Dethy	House Rue de l'Est	Cohousing de Schilders	Housing BedZed	Housing Reuilly (Lot Ae)	Jeugdkliniek	Circl Pavilion	Mundo-Madou
Cluster	Renovation for social and cultural facilities				Housing										
Project Surface (m²)	1.009	3.650	4.000	4.000	160	200	255	255	290	1.200	2.500	6.330	3.334	3.350	6.500
New construction							TRUE			TRUE	TRUE		TRUE	TRUE	
Layers with reuse	8	4	7	1	4	5	2	4	2	1	2	2	4	2	1
Project ID	#01	#02	#03	#04	#05	#06	#07	#08	#09	#10	#11	#12	#13	#14	#15
Structure															
Total mass layer (kg)	20.133	not calc.	178.130	not calc.	16.968	not calc.	not calc.	19.080	not calc.	not calc.	12.709.000	not calc.	301.674	9.308.260	not calc.
Reused mass layer (kg)	8.674	0	11.590	0	1.388	0	0	2.784	0	0	98.000	0	28.915	0	0
Reuse rate (%)	43,08%	0,00%	6,51%	0,00%	8,18%	0,00%	0,00%	14,59%	0,00%	0,00%	0,77%	0,00%	9,58%	0,00%	0,00%
Skin															
Total mass layer (kg)	1.505	18.721	23.296	not calc.	not calc.	11.325	36.883	26.157	15.966	160.414	2.517.000	not calc.	244.996	357.892	not calc.
Reused mass layer (kg)	300	0	4.526	0	0	7.595	5.412	585	5.056	89.238	0	0	19.402	0	0
Reuse rate (%)	19,94%	0,00%	19,43%	0,00%	0,00%	67,06%	14,67%	2,24%	31,66%	55,63%	0,00%	0,00%	7,92%	0,00%	0,00%
Space Plan															
Total mass layer (kg)	30.157	358.841	60.870	62.895	18.162	4.855	38.321	34.016	125.279	not calc.	1.852.000	1.343.958	62.020	1.466.998	128.746
Reused mass layer (kg)	15.468	3.744	12.770	16.540	3.095	405	3.207	2.183	2.355	0	182.000	25.686	833	63.123	31.342
Reuse rate (%)	51,29%	1,04%	20,98%	26,30%	17,04%	8,34%	8,37%	6,42%	1,88%	0,00%	9,83%	1,91%	1,34%	4,30%	24,34%
Service - HVAC															
Total mass layer (kg)	8.027	13.391	22.471	not calc.	2.800	2.262	not calc.	3.310	not calc.	not calc.	32.500	32.428	43.342	43.550	not calc.
Reused mass layer (kg)	61	6.952	1.990	0	825	82	0	336	0	0	0	8.500	0	0	0
Reuse rate (%)	0,76%	51,92%	8,86%	0,00%	29,46%	3,64%	0,00%	10,15%	0,00%	0,00%	0,00%	26,21%	0,00%	0,00%	0,00%
Rule of thumb used						TRUE		TRUE			TRUE		TRUE	TRUE	
Service - Elec															
Total mass layer (kg)	683	not calc.	16.207	not calc.	not calc.	not calc.	not calc.	1.018	not calc.	not calc.	10.000	not calc.	13.336	13.400	not calc.
Reused mass layer (kg)	129	0	207	0	0	0	0	0	0	0	0	0	312	0	0
Reuse rate (%)	18,91%	0,00%	1,28%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	2,34%	0,00%	0,00%
Rule of thumb used			TRUE					TRUE			TRUE		TRUE		
Service - Sanitary															
Total mass layer (kg)	248	3.702	4.424	not calc.	480	44	765	764	not calc.	not calc.	7.500	not calc.	10.002	10.050	not calc.
Reused mass layer (kg)	132	1.499	824	0	405	30	30	0	0	0	0	0	0	0	0
Reuse rate (%)	53,25%	40,49%	18,63%	0,00%	84,38%	67,77%	3,92%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
Rule of thumb used								TRUE			TRUE		TRUE	TRUE	
Outdoor - Infrastructure															
Total mass layer (kg)	7.754	N/A	42.375	N/A	N/A	not calc.	not calc.	N/A	not calc.	not calc.	3.676.000	N/A	N/A	N/A	N/A
Reused mass layer (kg)	0		0			0	0		0	0	0				
Reuse rate (%)	0,00%		0,00%			0,00%	0,00%		0,00%	0,00%	0,00%				
Outdoor - Surfaces															
Total mass layer (kg)	130.947	N/A	36.964	N/A	N/A	872	not calc.	N/A	not calc.	not calc.	1.038.000	N/A	N/A	112.646	N/A
Reused mass layer (kg)	130.947		6.370			773	0		0	0	3.000			97.410	
Reuse rate (%)	100,00%		17,23%			88,67%	0,00%		0,00%	0,00%	0,29%			86,47%	
Outdoor - Furnishings															
Total mass layer (kg)	2.317	N/A	N/A	N/A	N/A	not calc.	not calc.	N/A	not calc.	not calc.	not calc.	N/A	N/A	N/A	N/A
Reused mass layer (kg)	1.955					0	0		0	0	0				
Reuse rate (%)	84,39%					0,00%	0,00%		0,00%	0,00%	0,00%				
Total reuse rate (when available)															
Total mass of materials (kg)	201.771		384.737		38.410	19.358	75.970	84.345	141.245	160.414	21.842.000	1.376.386	675.369	11.312.795	128.746
Total mass of reused mater	157.666	12.195	38.277	16.540	5.713	8.885	8.649	5.888	7.410	89.238	283.000	34.186	49.462	160.533	31.342
Total reuse rate (%)	78,14%		9,95%		14,87%						1,30%		7,32%	1,42%	24,34%
Total mass of reused mater	156	3	10	4	36	44	34	23	26	74	113	5	15	48	5

Légende

Category 1 : Renovations for social and cultural facilities

Category 2 : Housing

Biopartner 5	Kaysersberg waste collection centre	Botany Institute Liège University	Pulse offices	Multi	Green House	Circular Pavilion	Sanitary block	Tree House	VLA office	Droit et habitat' premises	Reuse Centre La Fabrique	Garden of Reuilly	Molenbeek town square	Croeselaan	Cremerstraat	Garden of Mellinet
Tertiary building					Micro project / Demonstrator							Outdoor spaces				
6.827	7.535	8.600	33.588	45.120	7,7	7,7	18	24	100	135	204	4.820	6.300	13.599	12.000	130.000
TRUE	TRUE		TRUE		TRUE	TRUE	TRUE	TRUE				/	/	/	/	/
4	5	3	1	2	3	3	4	4	6	4	2	2	1	2	2	2
#16	#17	#18	#19	#20	#21	#22	#23	#24	#25	#26	#27	#28	#29	#30	#31	#32
4.595.763	1.673.287	not calc.	not calc.	not calc.	2.288	7.949	20.936	3.782	93	2.694	1.573	N/A	N/A	N/A	N/A	N/A
159.000	29.345	0	0	0	2.278	7.366	261	3.782	93	0	0					
3,46%	1,75%	0,00%	0,00%	0,00%	99,54%	92,67%	1,25%	100,00%	100,00%	0,00%	0,00%					
1.464.334	not calc.	512.509	not calc.	2.868.153	1.114	1.162	9.454	340	1.764	378	N/A	N/A	N/A	N/A	N/A	N/A
411.171	0	33.774	0	93.455	1.114	1.039	5.263	273	497	0						
28,08%	0,00%	6,59%	0,00%	3,26%	100,00%	89,40%	55,67%	80,41%	28,17%	0,00%						
2.769.893	64.832	not calc.	2.695.204	9.005.503	52	192	939	576	6.583	9.430	10.274	N/A	N/A	N/A	N/A	N/A
82.252	873	0	543.630	115.524	52	192	375	576	5.625	915	2.263					
2,97%	1,35%	0,00%	20,17%	1,28%	100,00%	100,00%	39,90%	100,00%	85,45%	9,70%	22,03%					
88.751	not calc.	not calc.	not calc.	not calc.	N/A	N/A	234	N/A	1.828	1.755	1.127	N/A	N/A	N/A	N/A	N/A
0	0	0	0	0			0		528	79	0					
0,00%	0,00%	0,00%	0,00%	0,00%			0,00%		28,88%	4,50%	0,00%					
TRUE							TRUE			TRUE						
27.308	not calc.	not calc.	not calc.	not calc.	N/A	N/A	72	N/A	400	540	739	N/A	N/A	N/A	N/A	N/A
0	0	0	0	0			0		40	36	0					
0,00%	0,00%	0,00%	0,00%	0,00%			0,00%		10,00%	6,74%	0,00%					
TRUE							TRUE			TRUE						
3.781	564	not calc.	not calc.	not calc.	N/A	N/A	177	51	300	239	165	N/A	N/A	N/A	N/A	N/A
285	143	0	0	0			167	39	5	165	53					
7,54%	25,35%	0,00%	0,00%	0,00%			94,42%	77,17%	1,67%	69,19%	32,15%					
N/A	not calc.	not calc.	N/A	N/A	N/A	N/A	173	N/A	N/A	N/A	N/A	not calc.	not calc.	6.894.657	not calc.	not calc.
	0	0					0					0	0	1.505.000	0	0
	0,00%	0,00%					0,00%					0,00%	0,00%	21,83%	0,00%	0,00%
N/A	1.447.010	65.590	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1.472.921	2.359.436	2.384.387	15.142.577	14.019.960
	10.340	14.431										543.840	2.254.414	115.000	3.851.037	2.477.534
	0,71%	22,00%										36,92%	95,55%	4,82%	25,43%	17,67%
N/A	7.591	55	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	256.976	not calc.	N/A	11.273	296.667
	706	12										1.000	0		1.260	229.730
	9,30%	22,20%										0,39%	0,00%		11,17%	77,44%
8.949.831	3.185.693	578.155		11.873.657	3.454	9.303	31.985	4.860	10.968	15.036	13.878	1.472.921	2.359.436	9.279.044		
652.708	41.407	48.217	543.630	208.978	3.444	8.597	6.066	4.781	6.695	1.196	2.316	544.840	2.254.414	1.620.000	3.852.297	2.707.264
7,29%					99,70%	92,41%	18,97%	98,39%	61,04%	7,95%	16,69%			17,46%		
96	5	6	16	5	447	1116	337	199	67	9	11	113	358	119	321	21

Category 3 : Tertiary buildings

Category 4 : Micro-projects et demonstrators

Category 5 : Outdoor spaces

- We can also see, when we look at the projects column by column, that some have a multi-layered approach, achieving reuse rates in most of the layers concerned (this is particularly the case for projects in the first category), while others focus their reuse efforts on a smaller number of layers (a strategy found particularly in housing and tertiary building projects).

☞ There is an important nuance to be borne in mind when reading this table:

- Cells left completely blank correspond to layers which, in a given project, were not affected by the work. For example, renovation work on an existing building that did not affect the structure at all.

- Cells explicitly indicating 0% correspond to situations where the work carried out did affect a given layer, although there was no reuse within it.

3.2 Analysis of the results

This section details the rates achieved in the projects.

A few comments on the analysis of reuse rates by category and by layer

As a first approach, it is important to note that the reuse rate depends on the total quantity of materials used for the works. The greater the total mass, the greater the mass of reused materials must be to achieve a high rate. It is clear that absolute quantities have an impact on the rates achieved. The projects analysed show orders of magnitude that are sometimes very far apart.

The reuse rate also depends on the mass of the elements involved. For the same layer, the use of heavier materials logically leads to a higher rate. These rates are therefore not always representative of the efforts made, but they are one indicator among others that should be studied.

☞ A few indications about the analysis itself:

- When the quantity of materials reused per layer was too low (of the order of a few kilograms) and the corresponding rate was also too low, it was not included in the analysis. We then considered the reuse in the layer concerned to be marginal.

- When the rates achieved within a category are too heterogeneous, indicating an average or median rate is not relevant. We have therefore chosen to indicate only the minimum and maximum values. Similarly, there is no point in expressing the average rate when the sample under consideration contains only two projects.

- Finally, the expression of minimum and maximum reuse rates per layer only includes projects for which there has been reuse (a rate of 0% is therefore not taken into account as a minimum reuse rate).

In the following chapters, we analyse the rates achieved for each layer within each project category.

Category 1: renovations for social and cultural facilities

This subgroup comprises four projects ranging in size from 1,000 to 4,000 m². It concerns only renovation projects in which reuse efforts have been coupled with significant preservation of existing buildings.

Structure

In these projects, the structural layer is generally absent or negligible. Indeed, these projects have all chosen to integrate into existing built structures, which have been altered very little. Some projects do have an inflow of materials for structural work, but these are generally minor in terms of quantity: these are relatively minor additions or occasional reinforcements (such as the construction of a covered terrace in the case of the Maison des Canaux, for example, where reused steel was used to a large extent, achieving a reuse rate of 43%).

Skin

Operations concerned	2 projetcs out of 4
Minimum rate	19,43 %
Maximum rate	19,94 %
Average rate	**19,68 %**

The three projects have reuse rates in the same orders of magnitude, so the average reuse rate presented here can be considered consistent (while taking into account the small size of the sample).

Space plan :

Operations concerned	4 projects out of 4
Minimum rate	1,04 %
Maximum rate	43,78 %
Average rate	**23,02 %**

Both the Takeda School and Zinneke projects have a reuse rate of around 23%, which represents around 15 tonnes of materials each, for a surface area of 4,000 m². The rate given here can be considered consistent (taking into account the small size of the sample).

Service HVAC

Operations concerned	2 projects out of 4
Minimum rate	8,86 %
Maximum rate	51,9 %
Average rate	-

Expressing an average rate for this layer in this category of project is not relevant because there are only two projects and the quantities are very different:

- 52 units (corresponding to 6.9 t) of radiators from reuse out of 13.4 t for the Grande Halle Colombelle project, giving a rate of 52%.

- 20 radiators and 1 ventilation unit, corresponding to 1.9 t out of 22.5 t for the Zinneke project, giving a reuse rate of 8.9%.

Service - Sanitary

Operations concerned	3 projects out of 4
Minimum rate	18,6 %
Maximum rate	56,4 %
Average rate	38,5 %

For this layer, the reuse rates are not very representative of the effort made for each project. Indeed, by reusing 132kg (out of 248kg), the Maison des Canaux project has the highest reuse rate at 53.25%, while the Zinneke project achieves 40% by reusing 1.5t (out of 3.7t). The rate is highly dependent on the total quantity of material reintegrated into this layer - which is highly dependent on the facilities in place and the possibility of maintaining them or, on the contrary, the need to replace them.

Outdoor - Surfaces

Operations concerned	2 projects out of 4
Minimum rate	17,2 %
Maximum rate	87,6 %
Average rate	52,4 %

Only two projects used reclaimed materials for their outdoor surfaces. Moreover, the rates show very significant variations. The average rate expressed here is therefore not very representative.

It is noteworthy that the Maison des canaux project has used wood from windows and doors, and reclaimed stone and cobblestones dry-assembled to create the exterior flooring, enabling them to achieve a rate of 100%.

Outdoor furnishings

Operations concerned	1 project out of 4
Rate	84,4 %

Only one of the four projects (the Maison des Canaux) involved the production of permanent outdoor furniture. The rate shown here cannot therefore be considered representative.

Category 2 : housing

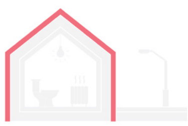
This category includes eight projects of various sizes: six have a surface area of between 100 and 300 m², two have a surface area of between 1,000 and 2,500 m² and one has a surface area of over 6,000 m². This category includes both renovation and new-build projects.

Structure

Operations concerned	3 projects out of 8
Minimum rate	0,77 %
Maximum rate	14,59 %
Average rate	-

The rates given here conceal highly variable absolute quantities. Thus, the lowest rate (0.77%) corresponds to the project that has reused the largest quantity of structural materials (98 t of steel sections, for Housing Bedzed). By comparison, the other two projects (House Dethy and House Warland) reused 7 t and 17 t of structural materials respectively, achieving reuse rates of 8% and 15%. It should be noted that these two projects involve the renovation of single-family homes, whereas Bedzed is a new build of collective housing.

In any event, given the small sample, it is not possible to deduce an indicative average rate here.



Skin

Operations concerned	5 projects out of 8
Minimum rate	2,24 %
Maximum rate	67,06 %
Average rate	23,02 %

The reuse rates achieved within this layer depend quite directly on the choice of materials. The three projects that achieved the highest rates (32%, 56% and 67%) in this layer did so by reusing facing brick - a relatively bulky element compared with other solutions (wood, for example).

For example, Schilder's Cohousing project reused 89t of bricks (out of the 160t of materials making up the layer skin), giving it a reuse rate of 55.63%. The Clos Dupont project also reused 7t of brick and the Rue de l'Est project 5t, achieving reuse rates of 67.06% and 31.66% respectively.

It is difficult to generalise the average rate achieved here for all facade construction solutions. Nevertheless, it can be inferred that the choice of reclaimed brick generally makes it possible to achieve high rates, of over 20%.

Space plan

Operations concerned	7 projects out of 8
Minimum rate	1,88 %
Maximum rate	17,04 %
Average rate	7,3 %

The project that reused the largest mass of reused materials was BedZed, with 182 t of wood reused to make the interior wall framing. Given the total mass of the layer space plan in this project (1,852 t), and given the comparatively lighter nature of wood, the rate achieved is 10%.

In the other projects, the most frequently reused materials are floor tiles, wall and ceiling coverings and interior woodwork (doors, built-in cupboards, etc.).

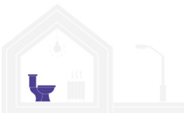
The average rate expressed here (between 5 and 10%) seems plausible and can be considered representative.

Service - HVAC

Operations concerned	4 projects out of 8
Minimum rate	3,64%
Maximum rate	29,46%
Average rate	-

The materials that contribute to the reuse rate in this layer are mainly radiators (cast iron, steel and aluminium). The rate varies greatly depending on the number of radiators, their composition (cast iron cannot be compared with aluminium!) and whether or not the projects concerned were able to use existing sanitary installations.

On the basis of the available data, it is not possible to give a relevant indicative rate.



Service – Sanitary

Operations concerned	3 projects out of 8
Minimum rate	3,92 %
Maximum rate	84,38 %
Average rate	-

This layer also shows that the reuse rate varies greatly depending on whether it was necessary to (re)build the entire sanitary installation or, on the contrary, whether the work only involved replacing individual items of equipment (washbasins, bathtubs, toilet bowls, etc.).

For example, in the Maison Vignette and the Clos Dupont houses, 30 kg of materials were reused in each case. In one case - a new build - this gives a rate of 4%, in the other - a renovation - a rate of 68%!

On the basis of the available data, it is not possible to give a relevant indicative rate.

<u>Outdoor - Surfaces :</u>

Operations concerned	2 projects out of 8
Minimum rate	0,29 %
Maximum rate	87,67 %

Only two projects in this category reused outdoor surface elements. In addition, the landscaping of the surroundings represents very different surface areas (and, by extension, quantities of materials) from one project to another.

For Bedzed, this layer represents more than 1,000 t of materials, within which 3 t of granite kerbstones were reused (leading to a rate of 0.29%). For the Clos Dupont project, we are talking about a small outdoor terrace, involving just under 800 kg of material, of which 700 kg of concrete paving stones were reused (leading to a particularly high rate of 87.67%).

On the basis of the available data, it is not possible to give a relevant indicative rate.

Category 3 : tertiary buildings

There are eight projects in this category. Six of them have a surface area of between 3,000 and 8,000 m², and two are larger, with a surface area of between 33,000 and 45,000 m². The works studied involve 5 new constructions and 3 renovation projects of existing buildings. This category includes a variety of programmes, with the majority of office space (possibly combined with other functions such as conference rooms, shops, etc.) but also a waste collection centre and a clinic.

Structure :

Operations concerned	3 projects out of 8
Minimum rate	1,75 %
Maximum rate	9,58 %
Average rate	**4,93 %**

The projects concerned by the structural layer are all new constructions. The vast majority of the elements reused are steel or timber frames, but there is also one case of concrete retaining walls being reused.

In absolute value and compared with other layers, the masses involved in reuse are quite considerable: between 30 and 160 t. However, they represent comparatively lower rates of re-use than in other layers, due to the total mass of material flows required for the structural layer.

Despite a relatively small sample, the average rate given here can be considered a useful indication of a plausible target for new projects that choose to reuse structural elements.

Skin :

Operations concerned	4 projects out of 8
Minimum rate	3,26 %
Maximum rate	28,08 %
Average rate	**14,49 %**

The two highest reuse rates (around 25%) concern new-build projects. The materials reused and re-employed are varied, ranging from reused windows and terrace boards to stone paving and rubble reused in gabion walls.

Despite a relatively small sample, the average rate given here can be considered a useful indication of a plausible target for projects that choose to reuse envelope elements.

Space plan :

Operations concerned	7 projects out of 8
Minimum rate	1,28 %
Maximum rate	24,34 %
Average rate	**7,81 %**

The office renovation project Mundo Madou and the new construction project Pulse have the highest rates of re-use in this layer (around 20%), which is also the only one to include re-use. The other projects range from 0.25% to 4.3%.

The range of materials reused in this flow is highly diverse: flooring, wall cladding, insulation materials, woodwork, partitions, handrails etc.

The Mundo Madou project alone, for example, reused no fewer than 11 different types of material, representing 24.34% of the total mass of this layer.

Despite significant variations in the rates achieved within the different projects analysed, the average rate given here can be considered a useful indicative target for similar projects choosing to reuse materials for interior finishes. The analysis carried out here shows that there is a wide range of possibilities for achieving reuse rates within this layer.

Service – Electricity :

Operations concerned	1 project out of 8
Rate	2,34 %

The construction project for the youth clinic is the only one in this category to have reused electrical components: lighting, cable trays, various electrical components, alarms and detectors.

On the basis of the available data, it is not possible to give a relevant indicative rate.

Service – Sanitary :

Operation concerned	2 projects out of 8
Minimum rate	7,54 %
Maximum rate	25,35 %

There are only two projects that have reused sanitary equipment (Biopartner 5 and Kaysersberg). One was a toilet bowl and the other a sink.

On the basis of the available data, it is not possible to give a relevant indicative rate.

Outdoor - Surfaces :

Operations concerned	3 projects out of 8
Minimum rates	0,71%
Maximum rate	86,47 %

The materials used in this layer are concrete and asphalt slabs. There are very large differences between the various projects, which mainly have to do with the surfaces of the surrounding areas and their scale within the projects.

On the basis of the available data, it is not possible to give a relevant indicative rate.

Outdoor - Furnishings :

Operations concerned	2 projects out of 8
Minimum rate	9,30 %
Maximum rate	22,20 %

The rates measured here are not sufficient to infer relevant indicative rates. Not only because the sample is too small, but also due to the fact that the orders of magnitude vary too widely between projects.

Category 4 : micro-projects and demonstrators

This category includes seven projects which have in common the fact that they are small-scale and have set themselves the objective of pushing reuse strategies to the maximum. However, there are two cases in point:

- Four of them (the ‘Chiro’ sanitary block, the VLA office, the Droit & Habitat office and the ‘La Fabrique’ collection centre) operate in fairly conventional contexts.

- The other three are closer to a form of micro-architecture that avoids certain constraints such as durability over time (temporary structures) or accommodating certain functions (no sanitary facilities, no heating installation, etc.).

In any case, most of these projects achieve very high reuse rates, foreshadowing strategies that may well find their way into more conventional construction practices.

Structure :

Operations concerned	5 projects out of 7
Minimum rate	1,25 %
Maximum rate	100 %
Average rate	78,69 %

Among the five projects involved, between 93 kg and 5.2 t of structural materials were reused. Compared with the quantities involved in this layer in the other project categories, these figures are very low.

The average rate shown here is not representative.

Skin :

Operations concerned	5 projects out of 7
Minimum rate	28,17 %
Maximum rate	100 %
Average rate	70,73%

The materials reused in the layer are mainly plywood or rigid insulation panels, external woodwork and sheet metal roofing.

The average rate shown here is not representative.

Space plan :

Operations concerned	7 projects out of 7
Minimum rate	9,70 %
Maximum rate	100 %
Average rate	65,30 %

All the projects have reused materials in the space plan layer, in quantities ranging from 50 kg to 5.6 t. The materials are varied (floor coverings, wall coverings, glazed partitions, built-in cupboards and interior woodwork) and, in the more permanent projects, fairly representative of what can be found in the other categories.

Due to the more specific projects in the sample, the average rate shown here is not representative.

Service - HVAC :

Operations concerned	2 projects out of 7
Minimum rate	4,50 %
Maximum rate	28,88 %

The reuse of materials here is exclusively focused on steel and cast iron radiators.

Service - Electricity :

Operation concerned	2 projects out of 7
Minimum rate	6,74 %
Maximum rate	10 %

An electrical panel and some spotlights and LED tubes were reused in the two projects covered by this layer.

Service – Sanitary :

Operations concerned	5 projects out of 7
Minimum rate	1,67 %
Maximum rate	94,42 %
Average rate	54,92 %

Sinks, toilet, towel and paper holders, water tanks, faucets and grab bars were reused in the various projects. Despite the larger sample than for the other layers in this category, the large differences between the minimum and maximum rates make the average rate shown here unrepresentative.

Category 5 : outdoor spaces

This category includes 5 projects for outdoor development, involving roadworks and, in some cases, landscaping. The projects range in size from 5,000 m^2 to over 130,000 m^2.

By definition, the projects included in this category only concern the three outdoor layers.

Outdoor - Infrastructure :

Operations concerned	1 project out of 5
Rate	21,83%

Only one project out of five reused infrastructure materials. In this case, aggregates were reused in the Croeselaan project, representing a total mass of 1,500 t (one fifth of the mass of this layer). As this is the only occurrence, not only in this category but also in all the projects concerned with outdoor development, this rate cannot be considered representative.

Outdoor - Surfaces :

Operations concerned	5 projects out of 5
Minimum rate	4,82 %
Maximum rate	95,55 %
Average rate	**36,08 %**

All the projects have reused materials for the external surfaces. This mainly involved stone, concrete and brick paving. The quantities involved vary between 115 t and 2,500 t.

Despite the wide variations, the average rate given here can be considered a plausible target for outdoor development projects that aim to reuse outdoor flooring. Indeed, there is a certain homogeneity in the materials used.

Outdoor - Furnishings :

Operations concerned	3 projects out of 5
Minimum rate	0,39 %
Maximum rate	77,44%
Average rate	29,67%

The materials reused in this layer are bicycle racks, lighting posts and a gate.

Because of this wide diversity, the large differences between the minimum and maximum rates and the small sample size, the average rate given here is not representative.

Can we extrapolate general indicative rates?

One of the questions that arises from the analysis of these reuse rates is whether it is possible to deduce indicative rates that could be applied on a large scale for a wide range of projects.

The answer to this has to be balanced

☞ In the first instance, the analysis carried out here tends to show that it is difficult to generalise indicative rates for all categories of projects combined (see below, chapter 4, for methodological limitations). On the contrary, the analysis confirms the extent to which reuse practices are highly contextual and the extent to which the rates actually achieved depend on the type of project (new build or renovation), the quantities of materials involved, the programmes and, more broadly, the architectural choices made by the designers and their clients.

However, in certain layers and for certain categories of project, we can see the emergence of data which present a certain plausibility (despite all the biases mentioned in the course of the analysis and discussed below in chapter 4).

The table below shows the data that could be used as indicative targets in cases close to the projects analysed. The figures in parenthesis refer to assumptions that are discussed below.

	Cat 1 Renovations for social and cultural facilities	Cat 2 Housing	Cat 3 Tertiary buildings	Cat 4 Micro-projects and demonstrators	Cat 5 Outdoor spaces	**Target**
Structure	/	/	(5 %)	/	/	**[1 - 5 %]**
Skin	15 %	(23 %)	15 %	/	/	**[5 - 15 %]**
Space Plan	23 %	7 %	8 %	(65 %)	/	**[10 - 25 %]**
Service – HVAC	/	/	/	/	/	
Service – Electricity	/	/	/	/	/	
Services – Sanitary	/	/	/	/	/	
Outdoor – Infrastructure	/	/	/	/	/	
Outdoor – Surfaces	(52 %)	(50 %)	(50 %)	/	36 %	**[30 - 50 %]**
Outdoor – Furnishings	/	/	/	/	/	

Structure

Overall, the reuse of structural elements remains relatively uncommon. However, it is no longer a completely unexplored terra incognita. Both within the sample of 32 projects and beyond, more and more projects are following this path, and impressive projects are being built on a regular basis.

This tendency is accompanied by a gradual structuring of working methods and risk management protocols, paving the way for a possible generalisation of these practices[1].

Our analysis shows that the reuse of structural elements often involves quantities which, in absolute terms, are substantial (and therefore also reductions in the environmental impact).

1- See the work undertaken on the issue of insurance for the reuse of materials, as part of the FCRBE project.
https://vb.nweurope.eu/fcrbe

The structural layer, however, also tends to be very heavy (particularly for new-build projects). As a result, reuse rates remain relatively low – between 1 and 5% in mass if an estimated range had to be given.

The difference between new builds and renovations plays an important role here. Most renovation projects retain the existing structures and therefore manage to drastically reduce material requirements.

☞ At this stage, it would undoubtedly be premature to require the systematic reuse of structural elements. However, it is an exemplary approach that deserves to be encouraged, and one that should be considered alongside efforts to preserve the existing buildings.

Skin

Works on building envelopes appear to lend themselves relatively well to the reuse of materials. The existing market offers various solutions in this respect, including wood cladding, brick facing and even windows. Several projects in our sample also re-used insulation materials, although these are relatively uncommon on the reuse market.

This layer is particularly subject to the biases inherent in the choice of mass as a unit: apart from bricks, there are many rather light elements – although their reuse is not intrinsically less attractive than that of bricks (wood, insulation, etc.). This is an aspect that should be taken into account when setting a possible reuse rate.

☞ In the context of efforts to improve energy efficiency, much of the work to come will involve the building envelope. It is worth encouraging the use of reused materials where the context allows. As mentioned, setting an indicative rate depends very much on the planned construction solution. As a guide, a range of between 5 and 15 % (by mass) seems achievable if the project is suitable for the application of timber cladding or brick facing to a substantial part of the façade. Reusing glazing - where possible - also helps to meet (and even exceed) this target.

Space plan

Unsurprisingly, the layer space plan is the one that features in the greatest number of projects. It is also the one that uses the widest range of reused materials.

☞ It is also a layer that is relatively unaffected by the difference between new build and renovation projects. In most cases, the work involves interior finishes – although in the case of renovation, it is of course possible to explore the possibility of retaining a significant proportion of the original finishes in order to minimise the flow of materials required for the works.

☞ Our analysis suggests indicative reuse rates within the layer space plan of between 10% and 25% (by mass). This does not mean that all construction projects in North West Europe could reach this target overnight. Clearly, a generalisation of this target would have unpredictable impacts on the reuse market. On the other hand, it is not absurd to set these orders of magnitude (and even more, in certain specific cases) as a reasonable target for projects corresponding to those analysed here and which wish to set themselves reuse objectives.

Services

The three layers relating to technical equipment are trickier. The data collected here does not allow us to establish relevant indicative rates. However, a number of interesting observations can be made.

In our sample, the reuse of technical equipment mainly concerns visible elements (toilet bowls, washbasins, radiators, etc.) and, to a lesser extent, certain machines (water heaters, ventilation units). The “hidden” elements of these installations (pipes, ducts, etc.) are almost never reused in our sample of projects.

☞ This makes a very big difference between renovation projects, which can afford to keep some of the existing installations, and those that have to install (or re-install) everything from scratch.

Quantifying material flows relating to technical installations is not a simple matter. It is a field in which it is complicated to find detailed data. That said, the reuse of technical equipment is a subject that is currently the focus of a number of research projects, suggesting that such practices could become widespread in the future[1].

As it stands, the projects analysed demonstrate that the reuse of various relatively simple technical equipment is possible and deserves to be encouraged. Incentives based on something other than reuse rates (in mass) would be more appropriate (e.g. qualitative targets, targets expressed per piece, etc.).

<u>Outdoor – Infrastructures</u>

The projects analysed here seem to indicate that the reuse of infrastructural layers in road and landscaping works is still very uncommon. In a way, this practice tends to slide into the realm of soil management – a crucial subject, but quite different from the one addressed here.

<u>Outdoor – Surfaces</u>

The figures vary greatly depending on the scale of the project. There are small-scale, almost domestic, landscaping projects alongside much larger-scale roadworks.

However, there is a certain congruence in the data collected and in the materials reused: natural stone paving blocks, concrete paving blocks and terracotta paving blocks. These are materials that are relatively common on the reuse market and for which there are suppliers capable of delivering large quantities. They are also materials that lend themselves well to reuse.

☞ For all these reasons, it is no exaggeration to formulate indicative reuse rates within a range of 30% to 50% (by mass). Depending on

1- See for example Loreau, S., Stephan, A., Cooper, D. R., & Maerckx, A. (2022). "Assessing material and embodied flows related to building services in office buildings - the case of Brussels, Belgium". *IOP Conference Series: Earth and Environmental Science*, 1122(1), 012030. Et Loreau, S., Stephan, A., Cooper, D., & Maerckx, A.-L. (2022, 5-7 Oct 2022). *Identifying building system reuse pathways using physical reliability and technological performance metrics - the case of chillers and their components.* Paper presented at the International Building Decarbonization Conference 2022, Athens, Greece.

the specific context, this target may of course be revised upwards (some projects have managed to achieve rates of over 90%) or downwards (if the context poses specific constraints).

Outdoor – Furnishings

On the basis of the data collected through this analysis, it is not possible to establish indicative reuse rates. However, the projects analysed show that this is a type of application that can lend itself admirably to reuse. If quantitative targets were to be set, they would have to be based primarily on a contextual study.

3.3 Evaluation of the environmental benefits

In the 32 construction and renovation projects studied, our analysis was carried out a posteriori. As a result, we did not always have all the information about the exact origin of the materials reused, their age or the entire process that led to their reuse.

In this context, to measure the environmental benefits of reuse, it seemed to us that the most relevant approach was to measure the impact saved compared to the use of new materials. This approach does not take into account the previous life of the material.

According to the stages in the life cycle of materials as set out in standard EN 15804, it can be considered that reusing a material in a new construction avoids the impacts inherent in phases A1 to A3 (i.e. the production phases) of the life cycle of building components.

In order to assess these values, we used reference values.

In this case, the analysis proposed here is based on a carbon database established in the context of the *Label Bas Carbone Rénovation* (LBC). This is a French government label that provides a framework for assessing the carbon impact of a renovation project at every stage of its life cycle. The LBC database is based on the French *INIES* database, which contains a growing number of environmental and health declaration sheets for construction materials and components (see box). The database used contains a list of average impacts for numerous categories and families of construction products (seebox).

Representativeness of the *INIES* database

The *INIES* database is currently the most complete library of environmental declaration sheets in Europe. Although it focuses on products sold in France, it covers a wider scope of production. In this sense, it is representative of the scope of the projects analysed here. These are located in Belgium (14), France (9), the Netherlands (8) and the UK (1). An analysis of the origins of the products documented in the *INIES* database shows that these countries are also represented.

The database created for the Label Bas Carbone can therefore be used as a reference base to assess the impacts by category or by product family. On the other hand, while the Label Bas Carbone Rénovation takes the approach of encouraging reuse by considering that the impacts of the entire life cycle are avoided thanks to reuse, for our part we have chosen to estimate the gain more realistically by considering that only the impacts of phases A1 to A3 are avoided thanks to the reuse of materials. These will have to be installed, maintained and, if necessary, managed at the end of their life in a way that is not fundamentally different from that for new components.

Category or equivalent product family?

The Low Carbon Label database is structured on a tree structure at two levels: firstly, there are categories, which themselves contain families of materials.
The categories cover general functions in construction, without referring to specific materials (for example, wall cladding)[1]. Each category contains families of products that fulfil this function (for example, cement tiles). An average environmental impact is assigned to each family and also to each category.
In our approach, the question therefore arose as to whether the reuse of a given material was a substitute for a category or a family. In practice, both scenarios can be encountered in the development of construction projects.
In the first case, the designers of a project adopt an open approach and look for a reusable material likely to meet a general function, without necessarily settling on a specific material. They will choose a particular batch depending on the opportunities available at the time. So the thinking here is at the level of categories.
In the second case, reuse is more targeted. The designers have a precise idea of the material needed and try to find it through various reuse channels. The thinking then shifts to the product family level.
For our analysis, as we did not necessarily have the information concerning the genesis of the projects, we systematically considered that the second scenario was the one that applied, which today seems to be more common, and therefore used the impact at product family level in our estimates.

1- The list of categories was established by the French legislator in Appendix 1 of the Order of 23 December 2013 on the environmental declaration of construction and decoration products intended for use in building works.

Calculation steps :

To estimate the carbon avoided in the projects studied, we implemented the following approach:

- Step 1: Based on a detailed survey of the materials reused in the 32 projects in the corpus, identification of the corresponding product families in the LBC database.

- Step 2: calculation of greenhouse gas emissions in phases A1 - A3 for these product families.

- Step 3: search for additional data for families not listed in the LBC method (INIES, ADEME databases or other international sources).

- Step 4: conversion of the quantities calculated into functional units.

- Step 5: calculation of the total carbon impact avoided.

The environmental benefits of reuse are measured in the detailed project sheets. It is expressed in kilograms of carbon equivalent corresponding to the quantities involved in each project. We have expressed these figures as negative values: the minus sign expresses the emissions avoided thanks to reuse.

For some materials, we have not found sufficiently reliable data. For these, we have not provided any information.

In the case of certain wood components, the sum of greenhouse gas emissions during phases A1-A3 can lead to negative results. This is because some LCAs take into account the carbon absorbed by the metabolism of trees and plants through photosynthesis (known as biogenic carbon). In some cases, the biogenic carbon contained in the wood is greater than the carbon equivalent emissions linked to its production.

☞ The result is a 'negative' contribution to this specific impact and to these phases of the life cycle. In our approach based on the principle of substitution (measuring avoided emissions), these data were difficult to interpret: how could we represent the avoidance of negative emissions? To avoid this, we used a simplified formula to extract from the impact calculation the biogenic carbon corresponding to the quantities of wood involved[1].

1- For the sake of simplicity in this analysis carried out after the projects have been completed, we are using a default biogenic carbon content for all types of wood, provided by standard NF EN 16449 (2014), which gives an associated CO_2 capture rate of 1.637kg.CO2/kg.

4. DISCUSSIONS

This section presents the limitations and biases inherent in our approach.

4.1 Size of the sample

Our sample (32 projects analysed) remains relatively limited. This makes our results less representative, particularly for certain layers in which very few projects incorporated reused elements.

This limitation stems from the time and resources available to us when carrying out this analysis. In the future, we are optimistic that more and more projects will adopt the habit of monitoring and reporting on their reuse efforts in order to gradually add to the collection of available case studies.

☞ Carrying out a retrospective analysis of projects in which we have not participated undoubtedly requires more time and research than following a project "live", as it progresses and with direct access to the relevant data.

4.2 Pioneering projects

Although we have chosen projects with the potential for replication rather than those that are highly experimental, these 32 projects all have a remarkable and/or innovative character precisely because they have chosen to reuse materials.

Seen from a broader perspective, and despite increasingly significant efforts to encourage reuse, the vast majority of the construction industry continues not to reuse materials.

As it stands, this bias is unavoidable. It is to be hoped that it will fade with time and with a gradual increase in the adoption of reuse practices.

4.3 Assumptions and extrapolations

The calculation of the mass of the elements and materials has been carried out with the utmost care and a high level of precision, based on the maximum available data. However, due to the lack of precise information for certain elements, we were forced to make assumptions and make extrapolations that could weaken the final results somewhat.

This situation largely stems from the retrospective (*ex post*) dimension of our analysis. We met a series of obstacles to access the information: lack of responsiveness of the organisations who were involved in the projects, information lost or difficult to access, and so on.

☞ In an ideal world, each material used on a construction site would be duly identified, recorded (and weighed!) before being implemented. Similarly, each element leaving the construction site would also be identified and quantified. Such monitoring would undoubtedly be tedious to implement, but it would allow the automatic and precise calculation of the reuse and reclamation rates actually achieved.

More realistically, the calculation of the reuse rates can be anticipated from the start of the project, and more particularly when the bill of quantities is drawn up. The calculation of the reclamation rate can, for its part, be established on the basis of slips used for waste management and a meticulous listing of the reclaimed elements (which can, if necessary, be based on a prior inventory of reusable materials).

4.4 Be cautious with indicators

The reuse rate is an indicator that can, up to a certain point, account for the efforts undertaken or expected in terms of reusing materials. This is an approach that aims to be relatively simple and homogeneous but which, in no case, can claim to account for all the dimensions inherent in reuse.

☞ Reuse cannot be reduced to a question of quantity. It is an approach that carries with it cultural, social, economic and environmental dimensions, which are equally, if not more, significant than a purely quantitative aspect. These dimensions are not always easily measurable or quantifiable. In this respect, the reuse rate can be a practical *proxy*, likely to give general indications with relatively light monitoring efforts. However, it is important not to make it an end in itself, at the risk of losing important aspects of reuse practices.

In the same vein, the reuse rate is only one facet of circularity efforts. This should not be used as an excuse to ignore other important aspects (in particular the preservation rate of existing buildings!).

5. CONCLUSION

Reporting on the reuse rates achieved in various projects is a practice that deserves to be encouraged more widely. This would create a positive emulation and allow progress to be monitored over time at various levels (within an architectural firm, a construction company, a city, a region or even a given country).

To achieve this, however, we need to ensure that the approach adopted is harmonised and consistent. If each project owner, architect or design office uses its own calculation method, with definitions that are too different, all these accounting efforts will be of little use, as they will not make it possible to compare the different results.

In this respect, public authorities can play an important role by establishing common frameworks and harmonised measures.

This document - and the other sections to which it refers - is intended to make a contribution in this direction.

APPENDIX 1: DETAILS EXPLANATION OF THE ASSUMPTIONS

As explained previously (see chapter 1 and 2 of this document), to calculate the mass of the elements and materials, we relied on the following elements (in order of preference):

1. Technical data sheets for materials specific to the project.
2. Reference databases.
3. Specific assumptions.

In this appendix, we describe in detail the reference databases used and the specific assumptions we made. This analytical work constantly required us to make micro-decisions, to arbitrate between several choices, to formulate hypotheses and then to remain consistent with them. Here are the details of our choices.

1. Reference database

1.1 ICE et KBOB

We mainly used two databases: (1) *The Inventory of Carbon and Energy* (also known as the *ICE database*) and (2) the *Ecobalance Data Platform* from KBOB/ecobau construction[1].

The *ICE database* was created by Dr Craig Jones when he was a research scientist at the University of Bath (UK) and worked for Professor Geoff Hammond in the research team on Sustainable Energy (SERT). It is freely accessible and frequently updated by Circular Ecology, an environmental consultancy spin-off from the university. It contains data on over 200 materials, divided into more than 30 main categories.

The *LCA data platform for the construction industry* is a Swiss database set up by KBOB. Its aim is to present up-to-date and nationally relevant information on construction materials, technical building equipment, energy systems and means of transport.

By combining these two databases, we had data on the density of more than 500 building materials, which were used to calculate the mass of homogeneous elements. For certain very specific materials, we had to look for this data in more specific sources (for certain wood species or certain local stone varieties, for example, for which we generally found the information in the technical documentation drawn up by the concerned federations).

1.2 Internal database and unit masses

For composite materials and/or materials whose volume is complex to measure (e.g. of sanitary equipment, electrical appliances, ventilation machines, etc.), we used unit masses.

Unlike data relating to density, unit masses do not seem to be systematically included in reference databases. We therefore built

1- KBOB (Conference for the coordination of construction and building services of public contracting authorities of the Swiss Confederation). Data from life cycle assessments in construction - 2016 our own database as the analysis progressed by compiling data from technical data sheets for materials similar to those present in the analysed projects[1].

2. Specific assumptions

Despite the precision of the databases used, in some cases, the calculation of the mass of an element or an assembly of materials requires making assumptions. For example, while it is relatively easy to find the density and the dimensions of a brick in order to calculate its mass, it is not easy to know the thickness of mortar used to assemble these bricks. However, this information is crucial when it comes to accurately calculating the reuse rate in a brick wall. The thickness of the joints is sometimes mentioned in the specifications of the works. If this information was available, we used it. Otherwise, we made assumptions and established internal rules to be consistent between projects. The following section presents the main rules of thumb used for our analysis.

2.1 Conservative calculations

As a general rule, when we had several different values for a material or element, whether in terms of density or unit weight, ☞ we either averaged the different values or gave priority to the least advantageous values (i.e. those that tended to reduce the reuse rate). In this way, we ensured that we did not overestimate the reuse rates we were calculating.

2.2 Calculation of the mortar in the case of a brick wall

Let’s go back to the example of the brick wall. When we did not have access to the specific thickness of mortar used in a project, we then used a reference thickness: 0.012 m (12 mm).

It is the reference thickness used by the Belgian tool Totem (*Tool to Optimise the Total Environmental impact of Materials*). Using the dimensions of the bricks, we could deduce the brick-to-mortar ratio

1- Database available on demand.

☞ of the wall to calculate the mass of each elements. Since the mortar is always new, a wall made entirely of reused bricks will therefore never be 100% reused. In general, the mortar represents 20 to 30% of the surface of a brick wall, which is not negligible.

2.3 Calculation of the martyr in the case of stone pavers

For natural stone pavers, we factored in the mortar between the pavers and the screed just below the pavers, which are both necessary for the sound layout of the material.

When we could not find the mortar-to-paver ratio in the available documentation, we used this generic value: 80% of pavers for 20% of mortar (on the surface).

This value is based on one of the projects we analysed (Caserne of Mellinet) and for which we could access specific data. It allowed us to estimate that the ratio was somewhere between 80/20 and 90/10. Following our conservative approach, we adopted the 80/20 value as a rule of thumb for the other projects when this information was unavailable.

For what concerns the mortar beneath the pavers, we used a generic value of 3 cm (using data from Totem).

2.4 Simplified calculation for the windows' mass

To calculate the mass of certain windows, we have used a simplified approach which only takes into account the glass and not the frame. The mass of the frame can in fact be considered negligible in certain cases meeting the following conditions:

- Double-glazed windows.
- Wooden or aluminium frames (not applicable to PVC).
- Relatively standard dimensions where the frame represents no more than 30% of the total surface area of the window.

In the case responding to these conditions (and for which we had no access to more specific data), we used the following reference values :

- Security glass = 35 kg/m².

- Standard double-glazed windows (non-secured) = 20 kg/m².

2.5 Assessment of the mass of equipment (sanitary, HVAC, electricity)

The layers relating to the various building equipment are those for which we generally had little information and precise data. They also proved the most time-consuming to calculate, as they are made up of a vast array of very specific elements.

Where data was lacking, too incomplete or too imprecise, we used a very simplified calculation based on reference values. These values come from the scientific literature on the carbon impact of service installations in the United States, more specifically in new office buildings[1]. In this type of building, the authors estimated that heating and ventilation installations weighed on average 13 kg/m², electrical installations 4 kg/m² and sanitary installations 3 kg/m².

However, care must be taken when using these estimates, particularly in the context of renovation projects: these values calculate all the service installations, whereas in a light renovation, for example, a significant proportion of the elements are often retained. The use of these estimates in this type of project to calculate flows in is therefore imprecise, and we have not applied it in such cases. Likewise, this formula is probably not suitable for other context.

2.6 Table of the elements per layer

Defining which layer each element belongs to is not always easy, and while for some elements this is quite obvious, for others two or more layers may be appropriate according to interpretations. So

1- Rodriguez B. X. & Alberti M. (2019). *Embodied carbon of heating ventilation air conditioning and refrigerants* (hvac r) systems. Dissertation at the University of Washington Libraries.

we have made choices, often on a case-by-case basis, depending on the specifics of the project.

The reader will find below a table detailing to which layer we usually attributed discussable elements.

Layer	Element	Notes
01. Structure		
01. Structure	Beams	
01. Structure	Columns	
01. Structure	Load-bearing walls	
01. Structure	Foundations	
01. Structure	Floor slabs	
01. Structure	Joists	
01. Structure	Window and door lintels	
01. Structure	Retaining walls	
01. Structure	Poured concrete stairs	
01. Structure	Bridge structure	
01. Structure	Structure of terraces/patios	
01. Structure	Load-bearing brick walls	Including mortar
02. Skin		
02. Skin	Facade material	
02. Skin	Facade structure	
02. Skin	Insulation	If part of exterior wall. If part of interior partitions, count as space plan
02. Skin	Exterior doors	
02. Skin	Exterior windows	
02. Skin	Exterior window sills	
02. Skin	Outdoor motorized sunscreen	
02. Skin	Roof cladding	
02. Skin	Underlay	
02. Skin	Rainwater pipes	
02. Skin	Insulation/sealing between building and ground	
02. Skin	Balcony structure and finishes	
02. Skin	Awnings and their structure	Structure supporting only the element itself
02. Skin	External glass railing	
02. Skin	Brick cladding	Including mortar
03.01 Services - HVAC		
03.01 Services - HVAC	Ventilation systems	
03.01 Services - HVAC	Radiators	
03.02 Services - Electricity		
03.02 Services - Electricity	Electrical cables	
03.02 Services - Electricity	Electrical panels	
03.02 Services - Electricity	Outlets	
03.02 Services - Electricity	Electrical applicances	
03.02 Services - Electricity	Kitchen appliances	
03.02 Services - Electricity	Fixed lighting fixtures	
03.02 Services - Electricity	Fixed fire equipment	
03.02 Services - Electricity	Fixed fire alarms	
03.02 Services - Electricity	CO2 detector	
03.02 Services - Electricity	Security equipment	
03.02 Services - Electricity	Security alarms	
03.02 Services - Electricity	Security cameras	
03.03 Services - Sanitary/Plumbing		
03.01 Services - Sanitary/Plumbing	Toilets	
03.01 Services - Sanitary/Plumbing	Bathroom sinks	
03.01 Services - Sanitary/Plumbing	Bathtubs and showers	
03.01 Services - Sanitary/Plumbing	Grab bars	
03.01 Services - Sanitary/Plumbing	Water pipes	
03.01 Services - Sanitary/Plumbing	Kitchen sink	
03.01 Services - Sanitary/Plumbing	Water tanks	Even if outdoors, since they are an extension of the sanitary system
03.01 Services - Sanitary/Plumbing	Pipes	Outdoor extension of the sanitary system
04. Space Plan		
04. Space Plan	Non-load bearing walls and partitions	Including any structure within that assembly
04. Space Plan	Glass partitions	
04. Space Plan	Interior windows	
04. Space Plan	Interior doors	
04. Space Plan	Flooring materials	Including underflooring, screed, and other floor supporting structure
04. Space Plan	Baseboards	
04. Space Plan	Railings	
04. Space Plan	Drop ceilings	
04. Space Plan	Acoustic panels	

Layer	***Element***	***Notes***
04. Space Plan	Service hatches	
04. Space Plan	Partitions that cover service ducts	"Gaine technique" if they are have wood or plasterboard lining
04. Space Plan	Fixed or built-in furniture	
04. Space Plan	Shelves, cabinets, millwork	
04. Space Plan	Closet doors	
04. Space Plan	Mailboxes	
04. Space Plan	Baby changing tables	
04. Space Plan	Kitchen cabinets	
04. Space Plan	Kitchen islands	
04. Space Plan	Kitchen countertops	
04. Space Plan	Plaster	If it is thicker than 0.5 cm and considered a finish on its own
04. Space Plan	Fixed mirrors	
04. Space Plan	Interior stairs	If they are not poured concrete
04. Space Plan	External staircases	Can be evaluated on a case by case basis
05. Outdoor - Infrastructure		
05. Outdoor - Infrastructure	Retaining walls	
05. Outdoor - Infrastructure	Road works (underneath the asphalt surface)	
05. Outdoor - Infrastructure	External wall foundations	
05. Outdoor - Infrastructure	Fence foundations	
05. Outdoor - Infrastructure	Sand or soil supporting any pavers or paths	
05. Outdoor - Infrastructure	Underground networks of pipes	
05. Outdoor - Infrastructure	Valves	
05. Outdoor - Infrastructure	Manhole covers	
05. Outdoor - Infrastructure	Meshes	
05. Outdoor - Infrastructure	Grills	
05. Outdoor - Infrastructure	Water meters	
05. Outdoor - Infrastructure	Electrical meters	
05. Outdoor - Infrastructure	Control boxes	
05. Outdoor - Infrastructure	Inspection chamber	
05. Outdoor - Infrastructure	Topsoil	Underneath the humus layer
06. Outdoor - Surfaces		
06. Outdoor - Surfaces	Road surfaces (ex: asphalt)	
06. Outdoor - Surfaces	Mulch, gravel, or pavers used to mark areas	
06. Outdoor - Surfaces	Mulch, gravel used as planting areas	
06. Outdoor - Surfaces	Exterior stairs	If bearing on the ground
06. Outdoor - Surfaces	Terraces, patios	Can be evaluated on a case by case basis
06. Outdoor - Surfaces	Pavers	Including the mortar in between them and the layer of mortar below them
07. Outdoor - Furnishings		
07. Outdoor - Furnishings	Fences	
07. Outdoor - Furnishings	Gates	
07. Outdoor - Furnishings	Guardrails	
07. Outdoor - Furnishings	Sprinklers	
07. Outdoor - Furnishings	Water fountains	
07. Outdoor - Furnishings	Bike racks	
07. Outdoor - Furnishings	Playground and gym equipment	
07. Outdoor - Furnishings	Sculptures	
07. Outdoor - Furnishings	Billboards	
07. Outdoor - Furnishings	Benches, tables, other fixed outdoor furniture	
07. Outdoor - Furnishings	Tree trellises and supports	
Exclusions		

We are not including a “site” layer. Instead, we are breaking up anything that has to do with site into the three categories in sections 05, 06, 07.

We are not including:
- Loose furniture including loose lighting fixtures
- Paints, primers, varnishes, and other surface finishes thinner than 0.5 cm
- Plants and trees
- Signage
- Elevators

FR
Nous n'incluons pas de layer "site". En revanche, nous répartissons tout ce qui a trait au site dans les trois catégories des sections 05, 06 et 07.

Nous n'incluons pas :
- Les meubles, sauf s'ils sont fixes, y compris les appareils d'éclairage, sauf s'ils sont encastrés
- Les peintures, vernis et autres finitions de surface d'une épaisseur inférieure à 0,5 cm.
- Les plantes et les arbres
- La signalétique
- Les ascenseurs