Application of Life Cycle Assessment (LCA) methodology for valorization of building demolition materials and products

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ABSTRACT

The VAMP project (VAlorization of building demolition Materials and Products, LIFE 98/ENV/IT/33) aims to build an effective and innovative information system to support decision making in selective demolition activity and to manage the valorization (recovery-reuse-recycling) of waste flows produced by the construction and demolition (C&D) sector. The VAMP information system will be tested it in Italy in some case studies of selective demolition. In this paper the proposed demolition-valorization system will be compared to the traditional one in a life cycle perspective, applying LCA methodology to highlight the advantages of VAMP system from an eco-sustainability point of view. Within the system boundaries demolition processes, transport of demolition wastes and its recovery/treatment or disposal in landfill were included. Processes avoided due to reuse-recycling activities, such as extraction of natural resources and manufacture of building materials and components, were considered too. In this paper data collection procedure applied in inventory and impact assessment phases and a general overview about data availability for LCA studies in this sector are presented. Results of application of VAMP methodology to a case study are discussed and compared with a simulated traditional demolition of the same building. Environmental advantages of VAMP demolition-valorization system are demonstrated quantitatively emphasizing the special importance of reuse of building components with high demand of energy for manufacture.

Keywords: Demolition, Valorization, Building components and materials, Recovery, Reuse, Recycling, Landfill disposal, LCA

1. THE VAMP PROJECT

C&D activities produce over 40 million tons of waste a year in Italy[1]. Its composition is shown in Table 1. Compared with situation in USA there are obvious differences: much higher presence of clay materials, less percentage of concrete and negligible contribution of wood in C&D wastes.

About 90-95% of this enormous quantity of waste is disposed in landfill today. If an efficient 'secondary construction goods market' was organized and set up, the disposed waste could be transformed into reusable goods and recyclable material. This recovery network should be environmentally friendly, economically sustainable and easily accessible to waste producers and potential reusers [1].

VAMP is a two-year research project which began in November 1998 and which is scheduled to be completed at the end of 2000. Its final purpose is the setting up of a pilot project and trial run of innovative C&D waste e-commerce in the district of Modena and Reggio Emilia in Italy.

An Internet-based information system will manage and link the C&D waste supply and demand recorded in the area. The group of partners involved in the VAMP project is coordinated by Emilia-Romagna County Council.

Table 1. Composition of demolition waste in Italy and in USA[2]

Waste category	Italy	USA
Plain concrete	10	77
Reinforced concrete	20	
Clay materials	50	4.5
Asphalt	5	
Materials from excavation	6-10	
Wood		11
Paper and cardboard	0.6-4	
Metals	3	3.2
Plastics		0.3
Gypsum		4
Various	1-1.4	

The main goals of the project are:

- to reduce the quantity of C&D waste disposed of in landfill;
- to optimize all the recoverable, reusable and recyclable parts;
- to dispose correctly of waste parts with minimal environmental impact;
- to encourage the use of suitable waste coming from diverse places in the C&D activities;
- to promote the integration of all the already existing local recovery networks and to create favorable conditions for the development of new jobs with particular regard to underprivileged social categories [1].

The VAMP project has planned to reach its objectives by implementing four main actions:

- establishment of a code of practice to help architects and builders to select the most "environmentally friendly" techniques when carrying out the disassembly activities;
- design and development of the Internet-based "distributed information system" able to optimize the waste flows produced by the C&D sector;
- test on field of functions, tools and operational performances of the entire system, in two real demolition case studies;
- dissemination of the achieved results to inform and stimulate the application of the system in other areas [1].

2. APPLICATION OF LCA METHODOLOGY IN THE VAMP PROJECT

2.1 Goals and Scopes of the Study

Partners of the VAMP project realized that a quantitative verification and demonstration of environmental advantages should be necessary to support the VAMP decision making system. In the framework of a co-operation agreement, QUASCO, as a partner of the VAMP project, and ENEA, as supervisor of LCA application, decided to compare, in a life cycle perspective, the proposed VAMP demolition-valorization system to the traditional one that is characterized by landfill disposal of non-selective demolition. A scope of the study was to verify and evaluate the applicability of LCA methodology, such as data availability, to demolition and building waste valorization activities. The VAMP case studies will offer good possibilities to apply the developed LCA model in real experiments.

2.2 Functional Unit, System Boundaries and Allocation Rules

The functional unit is defined as the total amount of building waste of a demolition site. The VAMP system distinguishes four main material fluxes from demolition sites:

- R1: components and materials containing substances damaging the environment;
- R2: recoverable and reusable components;

- R3: recoverable and recyclable materials;
- R4: non recoverable parts.

The processes included in the system are shown in Figure 1. System boundaries include processes avoided due to reuse-recycling activities. Processes related to R1 category are excluded from the LCA system because their demolition and valorization are regulated by law, so they do not change in innovative and traditional demolition systems.

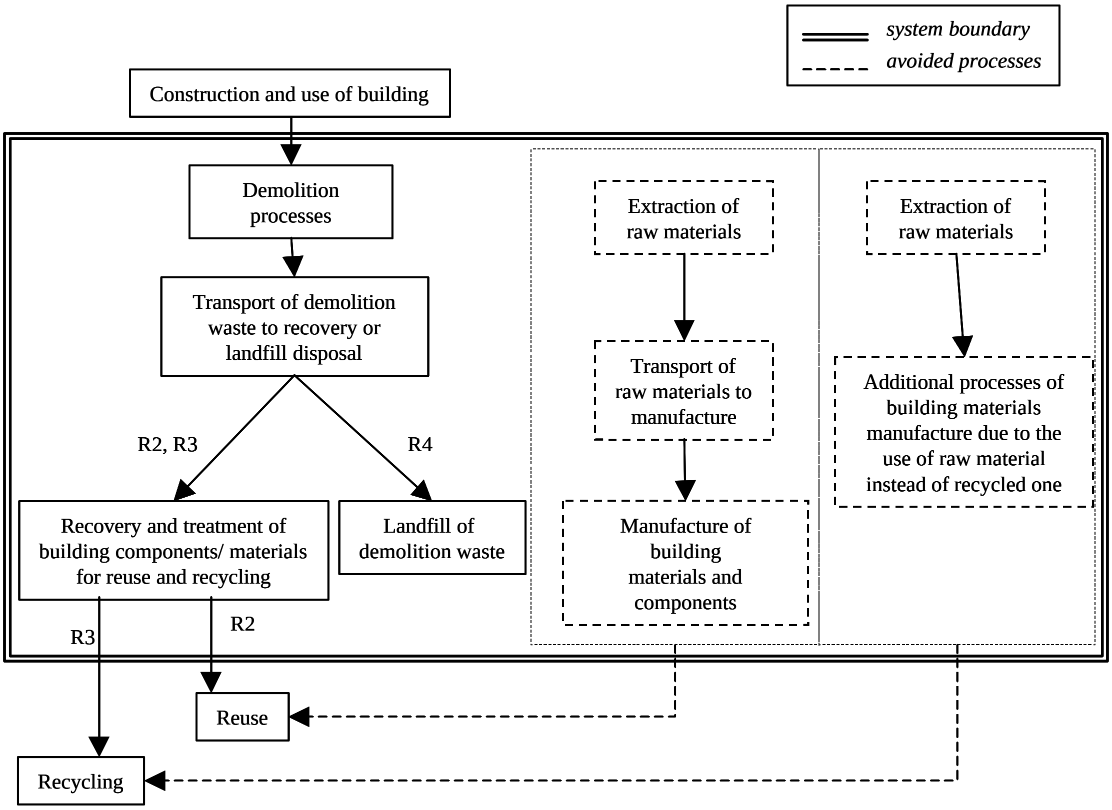

Figure 1. System boundaries of LCA study

Allocation of environmental inputs and outputs of demolition processes among demolished materials and components has to be defined by detailed process descriptions or by mass.

2.3 Inventory data collection

Before starting the data collection, the required quality of inventory data were discussed. Table 2 summarizes the defined data quality.

2.3.1 Data collection from demolition sites

The starting-point of an LCA study for demolition-valorization activity is the data collection from the specific demolition site in order to achieve qualitative and quantitative information about products (components and materials) derived from demolition processes. Energy consumption of demolition processes is the most important environmental data to consider as it can change in traditional or selective approaches due to differences in equipment type and in working time. Water is used also to minimize powder emission and its quantity can be differ with the various demolition processes. Powder and noise emission from demolition sites are excluded from our LCA model. On one hand their valuation is a general problem in LCA studies and their are not accepted methods for it, on the other hand, in a life-cycle prospective we should consider these kind of emissions in all process of the system studied that is hardly realizable because of the lack of data. Anyway in selective demolition suitable procedures are adopted to tackle these problems at source

Demolished wastes are transported to landfill and recovery sites. The exact place of destination (transport distances) and type of transport can differ for each demolition case study depending on local conditions; the collection of these information is so necessary for each specific site.

A future development of the LCA model could be the establishment of an inventory database containing quantitative and qualitative information about energy use and airborne emissions of building demolition equipment such as buckets, grave etc.

Table 2: Quality of inventory data sources

Process	Source of data for inventory
Demolition	on site (specific for the case study)
Transport to recovery or to landfill sites	on site and estimation (specific for the case study)
Recovery of - inert materials - iron, steel - wood - glass	on site from recovery sites (not specific for the case study)
Landfill of - demolition waste - waste from recovery processes	on site from landfills (not specific for the case study)
Extraction of raw materials - gravel - clay, wood, iron ore, sand, ecc.	 on site from caves* databases, bibliography
Transport of raw materials	estimation
Manufacturing of building materials and components	databases, bibliography
Additional processes due to use of raw materials instead of recycled one	bibliography

* Recovered and treated inert demolition wastes can be used in the place of gravel as unbound base course material or for low grade fill material. Because of its determinant quantity inside of the system studied, we found it necessary to collect data about extraction of gravel on site.

2.3.2 Data collection from recovery and landfill sites

Several enterprises of this sector were contacted to collect information on environmental inputs and outputs. The goal was the starting up of the development of a database containing complete inventory information that is specific for the local territory. Its use is generally possible in specific demolition case studies.

Good quality data were achieved about processes that are more determinant in our LCA model such as landfill sites for demolition waste, fixed and mobile recovery plants of inert waste. Usually the largest quantity of the material fluxes from demolition sites (expected 90-95% of the total mass) are sent to these processes.

The difficulties arose during this part of the work have to be highlighted. We had problems in obtaining ecobalances of recovery and landfill plants because this kind of analyses would require a large quantity of time and resource that small sized companies could not ensure. Just a few companies were accessible to supply high quality data during personal meetings and site visits. The future improvement of the database can be achieved by a more efficient engagement of the waste recovery sector in the project.

2.3.3 Bibliographic data collection

To correctly take in account avoided processes, a research in the available bibliography sources such as local environmental studies and international publications were performed on the most frequently reused components and recycled materials Table 3 summarizes all the consulted and evaluated bibliography sources.

The lack of complete bibliography sources on this field did not allow the use of the same data source for each processes. International database made by IVAM[3] has been considered as one of the richest and most credible data source. We highlight the importance to consider local studies results although they usually contain only partial information and incomplete inventory process data.

Table 3: Summary of bibliographic inventory data for building material and component production

Process	**Bibliography reference**
extraction of clay	[3,4]
wood harvesting	[3, 5, 6, 7, 8, 9]
iron mining	[10]
extraction of natural stone	[3]
manufacture of clay brick	[3, 11]
manufacture of clay tiles	[3, 5, 6, 12]
manufacture of wood roof trusses	[3, 7]]
manufacture of iron and steel	[3, 5, 6]
manufacture of glass	[3, 6]
manufacure of wood window frames	[13]
production of chips	[14]
other related studies	[15, 16, 17, 18, 19]

2.4 Impact Assessment

For impact assessment we chose five main impact categories that can characterize the environmental damage of different scenarios of demolition-valorization.

In all phases of the studied system, consumption of energy in different forms is the only or at least one of the most important environmental data. Characterization of the quantity of extracted natural resources for energy production – such as fossil fuels, nuclear energy, renewal energy sources etc. – is possible by primary energy content values determined in MJ.

There are two chosen impact categories which are in strict correlation with the quality of consumed energy such as electricity or mechanical energy for transport: greenhouse effect and acidification. Their use is advisable also because of their scientifically well-determined characterization factors.

Solid waste production and disposal in landfill is an obvious impact category for the demolition-valorization system. Characterization of solid waste disposal is carried out by mass, effects due to production of leachate and biogas were neglected because of the large quantity of inert waste in the system (about 95%).

Extraction of abiotic natural resources is an important impact category because of the characteristics of the main building materials and products used in Italy. For the characterization of natural resource extraction there are several available approaches in the bibliography [3, 20-23] but data credibility is not high because of lack of scientific methods. Moreover they are specific for different categories of natural resources, so are not applicable for all substances included in our system: in particular resources with large availability in nature (gravel, clay, sand), abiotic resources with limited availability (minerals of metals) and biotic resources (wood). At the end we followed Finnveden[21] approach, considering mass of extracted natural resources as characterization factor. It does not characterize the differences in abundance and social value of resources which should be parts of a measure of the seriousness of depletion. On the other hand there is also a need for simple measures and that when energy and materials are aggregated into several subcategories, similar results in qualitative terms may be obtained as when several more complicated methods are used.

With regard to avoided processes, we have to highlight that inclusion of other impact categories can be necessary in special cases. It can happen when processes related to building product manufacture have relevant airborne or waterborne emissions; in this case other categories such as ecotoxicity, neutrophication, photochemical smog etc. shall be analyzed.

3. A VAMP CASE STUDY - RESULTS OF LCA STUDY

The case study described in this paper was carried out in Reggio Emilia where a building, called "Ex-Sarsa" and built in the twentieth as a station and deposition site of a transportation company, was demolished. Table 4 describes the demolition processes, the valorization of demolished components/materials and the avoided processes considered in the LCA study.

Table 4: Application of VAMP demolition-valorization system in the “Ex-Sarsa” case study

Demolition processes	Demolished components and materials	Quantity	Destination	Reuse/ Recycling	Avoided processes
manual demolition of roof coating (8 hours)	clay tiles and lath bricks	110 t	inert waste recovery plant (10 km)	100% recycling	extraction of gravel
manual demolition of roof structure using crane (1hour)	wood roof trusses	2.4 t	on site reuse	100% reuse	tree harvesting; manufacture of structural timber
manual demolition of roof structure using crane (1hour)	wood parts	15 t	wood recovery plant (100 km)	100% recycling	tree harvesting; production of chips
demolition of external pavement by excavator (8 hours)	porphyry bricks	660 t	inert waste recovery plant (10 km)	70% reuse	extraction of natural stone; manufacture of stone brick
				30% recycling	extraction of gravel
demolition of masonry by grab bucket (22 hours)	clay bricks	350 t	inert waste recovery plant (10 km)	70% reuse	extraction of clay; manufacture of clay brick
				30% recycling	extraction of gravel
	wood parts	20 t	wood recovery plant (100 km)	100% recycling	tree harvesting; production of chips
	iron parts	1 t	iron recovery plant (40 km)	100% recycling	extraction of iron ore; production of sinter

For the traditional demolition-valorization system, it was estimated that masonry would have been demolished in less time (14 hours) because of lack of selection of clay bricks and wood parts, and inert wastes (clay tiles and lath bricks, porphyry bricks, clay bricks) and wood parts would have been disposed in landfill (15 km distance).

The summarized results of this case study (Figure 2-3) show that VAMP system has environmental advantages in all of the impact categories. If avoided processes are not considered, nevertheless use of energy, greenhouse effect and acidification are about 10% smaller in VAMP system then in traditional one. When avoided processes are considered, advantages of VAMP system seems to be obvious.

Analyzing detailed numeric results in Table 5 we can make further considerations. Energy consumption of demolition, transport and recovery/landfill stages of the demolished components/materials were in the same order (about 1000-5000

MJ). Only the relatively time-consuming demolition process of clay bricks and the transport of the large amount of porphyry had a significantly higher energy demand (15000-25000 MJ). Processes regarding iron parts had lower energy consumption because of the small quantity (30-100 MJ). Although the total energy demand of selective demolition was 20% higher than the traditional one, transport and recovery processes used 15%-37% less energy in case of the VAMP system mainly due to reuse activity that requires negligible energy for recovery. The most surprising result was the extremely high amount of avoided energy in VAMP system (1.2 TJ) mostly due to the reuse of clay bricks as entire components. In fact the manufacture of bricks from clay raw material has a high energy demand in the drying (about 27% of total energy demand) and firing (about 70% of total energy demand) phases[11].

The total amount of solid waste was much higher in the traditional system producing more than 1000 t waste disposed in landfill. A huge amount of natural resource extraction was avoided by the VAMP waste reuse-recycling system: 447 t porphyry, 442 t gravel, 343 t clay, 87 t wood and 1.45 t iron ore.

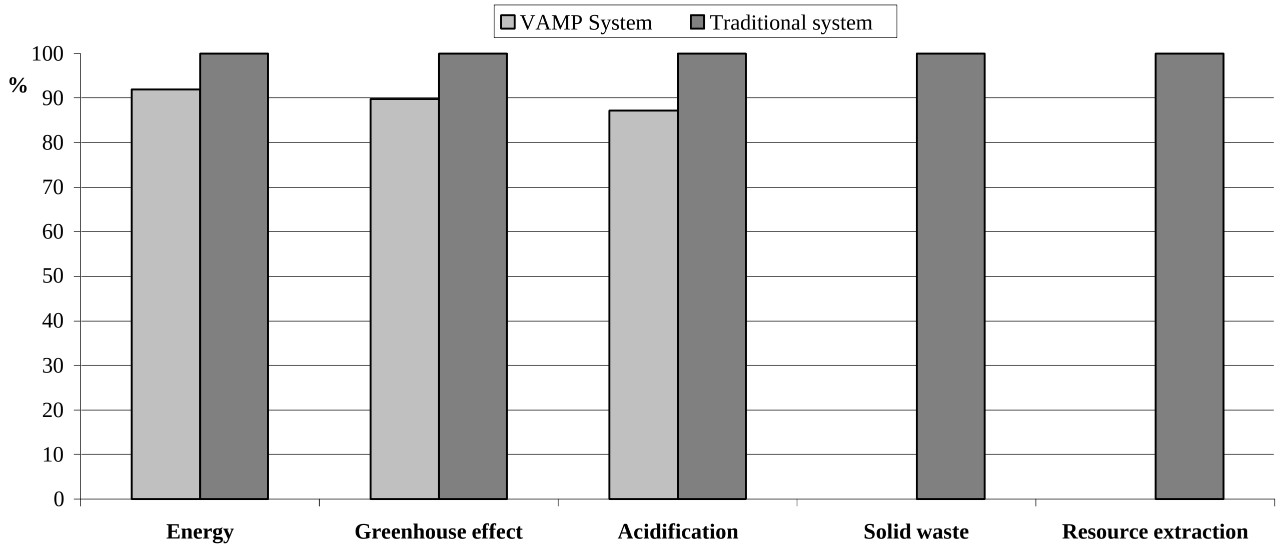

Figure 2: Comparison of different environmental impact categories (avoided processes excluded)

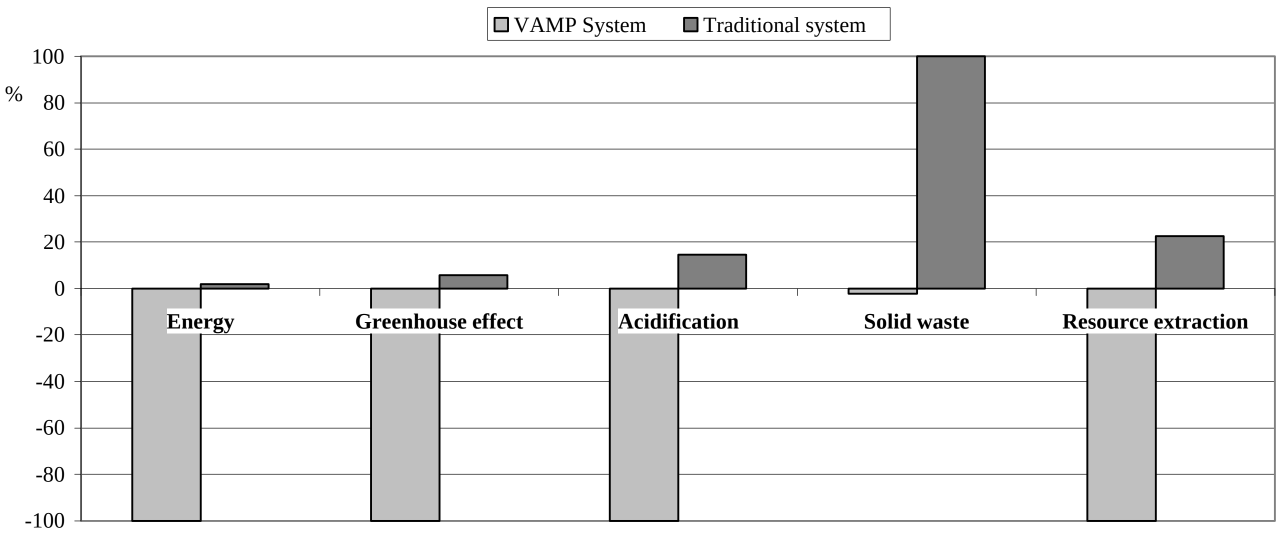

Figure 3: Comparison of different environmental impact categories (avoided processes included)

Table 5: Energy consumption, greenhouse effect, acidification, solid waste production and natural resource extraction in VAMP and traditional demolition-valorization of Ex-Sarsa case study (Dem.=demolition; Trans.=Transport; Rec.=Recovery)

	units	VAMP selective demolition-valorization				Traditional demolition-valorization			
		Dem.	Trans.	Rec.	Avoided processes	Dem.	Trans.	Landfill/Rec.	Avoided processes
clay tiles and lath bricks	MJ		2780	3140	-7800		4160	2040	
	kg CO_2		208	206	-466		311	156	
	kg SO_2		2.87.	2.28	-4.19		4.31	2.19	
	kg sol. waste								
	t resource				-112.8 (gravel)			29.6 (soil)	
wood roof trusses	MJ	847			-13400	847			-13400
	kg CO_2	50.6			-1020	50.6			-1020
	kg SO_2	0.456			-14.4	0.456			-14.4
	kg sol. waste				-0.45				-0.45
	t resource				-11.2 (wood)				-11.2 (wood)
wood parts	MJ	2140	8840	1480	-43600	1670	1330	650	
	kg CO_2	158.6	66.1	136	-3330	131.4	99.1	49.6	
	kg SO_2	1.96	9.13	1.91	-46.9	1.6	1.37	0.69	
	kg sol. waste				-1.46			35000	
	t resource				-75.9 (wood)			9.45 (soil)	
porphyry bricks	MJ	4500	16700	5730	-56400	4500	25000	12300	
	kg CO_2	344	1250	375	-3500	344	1870	936	
	kg SO_2	4.83	17.2	4.15	-34	4.87	25.8	13.2	
	kg sol. waste				-159			660000	
	t resource				-216 (gravel) and -447 (porphyry)			178 t soil	
clay bricks	MJ	22600	8800	3010	1110000	14500	13300	6500	
	kg CO_2	1890	661	197	-49150	1420	991	49.6	
	kg SO_2	26.5	9.13	2.18	-498	19.9	13.7	6.98	
	kg sol. waste				-23900			350000	
	t resource				-113 (gravel) and -343 (clay)			94.5 t soil	
iron parts	MJ	64.6	101	39.2	-52000	33.7	101	39.2	-52000
	kg CO_2	5.38	7.55	2.52	-1240	4.05	7.55	2.52	-1240
	kg SO_2	0.076	0.104	0.027	-5.58	0.057	0.104	0.027	-5.58
	kg sol. waste				-778				-778
	t resource				-1.45 (iron ore)				-1.45 (iron ore)
Total of life-cycle stages	GJ	30.1	37.2	13.4	-1283	21.5	43.9	21.5	-65.4
	kg CO_2	2450	2780	917		1950	3260	1640	
	kg SO_2	33.9	38.5	10.5		26.9	45.1	23.1	
	t sol. waste				-24.8			1155	-0.8
	t resource				-1320			311.5 t soil	-12.6
Total of life-cycle (avoided processes excluded)	GJ	83.6				91			
	kg CO_2	6150				6850			
	kg SO_2	82.9				95			
	t sol. waste					1155			
	t resource					311.5			
Total of life-cycle (avoided processes included)	GJ	-1200				21.6			
	kg CO_2	-79600				4610			
	kg SO_2	-520				75.3			
	t sol. waste	-24.8				1154			
	t resource	-1320				299			

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CONCLUSIONS

A model using life-cycle approach has been developed for the activity of building demolition and for valorization of demolished waste by the application of LCA methodology. Data collection procedure for demolition sites, initial database for waste recovery processes, a summary of bibliographic inventory data for building materials and components manufacture and impact assessment methods were prepared. The case study results showed clearly the environmental advantages of the VAMP system. Besides the quite obvious conclusions, such as huge amount of avoided solid waste in landfill and extracted natural resources, we highlighted the importance of the building component reuse activity. In the case study presented in this paper, an extremely relevant energy consumption was avoided because of the reuse of clay bricks as entire components. The application of LCA to other VAMP case studies in the year 2000 will help us to collect still more credible data for inventories. Environmental analyses will be integrated by an economic comparison of VAMP and traditional demolition-valorization activities.

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