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A methodology for predicting the severity of environmental impacts related to the construction process of residential buildings

Marta Gangolells [a*], Miquel Casals [a], Santiago Gassó [b], Núria Forcada [a], Xavier Roca[a] , Alba Fuertes[a]

[a] Technical University of Catalonia. Department of Construction Engineering. Group of Construction Research and Innovation (GRIC). C/ Colom, 11. Ed. TR5. 08222 Terrassa (Barcelona). Spain.

[b] Technical University of Catalonia. Engineering Project Department. C/ Colom, 11. Ed. TR5. 08222 Terrassa (Barcelona). Spain.

[*] Corresponding author: Marta Gangolells. Tel: +(34) 93 7398947, Fax: +(34) 93 7398101. e-mail: marta.gangolells@upc.edu

ABSTRACT

This paper introduces a systematic approach for dealing with potential adverse environmental impacts at the pre-construction stage. The proposed methodology serves as an assessment tool for construction projects to measure the environmental performance of their construction activities. It also provides a consistent basis for comparisons and for future eco-labelling and environmental benchmarking among construction companies and construction sites. Within the methodological framework, nine categories of environmental aspects are proposed: atmospheric emissions; water emissions; waste generation; soil alteration; resource consumption; local issues; transport issues; effects on biodiversity; and incidents, accidents and potential emergency situations. The methodology includes twenty performance indicators developed with the help of a panel of experts. In order to avoid a typical shortcoming in environmental assessments methods, these environmental indicators, both direct and indirect, are always based on quantitative data available in the project documents. Significance limits for environmental aspects are also developed based on a statistical analysis of 55 new-start construction projects. Four case studies are provided to illustrate the practical use of the proposed methodology.

Keywords:
environmental impacts, environmental management, buildings, construction process.

1. INTRODUCTION

Construction project performance has traditionally been measured in terms of time, cost and quality. Lately, the environment has been considered the fourth dimension [1] and construction organizations have been urged to adopt Environmental Management Systems (EMS) in order to improve their environmental performance [2]. However, recent literature shows that construction firms have been slow to adopt environmental performance evaluations (EPE or ISO 14031) due to 'a lack of technological support, such as training, staff and expertise' and 'an increase in administrative costs' [3]. Therefore, it is commonly perceived that the application of EMS will involve the deployment of extra resources [4] without tangible benefits [5].

According to Chen and Li, there have been few studies on integrating aspects of environmental management in the construction planning stage in particular [6]. Moreover, current approaches to environmental control and management are highly qualitative [7]. A search of the Civil Engineering Database of the American Society for Civil Engineering and the Ei Compendex database found that only 2% of all papers on environmental management in construction provide quantitative methods [7]. Of the papers providing such methods, the approaches of Tam et al.[8], Cheung et al. [9], Shen et al.[10] and Liu et al. [11] are among the most noteworthy. Especially worthwhile is the Construction Pollution Index method, developed by Chen et al. [12], which has proved to be an efficient means of quantitatively evaluating the pollution and hazard levels of construction processes and projects. Chen et al. determined how to select the best construction plan by classifying adverse environmental impacts of construction operations/activities using the EnvironalPlanning method [7]. However, subjective judgements often influence the accuracy of the aforementioned methods.

The goal of this paper is to support the implementation of Environmental Management Systems in construction companies and help organizations to improve their environmental performance. For this reason, the purpose of this research is to develop a quantitative methodology for dealing with potential adverse environmental impacts at the pre-construction stage.

2. DEFINITION AND DEVELOPMENT OF THE METHODOLOGY

This paper presents a methodology for predicting and assessing the environmental impacts associated with the construction of new residential buildings. The proposed methodology is able to compare the overall environmental impact of various construction projects and to rank the significance of the various environmental impacts of each of these projects. The relevance of each environmental aspect at a particular site is identified prior to the construction stage and, therefore, significant impacts are highlighted in advance. Thus, it is possible to provide a range of measures for mitigating adverse impacts that can then be implemented during on-site construction activities. The methodology is also able to compare the absolute importance of a particular environmental aspect in various construction projects.

To predict the severity of environmental impacts related to the construction of residential buildings, the following methodology is proposed:

1. Identification of environmental aspects related to the construction process.
2. Assessment of the environmental aspects.

a. Development of indicators.
b. Formulation of the significance limits.
c. Determination of the overall environmental impact of a construction project.

2.1. IDENTIFICATION OF ENVIRONMENTAL ASPECTS

The identification of environmental aspects is the first step of this methodology. To do this, an exhaustive preliminary analysis with a process-oriented approach [13] is carried out. First, the main processes are identified and divided into smaller process steps. The environmental aspects associated with each construction process are then identified (Fig. 1).

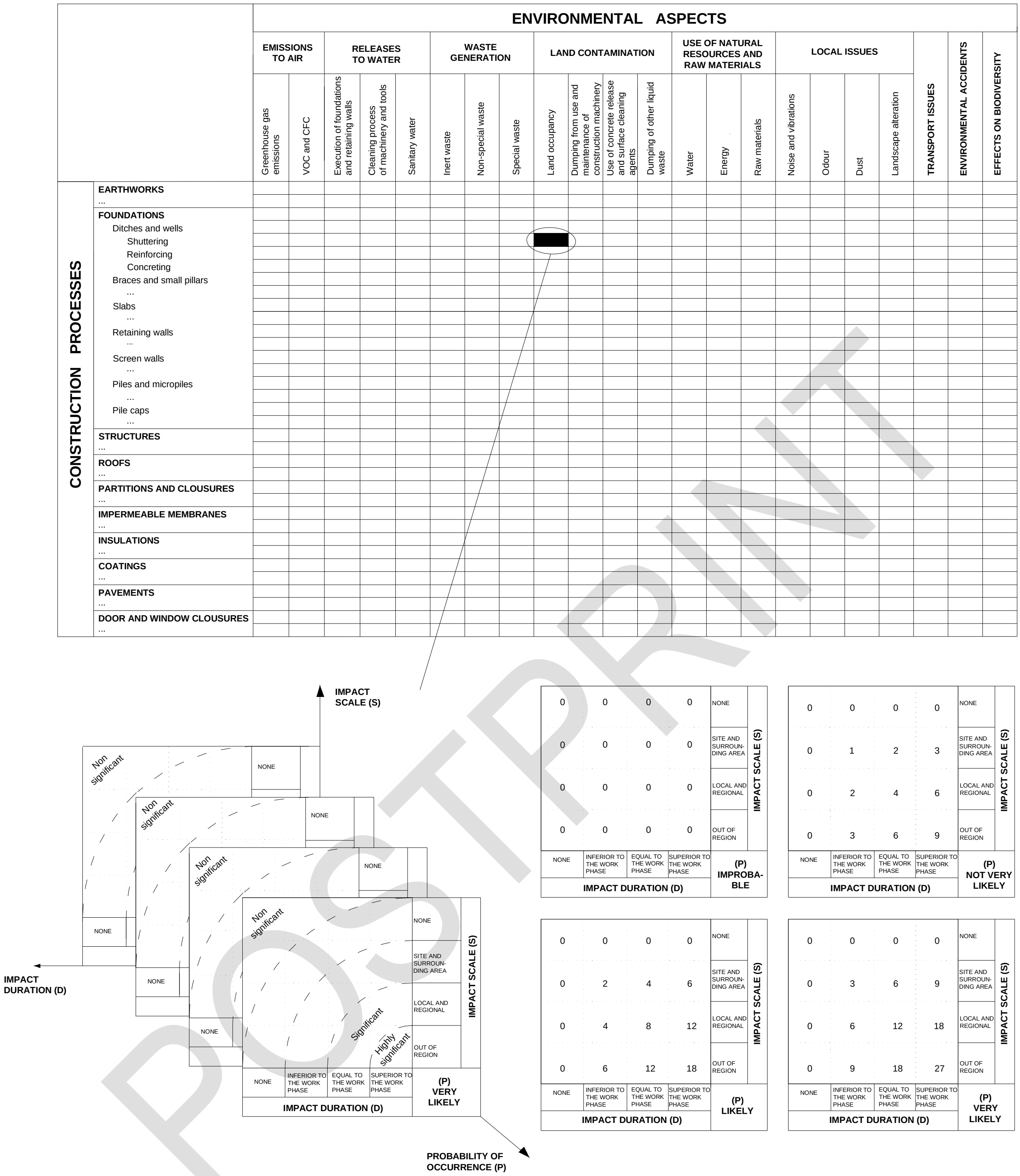

Fig. 1. Identification of environmental aspects in a process-oriented approach and numerical scales for the three components of significance: probability of occurrence (P), impact duration (D) and impact scale (S). Source: Partially adapted from [26].

2.1.1. Construction processes and activities initially considered

The construction processes initially considered were (1) earthworks, (2) foundations, (3) structures, (4) roofs, (5) partitions and closures, (6) impermeable membranes, (7) insulations, (8) coatings, (9) pavements and (10) door and window closures. These main construction processes were divided into smaller process steps as indicated by Roberts and Robinson [14]. A total of 219 stages and activities were ultimately considered in this initial environmental review (Fig. 1).

2.1.2. Environmental aspects initially considered

According to Chen et al., on-site construction activities usually result in soil and ground contamination, surface and underground water contamination, construction and demolition waste, noise and vibration, dust, hazardous emissions and odours, impacts on wildlife and natural features, and archaeology impacts [7]. Shen and Tam classified construction-related environmental impacts as the extraction of environmental resources such as fossil fuels and minerals; the extension of consumption of generic resources; the production of waste that requires the consumption of land for disposal; and the pollution of the living environment with noise, odours, dust, vibrations, chemical and particulate emissions, and solid and sanitary waste [15]. According to Gangolells et al., typical negative impacts of construction activities include atmospheric emissions, water emissions, soil alteration, waste generation, resource consumption and others (potential impacts on the community and on the local traffic and potentially hazardous scenarios) [16].

Many other approaches have been described and proposed [17], [18], [19], [20] but the literature reaches no consensus regarding the environmental aspects associated with the construction process. The Eco-Management and Audit Scheme (EMAS) [21] provides a standardized and comprehensive list of environmental aspects that covers almost all of the aforementioned environmental aspects. Thus, the authors used EMAS [21] as a guide to initially identify general environmental aspects:

(a) Emissions to air;
(b) Releases to water;
(c) Avoidance, recycling, reuse, transportation and disposal of solid and other wastes, particularly hazardous wastes;
(d) Use and contamination of land;
(e) Use of natural resources and raw materials (including energy);
(f) Local issues (noise, vibration, odour, dust, visual appearance, etc.);
(g) Transport issues;
(h) Risks of environmental accidents and impacts arising, or likely to arise, as consequences of incidents, accidents and potential emergency situations;
(i) Effects on biodiversity.

In order to increase the level of precision, some of these environmental aspects were divided into more specific aspects [22]. For example, the emission of greenhouse gases and the emission of volatile organic compounds (VOCs) and chlorofluorocarbons (CFCs) were considered, rather than just emissions to air.

2.1.3. Identification of environmental aspects related to the construction process

ISO 14004:2004 [23] states that when criteria for significance are being established, an organization should consider environmental criteria (such as scale, severity and duration of the impact, or type, size and frequency of an environmental aspect), applicable legal requirements (such as emission and discharge limits in permits or regulations, etc.) and the concerns of internal and external interested parties (such as those related to organizational values, public image, etc.).

Potential regulatory and legal exposure, the difficulty and cost of changing the impact, the effect of change on other activities and processes, the concerns of interested parties and the effect on the public image of the organization are considered business concerns. Some authors recommend excluding these criteria in the assessment process, arguing that they could lead to biased assessment results, or that the results might be misused [24].

According to Põder, the evaluation of the significance of environmental impacts can be facilitated by considering spatial scale (the physical area influenced by a particular environmental aspect), severity (the combination of quantity, toxicity, affected volume, surface area and temporal extent), probability (the likelihood of the event causing the environmental impact) and duration (persistence) of the environmental impact [24].

The severity of an environmental aspect varies with each specific building site, as there is a correlation between the magnitude of the project (quantities and toxicity of the materials involved, affected volume, or surface and temporal extent) and the effects caused. Other criteria do not depend on the construction project, so they can be used in this early stage to determine significant environmental aspects for every construction process: the scale of the impact, its probability of occurrence and its duration (Fig. 1).

A panel of experts from various professional fields were asked to evaluate the nine environmental aspects in terms of scale, duration and probability of occurrence for each construction stage. The panel of experts was composed of local experts from independent institutions as well as from stakeholder organizations related to both environmental and construction fields. The basic considerations for selecting participants included a background in construction management as well as familiarity with environmental issues. Finally, the consultation panel was composed of three associate professors at the Technical University of Catalonia (two from the construction field and the other one from the environmental field), three project managers working in construction SMEs, three experts from environmental consultancy firms and two observers. At a first stage, a personalized letter outlining the nature of the research and indicating that they would be called to arrange a meeting was mailed to all participants.

During the meeting, discussions focussed on the questionnaire prepared to facilitate data collection. The questionnaire was represented as a matrix whose columns were environmental aspects and whose rows where construction stages. To diminish the intrusion of subjectivity during the identification of environmental aspects, a four-interval scale was developed for each of the three aforementioned components of significance. The spatial extent or zone of environmental impact influence can range from site-specific to regional or national; therefore, the scale for extent of impact is a progression through geographical units. The probability of occurrence refers to the frequency of the event that causes the environmental impact. This component of significance was scaled in a similar way and ranged from low probability (rare) to relatively high probability (likely or frequent). The duration of an environmental impact was scaled by taking into account the length of time that the environmental impact lasts. In this case, the duration of an environmental impact was described quantitatively in relation to the duration of the construction phase.

The scale of the impact, its duration and its probability of occurrence can be cross-referenced; for example, noise arising from the earthworks phase is site-specific, short-term and has a high probability of occurrence, whereas the generation of greenhouse gas emissions that contribute to climate change during the cladding phase has an international scale and is persistent but has low probability of occurrence (excluding the transportation of materials). These three components of significance can therefore be represented graphically with the impact duration as the x-axis, the impact scale as the y-axis and the probability of occurrence as the z-axis. An impact is highly significant if it registers in the lower right part of the three graphs (Fig. 1).

In order to calculate the overall significance rating of an environmental impact in a specific construction stage, the four grade scales for the three components of significance are converted into numerical scales (Fig. 1).

For the sake of simplicity, the overall significance rating of an environmental impact in a particular construction stage was obtained using the following expression:

$$SG_i = D_i \cdot S_i \cdot P_i \qquad (1)$$

where SG_i denotes the overall significance rating of an environmental impact in a specific construction stage i. D_i denotes the impact duration, assumed to be 0 (none), 1 (shorter than the duration of the construction stage), 2 (equal to the duration of the construction stage) or 3 (greater than the duration of the construction stage). S_i corresponds to the impact scale, ranging from 0 (none), 1 (site and surrounding area), 2 (local and regional) to 3 (out of region). Finally, P_i denotes the probability of occurrence of the impact, assumed to be 0 (improbable), 1 (not very likely), 2 (likely) or 3 (very likely).

In this initial identification of environmental aspects, an environmental impact for a specific construction stage was considered significant if its overall significance rating was greater than 3. The resulting matrix allowed us to distinguish potential environmental impacts for each construction stage. With the help of the experts, and in order to make future assessments controllable and effective, some environmental aspects were aggregated whereas others where disaggregated.

As a result of this process, the significant environmental aspects for construction activities were obtained. The ‘atmospheric emissions’ category includes environmental aspects derived from the emission of greenhouse gases, VOCs and CFCs. All those environmental aspects with potential adverse impacts on the quality of surface water, groundwater or the sewage system were included in the ‘water emissions’ category. The ‘soil alteration’ category includes all the aspects related to land occupancy and potential adverse impacts due to the dumping of pollutant liquids. The methodology also includes all waste materials expected to be generated during construction: human waste, excavated material generated during earthworks, excess off-cuts of construction materials (reinforcement, concrete and formwork). Hazardous substances are also considered. Environmental aspects related to the use of resources (mainly water, electricity, fuel and raw materials) are also taken into account. Specific local issues such as suspended particles emission, dirtiness, noise, vibrations and visual impacts are also included in the methodology. Since construction work may also cause impacts on local traffic and transport, the methodology includes a category called ‘transport issues’. The ‘effects on biodiversity’ category includes all aspects related to vegetation loss, loss of soil fertility and potential adverse impacts due to the interception of river beds. Risks of environmental accidents and impacts arising, or likely to arise, as consequences of incidents, accidents and potential emergency situations are also considered. Specific environmental aspects are listed in Table 1.

ENVIRONMENTAL ASPECT		ENVIRONMENTAL INDICATOR [P]	SOURCE		SV[1] = 0	SV = 1	SV = 3	SV = 5
ATMOSPHERIC EMISSIONS								
AE-1	Generation of greenhouse gas emissions due to construction machinery and vehicle movements.	Volume of excavated material per m^2 of floor area $[m^3/m^2] \cdot C + 0.3 \cdot N$; where C=1.2 when special machinery is needed, otherwise C=1.0 and N is the number of power generators.	Bill of quantities / budget / geotechnical study	SF[2]	P[3] = 0.0000	$0.0000 < P < 0.3230$	$0.3230 \leq P < 2.7601$	$P \geq 2.7601$
				MF[2]	$P = 0.0000$	$0.0000 < P < 0.6646$	$0.6646 \leq P < 1.3454$	$P \geq 1.3454$
AE-2	Emission of VOCs and CFCs.	% of synthetic paints and varnishes.	Bill of quantities / budget	SF	$P = 0.0000$	$0.0000 < P < 5.1511$	$5.1511 \leq P < 43.0626$	$P \geq 43.0626$
				MF	$P = 0.0000$	$0.0000 < P < 5.1511$	$5.1511 \leq P < 43.0626$	$P \geq 43.0626$
WATER EMISSIONS								
WE-1	Dumping of water resulting from the execution of foundations and retaining walls.	Quantity of thixotropic fluid[4] per m^2 of floor area $[kg/m^2]$.	Bill of quantities / budget	SF	$P = 0$	-	-	$P \neq 0$
				MF	$P = 0.0000$	$0.0000 < P < 2.6335$	$2.6335 \leq P < 5.3469$	$P \geq 5.3469$
WE-2	Dumping of water resulting from the process of cleaning concrete chutes or dumping of other basic fluids.	Quantity of concrete per m^2 of floor area $[m^3/m^2]$.	Bill of quantities / budget	SF	$P = 0.0000$	$0.0000 < P < 0.8891$	$0.8891 \leq P < 1.1209$	$P \geq 1.1209$
				MF	$P = 0.0000$	$0.0000 < P < 0.3069$	$0.3069 \leq P < 0.5131$	$P \geq 0.5131$
WE-3	Dumping of sanitary water resulting from on-site sanitary conveniences.	Average number of workers per day.	Health and safety plan	SF	-	$0 < P < 6$	$6 \leq P < 13$	$P \geq 13$
				MF	-	$0 < P < 13$	$13 \leq P < 40$	$P \geq 40$
WASTE GENERATION								
WG-1	Generation of excavated waste material during earthworks.	Volume of excavated material ending up in landfill sites per m^2 of floor area $[m^3/m^2]$.	Bill of quantities / budget	SF	$P = 0.0000$	$P < 0.2851$	$0.2851 \leq P < 3.1400$	$P \geq 3.1400$
				MF	$P = 0.0000$	$P < 0.4299$	$0.4299 \leq P < 1.3461$	$P \geq 1.3461$

ENVIRONMENTAL ASPECT		ENVIRONMENTAL INDICATOR [P]	SOURCE		SV[1] = 0	SV = 1	SV = 3	SV = 5
WG-2	Generation of municipal waste by on-site construction workers.	Average number or workers per day.	Health and safety plan	SF	-	$P < 6$	$6 \leq P < 13$	$P \geq 13$
				MF	-	$P < 13$	$13 \leq P < 40$	$P \geq 40$
WG-3	Generation of inert waste.	Floor area [m^2].	Building specifications / drawings	SF	-	$P < 296.14$	$296.14 \leq P < 1{,}237.37$	$P \geq 1{,}237.37$
				MF	-	$P < 690.72$	$690.72 \leq P < 5{,}504.27$	$P \geq 5{,}504.27$
WG-4	Generation of ordinary or non-special waste (wood, plastic, metal, paper, cardboard or glass).	Floor area [m^2].	Building specifications / drawings	SF	-	$P < 296.14$	$296.14 \leq P < 1{,}237.37$	$P \geq 1{,}237.37$
				MF	-	$P < 690.72$	$690.72 \leq P < 5{,}504.27$	$P \geq 5{,}504.27$
WG-5	Generation of special (potentially dangerous) waste.	Floor area [m^2].	Building specifications / drawings	SF	-	$P < 296.14$	$296.14 \leq P < 1{,}237.37$	$P \geq 1{,}237.37$
				MF	-	$P < 690.72$	$690.70 \leq P < 5{,}504.27$	$P \geq 5{,}504.27$
SOIL ALTERATION								
SA-1	Land occupancy by the building, provisional on-site facilities and storage areas.	Site occupation per m^2 of floor area [m^2/m^2].	Building specifications / drawings	SF	-	$P < 0.5661$	$0.5661 \leq P < 2.5532$	$P \geq 2.5532$
				MF	-	$P < 0.1684$	$0.1684 \leq P < 0.3376$	$P \geq 0.33376$
SA-2	Use of concrete release agent at the construction site.	Use of concrete.	Building specifications / drawings	SF	-	Neither the structure of the building nor its facades are made of in-situ concrete.	The structure of the building or most of its facades are made of in-situ concrete.	The structure of the building and most of its facades are made of in-situ concrete.
				MF	-	Neither the structure of the building nor its facades are made of in-situ concrete.	The structure of the building or most of its facades are made of in-situ concrete.	The structure of the building and most of its facades are made of in-situ concrete.

ENVIRONMENTAL ASPECT		ENVIRONMENTAL INDICATOR [P]	SOURCE		SV[1] = 0	SV = 1	SV = 3	SV = 5
SA-3	Use of cleaning agents or surface-treatment liquids at the construction site.	% of facing brick closure.	Bill of quantities / budget	SF	P = 0.00%	0.00%< P < 14.85%	14.85% ≤ P < 76.51%	P ≥ 76.51%
				MF	P = 0.00%	0.00% < P < 14.85%	14.85% ≤ P < 76.51%	P ≥ 76.51%
		% of the floor area having discontinuous ceramic and/or stone surfaces.	Bill of quantities / budget	SF	P = 0.00%	0.00% < P < 30.33%	30.33% ≤ P < 60.72%	P ≥ 60.72%
				MF	P = 0.00%	0.00% < P < 30.33%	30.33% ≤ P < 60.72%	P ≥ 60.72%
SA-4	Dumping derived from the use and maintenance of construction machinery.	Volume of excavated material per m^2 of floor area [m^3/m^2] + 6E-5·floor area [m^2].	Bill of quantities / budget	SF	-	P < 0.3640	0.3640 ≤ P < 2.7536	P ≥ 2.7536
				MF	-	P < 0.7460	0.7460 ≤ P < 1.8660	P ≥ 1.860
SA-5	Dumping of water resulting from the execution of foundations and retaining walls.	Quantity of thixotropic fluid[4] per m^2 of floor area [kg/m^2].	Bill of quantities / budget	SF	P = 0	-	-	P ≠ 0
				MF	P = 0.0000	0.0000 < P< 2.6335	2.6335 ≤ P < 5.3469	P ≥ 5.3469
SA-6	Dumping of water resulting from the process of cleaning concrete chutes or dumping of other basic fluids.	Quantity of concrete per m^2 of floor area [m^3/m^2].	Bill of quantities / budget	SF	P = 0.0000	0.0000 < P < 0.8891	0.8891 ≤ P < 1.1209	P ≥ 1.1209
				MF	P = 0.0000	0.0000 < P< 0.3069	0.3069 ≤ P < 0.5131	P ≥ 0.5131
SA-7	Dumping of sanitary water resulting from on-site sanitary conveniences.	Average number of workers per day.	Health and safety plan	SF	-	0 < P < 6	6 ≤ P < 13	P ≥ 13
				MF	-	0 < P < 13	13 ≤ P < 40	P ≥ 40
RESOURCE CONSUMPTION								
RC-1	Water consumption during the construction process.	Water consumption[5] per m^2 of floor area [m^3/m^2].	Bill of quantities / budget	SF	-	P < 0.0592	0.0592 ≤ P < 0.1272	P ≥ 0.1272
				MF	-	P < 0.0606	0.0606 ≤ P < 0.0974	P ≥ 0.0974
RC-2	Electricity consumption during the construction process.	Floor area [m^2].	Building specifications / drawings	SF	-	P < 296.14	296.14 ≤ P < 1,237.37	P ≥ 1,237.37
				MF	-	P < 690.72	690.72 ≤ P < 5,504.27	P ≥ 5,504.27

ENVIRONMENTAL ASPECT		ENVIRONMENTAL INDICATOR [P]	SOURCE		SV[1] = 0	SV = 1	SV = 3	SV = 5
RC-3	Fuel consumption during the construction process.	Volume of excavated material per m^2 of floor area [m^3/m^2] · C + 0.3·N; where C=1.2 when special machinery is needed, otherwise C=1.0 and N is the number of power generators.	Bill of quantities / budget	SF	P = 0.0000	0.0000 <P < 0.3230	0.3230 ≤ P < 2.7601	P ≥ 2.7601
				MF	P = 0.0000	0.0000 < P < 0.6646	0.6646 ≤ P < 1.3454	P ≥ 1.3454
RC-4	Raw materials consumption during the construction process.	Weight[6] of structural floors, foundations, facades, partition walls, pavements and roofs per m^2 of floor area [kg/m^2].	Bill of quantities / budget	SF	-	P < 1,011.4	1,011.4 ≤ P < 2,530.6	P ≥ 2,530.6
				MF	-	P < 1,095.5	1,095.5 ≤ P < 1642.3	P ≥ 1,642.3
LOCAL ISSUES								
L-1	Dust generation in activities with construction machinery and transport.	Volume of excavated material per m^2 of floor area [m^3/m^2].	Bill of quantities / budget	SF	-	P < 0.2824	0.2824 ≤ P < 2.4987	P ≥ 2.4987
				MF	-	P < 0.5554	0.5554 ≤ P < 1.1686	P ≥ 1.1686
L-2	Dust generation in earthworks activities and stockpiles.	Volume of excavated material per m^2 of floor area [m^3/m^2].	Bill of quantities / budget	SF	-	P < 0.2824	0.2824 ≤ P < 2.4987	P ≥ 2.4987
				MF	-	P < 0.5554	0.5554 ≤ P < 1.1686	P ≥ 1.1686
L-3	Dust generation in activities with cutting operations.	% of facing brick closure.	Bill of quantities / budget	SF	P = 0.00%	0.00% < P < 14.85%	14.85% ≤ P < 76.51%	P ≥ 76.51%
				MF	P = 0.00%	0.00% < P < 14.85%	14.85% ≤ P < 76.51%	P ≥ 76.51%
		% of the floor area having discontinuous ceramic and/or stone surfaces.	Bill of quantities / budget	SF	P = 0.00%	0.00% < P < 30.33%	30.33% ≤ P < 60.72%	P ≥ 60.72%
				MF	P = 0.00%	0.00% < P < 30.33%	30.33% ≤ P < 60.72%	P ≥ 60.72%
L-4	Operations that cause dirtiness at the construction site entrances.	Floor area [m^2].	Building specifications / drawings	SF	-	P < 296.14	296.14 ≤ P < 1,237.37	P ≥ 1,237.37
				MF	-	P < 690.72	690.72 ≤ P < 504.27	P ≥ 5,504.27

ENVIRONMENTAL ASPECT		ENVIRONMENTAL INDICATOR [P]	SOURCE		SV[1] = 0	SV = 1	SV = 3	SV = 5
L-5	Generation of noise and vibrations due to site activities.	Time of activity, use of special machinery (road roller, graders and compactors, etc.).	Health and safety plan / geotechnical study / budget	SF	-	Normal activity during daytime hours (8:00-20:00) and no use of special machinery.	Normal activity during daytime hours (8:00-20:00) and use of special machinery.	Normal activity during nighttime hours (20:00-8:00).
				MF	-	Normal activity during daytime hours (8:00-20:00) and no use of special machinery.	Normal activity during daytime hours (8:00-20:00) and use of special machinery.	Normal activity during nighttime hours (20:00-8:00).
L-6	Landscape alteration by the presence of singular elements (cranes).	Number of cranes.	Building specifications / bill of quantities / drawings of the health and safety plan	SF	$P = 0$	-	$P < 1$	-
				MF	$P = 0$	$P < 2$	$2 \leq P < 4$	$P \geq 4$
TRANSPORT ISSUES								
T-1	Increase in external road traffic due to construction site transport.	Floor area [m^2].	Building specifications / drawings	SF	-	$P < 296.14$	$296.14 \leq P < 1{,}237.37$	$P \geq 1{,}237.37$
				MF	-	$P < 690.72$	$690.72 \leq P < 5{,}504.27$	$P \geq 5{,}504.27$
T-2	Interference in external road traffic due to the construction site.	Number of traffic cuts in non-instantaneous periods of time.	Health and safety plan	SF	$P = 0$	$0 < P < 4$	$4 \leq P < 15$	$P \geq 15$
				MF	$P = 0$	$0 < P < 4$	$4 \leq P < 15$	$P \geq 15$
EFFECTS ON BIODIVERSITY								
B-1	Operations with vegetation removal (site preparation).	Site occupation per m^2 of floor area [m^2/m^2].	Building specifications / drawings	SF	-	$P < 0.5661$	$0.5661 \leq P < 2.5532$	$P \geq 2.5532$
				MF	-	$P < 0.1684$	$0.1684 \leq P < 0.3376$	$P \geq 0.3376$

ENVIRONMENTAL ASPECT		ENVIRONMENTAL INDICATOR [P]	SOURCE		SV[1] = 0	SV = 1	SV = 3	SV = 5
B-2	Operations with loss of edaphic soil (site preparation).	Site occupation per m^2 of floor area [m^2/m^2].	Building specifications / drawings	SF	-	P < 0.5661	0.5661 ≤ P < 2.5532	P ≥ 2.5532
				MF	-	P < 0.1684	0.1684 ≤ P < 0.3376	P ≥ 0.3376
B-3	Operations with high potential soil erosion (unprotected soils as a consequence of earthworks).	Site occupation per m^2 of floor area [m^2/m^2].	Building specifications / drawings	SF	-	P < 0.5661	0.5661 ≤ P < 2.5532	P ≥ 2.5532
				MF	-	P < 0.1684	0.1684 ≤ P < 0.3376	P ≥ 0.3376
B-4	Opening construction site entrances with soil compaction.	Length of the entrance to the site [m].	Building specifications / drawings	SF	P = 0	P < 500	500 ≤ P < 3,000	P ≥ 3,000
				MF	P = 0	P < 500	500 ≤ P < 3,000	P ≥ 3,000
B-5	Interception of river beds, integration of river beds in the development, water channelling and stream water cutoff.	Number of contact points with river beds.	Drawings / geotechnical study	SF	P = 0	P = 1	P = 2	P > 2
				MF	P = 0	P = 1	P = 2	P > 2
INCIDENTS, ACCIDENTS AND POTENTIAL EMERGENCY SITUATIONS								
AC-1	Fires at areas for storing flammable and combustible substances.	Floor area [m^2].	Building specifications / drawings	SF	-	P < 296.14	296.14 ≤ P < 1,237.37	P ≥ 1,237.37
				MF	-	P < 690.72	690.72 ≤ P < 5,504.27	P ≥ 5,504.27
AC-2	Breakage of underground pipes (electric power cables, telephone lines, water pipes, or liquid or gaseous hydrocarbon pipes).	Site occupation per m^2 of floor area [m^2/m^2].	Building specifications / drawings	SF	-	P < 0.5661	0.5661 ≤ P < 2.5532	P ≥ 2.5532
				MF	-	P < 0.1684	0.1684 ≤ P < 0.3376	P ≥ 0.3376

ENVIRONMENTAL ASPECT		ENVIRONMENTAL INDICATOR [P]	SOURCE		SV[1] = 0	SV = 1	SV = 3	SV = 5
AC-3	Breakage of receptacles with harmful substances. Storage tanks for dangerous products.	Floor area [m^2].	Building specifications / drawings	SF	-	$P < 296.14$	$296.14 \leq P < 1{,}237.37$	$P \geq 1{,}237.37$
				MF	-	$P < 690.72$	$690.72 \leq P < 5{,}504.27$	$P \geq 5{,}504.27$

[1] SV: Severity of the environmental impact.

[2] SF: Single-family houses.
MF: Multi-family dwellings.

[3] P: Environmental indicator. P values can be extracted from the quantitative data available in the project documents.

[4] Quantity of thixotropic fluid for piles [kg]: $(0.276 \cdot D^2 + 0.242 \cdot D - 0.6413) \cdot L$; where D = piles diameter [cm] and L = piles length [m].
Quantity of thixotropic fluid for screen walls [kg]: $(0.276 \cdot t + 0.7381) \cdot A$, where t = screen wall thickness [cm] and A = total screen wall area [m^2].

[5] Water consumption [m^3] = $0.2 \cdot Ce + 0.6 \cdot G + 0.1 \cdot Co$; where Ce = amount of cement [m^3], G = amount of gypsum [m^3] and Co = amount of concrete [m^3].
Otherwise, water consumption [m^3]= $0.2 \cdot a \cdot Aw + 0.00882 \cdot Ag + 0.1 \cdot Co$; where a = 0.21 in masonry walls, 0.01 in thick partition walls, 0.004 in partition walls, Aw = wall area [m^2], Ag = plastered wall area [m^2] and Co = amount of concrete [m^3].

[6] Weight [kg]: $2{,}500 \cdot Co + 150 \cdot Af + 225 \cdot Aw$; where Co = amount of concrete [m^3], Af = floor area [m^2] and Aw = wall area [m^2].

Table 1. Evaluation of environmental impacts related to the construction process of a single-family house (SF) and a multi-family dwelling (MF).

2.2. ASSESSMENT OF THE ENVIRONMENTAL ASPECTS

When the environmental aspects were identified during the initial review, only environmental criteria not dependent on the construction project were analysed (scale, probability and duration of the impact). Therefore, in this stage we had to consider any remaining components of significance that matched those that depended on each specific building site: severity and potential regulatory and legal exposure.

In order to assess impact severity, a matrix model with several assessment criteria for each environmental aspect was developed. So as to include detailed criteria to help decision-makers determine whether an environmental aspect is significant, a four-interval scale was developed: non-existent impacts, non-significant impacts, marginally significant impacts and extremely significant impacts. To help achieve a homogeneous outcome, numerical limits were established between the four categories. As far as possible, these numerical limits were based on the existing regulatory framework. All remaining components of significance (severity and potential regulatory and legal exposure) were thus included in the methodology.

2.2.1. Determining environmental indicators

The principles for deriving environmental indicators laid down in the ISO 14031:1999 standard were carefully studied so as to develop comparable, target-oriented indicators that were balanced, continuous, frequential and comprehensible [25].

The developed indicators mainly focus on assessing the environmental performance of construction sites and their corresponding processes and operations. However, the design phase is also included to some extent, due to its significance in the overall environmental performance of a project.

In order to assess the severity of environmental aspects, direct environmental indicators were proposed whenever possible. Direct environmental indicators are unequivocal, so they help make the outcome of the process independent of the people who conduct the assessment. For example, the quantity of the thixotropic fluids used at a construction site (expressed in kg) is a good direct environmental indicator of the environmental aspect 'Dumping of water resulting from the execution of foundations and retaining walls', which is included in the 'water emissions' category. This parameter can be assessed based on the information contained in the Bill of Quantities.

However, sometimes direct indicators cannot be used in this methodology. According to Johnston, there is no universal measurement for widely different impacts (i.e. loss of habitat) [26]. Furthermore, the developed methodology is intended to assess the severity of the environmental aspects derived from the building construction process in advance (based on the construction project documents), which makes it much more difficult to find direct environmental indicators. When direct environmental indicators cannot be used, indirect indicators (other parameters that can be measured based on the project documents) are proposed. For example, the quantity of synthetic paints and varnishes used at the construction site (or percentage of the total) is a good indirect indicator of an environmental aspect included in the ‘atmospheric emissions’ category (emissions of VOCs and CFCs). This parameter can be obtained from the Bill of Quantities. Likewise, the number of construction workers is an indirect environmental indicator for the environmental aspect of generation of municipal waste at the construction site. This parameter can easily be found in the project’s Health and Safety Plan. Since indirect indicators are related to the environmental aspect being assessed, they make it possible to obtain an admissible order of magnitude, thereby ensuring the objectivity of the evaluation process. Indirect indicators allow an acceptable approximation without taking up a great deal of time.

Although indicators can sometimes be expressed as direct measurements, most are expressed as relative values (input figures are referenced to m^2 of floor area, assuming the floor area of a building as the sum of the area of each floor of the building measured to the outer surface of the outer walls). The use of environmental indicators per m^2 of floor area avoids penalties due to the size of a construction project. For the same reason, other environmental indicators are expressed as a percentage of a total amount. Aggregated depictions, in which figures of the same units are summed over more than one process step, are also used. Table 1 shows the developed indicators.

2.2.2. Obtaining significance limits

In order to establish numerical limits between non-existent impacts, non-significant impacts, marginally significant impacts and extremely significant impacts, 55 new-start construction projects were analysed. Of these projects, 25 were projects for the construction of between one and nine single-family houses. They varied in floor area from 245 to 4,868 m^2 ranging from one to four floors. The other 30 construction projects were for multi-family dwellings. They ranged in size from a small block of three dwellings with a total floor area of 405 m^2 to a property development of 88 dwellings and a floor area of 13,781 m^2.

A statistical analysis of the quantitative environmental indicators of these new-start construction projects was carried out. Although most of them were replicated with a normal distribution, the log-normal distribution probability density function suited some environmental indicators, especially in projects for single-family houses. As a starting point, we considered that a high proportion of residential construction projects involve a marginally significant impact. In order to establish upper and lower limits for marginally significant impacts, a 68% confidence interval $[\mu-\sigma, \mu+\sigma]$ was calculated for each environmental indicator. Thus, if an environmental indicator is lower than $\mu-\sigma$, the environmental aspect is considered non-significant. However, if the environmental indicator is higher than $\mu+\sigma$, the environmental aspect is considered extremely significant. Environmental indicators within $[\mu-\sigma, \mu+\sigma]$ are considered marginally significant.

Table 2 shows the estimated distribution for each of the quantitative environmental indicators considered in this analysis, as well as the means and standard deviations of the corresponding distributions. Also included are the upper and lower limits of the 68% confidence interval.

ENVIRONMENTAL INDICATOR	SINGLE-FAMILY HOUSES						MULTI-FAMILY DWELLINGS					
	Estimated distribution	Mean	Standard deviation	R^2	Lower limit	Upper limit	Estimated distribution	Mean	Standard deviation	R^2	Lower limit	Upper limit
Volume of excavated material per m^2 of floor area $[m^3/m^2] \cdot C + 0.3 \cdot N$.	Log-normal	-0.025	0.4659	0.9911	0.3230	2.7601	Gaussian	1.005	0.3404	0.9645	0.6646	1.3454
Volume of excavated material per m^2 of floor area $[m^3/m^2]$.	Log-normal	-0.076	0.4734	0.9746	0.2824	2.4987	Gaussian	0.862	0.3066	0.9800	0.5554	1.1686
Volume of excavated material per m^2 of floor area $[m^3/m^2]$ + 6E-5·floor area.	Log-normal	0.0005	0.4394	0.9829	0.3640	2.7536	Gaussian	1.306	0.5600	0.9570	0.7460	1.8660
Volume of excavated material ending up in landfill sites per m^2 of floor area $[m^3/m^2]$.	Log-normal	0.025	0.5210	0.9699	0.2851	3.1400	Gaussian	0.888	0.4581	0.9025	0.4299	1.3461
Quantity of concrete per m^2 of floor area $[m^3/m^2]$.	Gaussian	1.005	0.1159	0.9814	0.8891	1.1209	Gaussian	0.410	0.1031	0.9731	0.3069	0.5131
Site occupation per m^2 of floor area $[m^2/m^2]$.	Log-normal	0.080	0.3271	0.9457	0.5661	2.5532	Gaussian	0.253	0.0846	0.9632	0.1684	0.3376
Water consumption per m^2 of floor area $[m^3/m^2]$.	Gaussian	0.093	0.0340	0.9643	0.0592	0.1272	Gaussian	0.079	0.0184	0.9872	0.0606	0.0974
Weight of structural floors, foundations, facades, partition walls, pavements and roofs per m^2 of floor area $[kg/m^2]$.	Gaussian	1771.0	759.6	0.9362	1011.4	2,530.6	Gaussian	1,368.9	273.4	0.9696	1095.5	1,642.3
Floor area $[m^2]$.	Log-normal	2.782	0.3105	0.969	296.14	1,237.37	Log-normal	3.2900	0.4507	0.9658	690.72	5,504.27
% of facing brick closure.	Gaussian	0.4568	0.3083	0.9389	0.1485	0.7651	Gaussian	0.4568	0.3083	0.9389	0.1485	0.7651
% of synthetic paints and varnishes.	Log-normal	-1.173	0.4611	0.9843	5.1511	43.0626	Log-normal	-1.173	0.4611	0.9843	5.1511	43.0626

ENVIRONMENTAL INDICATOR	SINGLE-FAMILY HOUSES						MULTI-FAMILY DWELLINGS					
	Estimated distribution	**Mean**	**Standard deviation**	**R^2**	**Lower limit**	**Upper limit**	**Estimated distribution**	**Mean**	**Standard deviation**	**R^2**	**Lower limit**	**Upper limit**
% of the floor area having discontinuous ceramic and/or stone surfaces.	Log-normal	-0.367	0.1507	0.9546	0.3033	0.6072	Log-normal	-0.3674	0.1507	0.9546	0.3033	0.6071

Table 2. Statistical analysis for quantitative indicators.

We were unable to obtain enough data about some quantitative indicators (such as indicators for the environmental aspects WE-1, WE-3 and L-6). In these cases, the reference value of each environmental indicator was based on the results obtained in a construction project that could be considered standard (2,500 m^2 of floor area). However, the outcome of pilot experiences led us to correct some of these numerical values.

Not all of the environmental indicators included in this methodology are quantitative. The significance limits for indicators expressed in qualitative terms (such as indicators for the environmental aspects SA-2 and L-5) were derived with the help of the experts.

2.2.3. Determining the severity of environmental impacts in a construction project

Numerical scores were established for non-existent impacts (SV_i=0), non-significant impacts (SV_i=1), marginally significant impacts (SV_i=3) and extremely significant impacts (SV_i=5).

If the documents of a construction project lack the information needed to make a satisfactory appraisal of a certain environmental aspect, the environmental impact is automatically classified as extremely significant.

If, after conducting the assessment, any environmental aspect is found to have an extremely significant environmental impact (SVi>5), environmental procedures must be applied to minimize the impacts that are highlighted by the methodology.

2.2.4. Determining the overall environmental impact of a construction project

The methodology assesses the overall significance rating of a construction project as shown in (2).

$$R = \sum_{i=1}^{n} SV_i \qquad (2)$$

where R is the overall significance rating of a construction project and SV_i is the severity of a specific environmental aspect i.

The construction project with the highest sum is the project with the most significant environmental impact.

3. CASE STUDIES

After the design stage, four construction projects (P03, P05, U10 and U03) were studied in order to assess the environmental impacts associated with the erection of new buildings. Appendix 1 illustrates the main characteristics of these projects.

Of the selected case studies, P03 has the highest overall significance rating (106), followed by P05 (100), U10 (85) and U03 (69). Appendix 2 shows detailed assessment results.

The discussion section focuses on P03 and P05 because they had the highest overall significance ratings. P03 consisted of one six-storey building containing 31 dwellings and a two-storey underground car park. The structure was primarily a cast-in-situ reinforced concrete frame, consisting of concrete columns positioned according to a regular grid with reinforced concrete waffle slabs. The structure rested on a concrete slab foundation. The external facades were masonry walls with a trowelled finish. Masonry bricks with a plastered finish were used in the construction of the internal partitions. P05 was similar to P03 in terms of construction techniques and systems, but its design solution involved the placement of screen walls for the underground floor and facing bricks for the external facades.

4. DISCUSSION OF RESULTS

The assessment of P03 found that the generation of greenhouse gas emissions due to construction machinery and the movements of vehicles had an extremely significant impact. Therefore, an environmental procedure was established to review the quality labels of the construction equipment, machinery and vehicles, and another was established to verify the compulsory vehicle inspections.

Waste generation was also found to have an extremely significant impact at this construction site. Waste management procedures such as waste minimization, recycling and reuse, hazardous waste management, and transfer of waste management duties to the building contractors were implemented.

Because water consumption during the construction process also had an extremely significant impact, environmental procedures related to water-saving strategies and the detection of water leaks at the construction site were put into action. Electricity and fuel consumption were also highlighted as extremely significant impacts, so procedures to select energy-efficient equipment and to encourage fuel-efficient driving habits were implemented, in addition to vehicle-maintenance procedures.

A complaint-management system and an information system for the nearest neighbour were also implemented for all extremely significant impacts in the ‘local issues’ category. For example, the dirtiness of the construction site entrances and the increase in external road traffic were considered extremely significant impacts of P03. Other environmental procedures were established to minimize this dirtiness, to keep the vehicles clean and to use impervious sheeting when vehicles are leaving the site carrying loads of dusty materials.

The last extremely significant impact at P03 was ‘Fires at areas for storing flammable and combustible substances’. An environmental procedure designed for use in potential emergency situations was implemented.

P05 was similar to P03, but its design solution involved the placement of screen walls for the underground floor. Therefore, the environmental impact ‘Dumping of water resulting from the execution of foundations and retaining walls’ was found to be extremely significant. An environmental procedure related to the management of thixotropic fluids was therefore established. Since the external facades of P05 consisted of facing bricks, the environmental impacts ‘Use of cleaning agents or surface-treatment liquids at the construction site’ and ‘Dust generation in activities with cutting operations’ were considered extremely significant. Related environmental procedures were implemented.

5. CONCLUSIONS

We have presented a quantitative methodology for dealing with potential adverse environmental impacts during the pre-construction stage. The methodology compares the overall environmental impact associated with the erection of various residential projects and ranks the significance of the environmental impacts of these projects. The methodology also compares the absolute importance of a particular environmental aspect in the various projects being assessed.

Instead of providing a standard set of environmental aspects, this paper proposes an exhaustive preliminary analysis with a process-oriented approach. The methodology therefore obtains specific environmental aspects related to the construction process and tailored to regional specificities. The literature often stresses that organizations should not consider the identification of aspects a single-occasion process. Using the proposed analysis, organizations can add or remove environmental aspects whenever they want.

Another key feature in this methodology includes the development of 20 environmental indicators, both direct and indirect, based on quantitative data available in the project documents. Thus, the outcome of the process does not depend on the people who conduct it. Significance limits for environmental aspects were also developed based on the statistical analysis of 55 new-start construction projects.

The strength of the developed methodology lies in the fact that the environmental aspects are assessed prior to the construction stage. A range of measures can therefore be implemented to mitigate adverse impacts during the on-site construction activities.

The proposed methodology can help support the implementation of Environmental Management Systems in construction companies or simply help organizations to improve their environmental performance and general decision-making, assuming that the findings of the evaluation are used to make meaningful corrections.

6. FURTHER RESEARCH

Further research is needed in order to consider the main characteristics of the areas surrounding construction sites (mainly in terms of population, community and ecosystem). From an environmental point of view, impact L-5 (‘Generation of noise and vibrations due to site activities') should not be assigned the same relevance in an industrial area as in a residential area with hospitals or schools nearby. Local, regional and global concerns regarding environmental impacts should be also included in the proposed methodology by introducing a weighting system.

Further research is also needed to implement the methodology in a web-based information- and knowledge-management system with databases. This would allow data collected in previous assessments to be reused in order to refine the methodology, with particular refernce to the significance limits of the environmental aspects.

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APPENDICES

Appendix 1. Characteristics of four sample projects.

GENERAL INFORMATION				
Project reference	U03	U10	P03	P05
Type	SF	SF	MF	MF
Number of dwellings	1	5	31	8
Number of floors	1+2	1+2	2+6	1+5
Floor area [m^2]	295.62	1,134.00	7,198.42	1,065.60
Site occupation [m^2]	600.42	1,139.60	1,415.90	201.85
Site duration [months]	12	12	24	15
Average number of workers per day	5	9	15	10
Time of activity	Daytime	Daytime	Daytime	Daytime
EARTHWORKS AND FOUNDATIONS				
Volume of excavated material [m^3]	590.94	509.90	6,981.76	976.04
Volume of excavated material ending up in landfill sites [m^3]	590.94	450.30	6,349.00	976.04
Quantity of thixotropic fluid [kg]	0.00	0.00	15,997.41	6,921.36
STRUCTURE				
Material	In-situ concrete	In-situ concrete	In-situ concrete	In-situ concrete
FACADES				
Material	Masonry	Masonry	Masonry	Masonry
Surface [m^2]	448.73	1,156.70	2,916.93	345.36
Facing-brick closure [m^2]	85.26	0.00	0.00	345.36
Trowelled and screeded mortar-rendering area [m^2]	363.47	1,156.70	2,916.93	0.00
INTERIOR WALLS				
Material	Masonry	Masonry	Masonry	Masonry
Interior wall area [m^2]	235.40	2,250.22	12,260.44	1,511.61
INTERIOR FINISHES				
Vertical claddings				
Veneerings and discontinuous claddings [m^2]	221.27	575.00	2,718.75	406,38
Continuous claddings [m^2]	686.12	5,082.14	24,719.06	2,967.03
Horizontal claddings				
Continuous pavements [m^2]	102.40	145.75	2,983.00	393.28
Discontinuous pavements [m^2]	218.12	998.59	4,221.04	686.71
Continuous ceiling [m^2]	302.40	1,138.23	7,202.36	1,073.22
Discontinuous ceiling [m^2]	0.00	0.00	0.00	0.00
Plastered surface [m^2]	980.52	6,222.37	31,938.54	4,037.74

Acrylic painted surface [m^2]	737.00	5,914.81	28,410.06	3,845.45
Varnished or synthetic painted surface [m^2]	250.22	353.92	3,531.56	175.36
USE OF EQUIPMENT				
Use of special machinery	No	No	Yes	No
Number of power generators	0	1	2	0
Number of cranes	0	0	1	1
USE OF MATERIALS				
Cement [m^3]	22.42	328.47	1,804.52	99.82
Gypsum [m^3]	14.41	91.47	469.50	59.35
Concrete [m^3]	137.14	297.15	1,430.59	460.97
OTHERS				
Length of the entrance to the site	0	0	0	0
Number of contact points with river beds	0	0	0	0
Number of times traffic is cut off in non-instantaneous periods of time	0	0	0	0

SF: single-family houses; MF: multi-family dwellings.

Appendix 2. Assessment results for four construction projects.

ENVIRONMENTAL ASPECT		U03		U10		P03		P05	
		P	SV	P	SV	P	SV	P	SV
AE-1	Generation of greenhouse gas emissions due to construction machinery and vehicle movements.	1.9990	3	0.7496	3	1.7639	5	0.9160	3
AE-2	Emission of VOCs and CFCs.	33.95%	3	5.65%	3	11.06%	3	4.36%	1
WE-1	Dumping of water resulting from the execution of foundations and retaining walls.	0	0	0	0	2.2224	1	6.4953	5
WE-2	Dumping of water resulting from the process of cleaning concrete chutes or dumping of other basic fluids.	0.4639	1	0.2620	1	0.19874	1	0.4326	3
WE-3	Dumping of sanitary water resulting from on-site sanitary conveniences.	5	1	9	3	15	1	10	1
WG-1	Generation of excavated waste material during earthworks.	1.9990	3	0.3971	3	0.8821	3	0.9159	3
WG-2	Generation of municipal waste by on-site construction workers.	5	1	9	3	15	3	10	1
WG-3	Generation of inert waste.	295.62	1	1,134.00	3	7,198.42	5	1,065.60	3
WG-4	Generation of ordinary or non-special waste (wood, plastic, metal, paper, cardboard or glass).	295.62	1	1,134.00	3	7,198.42	5	1,065.60	3
WG-5	Generation of special (potentially dangerous) waste.	295.62	1	1,134.00	3	7,198.42	5	1,065.60	3
SA-1	Land occupancy by the building, provisional on-site facilities and storage areas.	2.0311	3	1.0049	3	0.1967	3	0.1894	3
SA-2	Use of concrete release agent at the construction site.		3		3		3		3
SA-3	Use of cleaning agents or surface-treatment liquids at the construction site.	19.00%	3	0.00%	0	0.00%	0	100.00%	5
		28.71%	1	19.82%	1	16.58%	1	19.78%	1

ENVIRONMENTAL ASPECT		U03		U10		P03		P05	
		P	SV	P	SV	P	SV	P	SV
SA-4	Dumping derived from the use and maintenance of construction machinery.	2.0167	3	0.5177	3	1.4018	3	0.9799	3
SA-5	Dumping of water resulting from the execution of foundations and retaining walls.	0	0	0	0	2.2224	1	6.4953	5
SA-6	Dumping of water resulting from the process of cleaning concrete chutes or dumping of other basic fluids.	0.4639	1	0.2620	1	0.1987	1	0.4326	3
SA-7	Dumping of sanitary water resulting from on-site sanitary conveniences.	5	1	9	3	15	3	10	1
RC-1	Water consumption during the construction process.	0.0908	3	0.1325	5	0.1091	5	0.0954	3
RC-2	Electricity consumption during the construction process.	295.62	1	1,134.00	3	7,198.42	5	1,065.60	3
RC-3	Fuel consumption during the construction process.	1.9922	3	0.7496	3	1.7639	5	0.9160	3
RC-4	Raw materials consumption during the construction process.	1,830.5	3	1,481.1	3	1,121.2	3	1,623.6	3
L-1	Dust generation in activities with construction machinery and transport.	1.9990	3	0.4496	3	0.9699	3	0.9160	3
L-2	Dust generation in earthworks activities and stockpiles.	1.9990	3	0.4496	3	0.9699	3	0.9160	3
L-3	Dust generation in activities with cutting operations.	19.00% 28.71%	3 1	0.00% 19.82%	0 1	0.00% 16.58%	0 1	100.00% 19.78%	5 1
L-4	Operations that cause dirtiness at the construction site entrances.	295.62	1	1,134.00	3	7,198.42	5	1,065.60	3
L-5	Generation of noise and vibrations due to site activities.		1		1		3		1
L-6	Landscape alteration by the presence of singular elements (cranes).	0	0	0	0	1	1	1	1
T-1	Increase in external road traffic due to construction site transport.	295.62	1	1,134.00	3	7,198.42	5	1,065.60	3

ENVIRONMENTAL ASPECT		U03		U10		P03		P05	
		P	**SV**	**P**	**SV**	**P**	**SV**	**P**	**SV**
T-2	Interference in external road traffic due to the construction site.	0	0	0	0	0	0	0	0
B-1	Operations with vegetation removal (site preparation).	2.0311	3	0.8543	3	0.1975	3	0.1894	3
B-2	Operations with loss of edaphic soil (site preparation).	2.0311	3	0.8543	3	0.1975	3	0.1894	3
B-3	Operations with high potential soil erosion (unprotected soils as a consequence of earthworks).	2.0311	3	0.8543	3	0.1975	3	0.1894	3
B-4	Opening construction site entrances with soil compaction.	0	0	0	0	0	0	0	0
B-5	Interception of river beds, integration of river beds in the development, water channelling and stream water cutoff.	0	0	0	0	0	0	0	0
AC-1	Fires at areas for storing flammable and combustible substances.	295.62	1	1,134.00	3	7,198.42	5	1,065.6	3
AC-2	Breakage of underground pipes (electric power cables, telephone lines, water pipes, or liquid or gaseous hydrocarbon pipes).	2.0311	3	0.8543	3	0.1975	3	0.1894	3
AC-3	Breakage of receptacles with harmful substances. Storage tanks for dangerous products.	2.0311	3	0.8543	3	0.1975	3	0.1894	3
OVERALL SIGNIFICANCE RATING			**69**		**85**		**106**		**100**

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