IDENTIFYING POTENTIAL ENVIRONMENTAL IMPACTS AT THE PRE-CONSTRUCTION STAGE

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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. Two case studies are provided to illustrate the practical use of the proposed methodology.

1. Introduction

Compared with other industries, construction has an important consumption of energy and non renewable resources and also generates a fairly large amount of pollutants, including air emissions, noise, solid waste and water discharge. Whereas there are a lot of studies aimed to keep down the energetic demand during the life span of a building or directed to choose environmental friendly materials, little research is focused on the environmental issues associated with the erection process.

According to Cole (2000), the limited attention given to the on-site construction impacts is due to (1) the perceived relatively lower significance of construction impacts compared with the lifecycle impacts associated with building design and management and (2) the inherent temporality related to the on-site construction (generally speaking, a non-existing environmental management in the construction process is not noticed during the life span of the building).

Although some of the environmental issues associated with the current construction and demolition processes are included in environmental assessment methods, their coverage is neither consistent nor comprehensive. In fact, construction impacts are often assessed only by the presence or absence of environmental protocols (Cole, 2000). In other cases, approaches to environmental control and management are highly qualitative (Chen et al., 2005). In this context, quantitative approaches provided by Tam et al. (2004), Cheung et al. (2004), Shen et al.(2005), Liu et al. (2006), Chen et al. (2000) and Chen et al. (2005) are especially worthwhile. However, subjective judgements often influence the accuracy of the aforementioned methods.

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2. Aim

The main objective of this paper is to develop a methodological framework to identify and assess the environmental impacts associated with the construction of new residential buildings.

The methodology facilitates the identification and quantification of the environmental impacts associated with building projects prior to the construction stage. The relevance of each environmental aspect at a particular site can be identified before the building construction stage starts and therefore, significant impacts are highlighted in advance. Thus, it is possible to provide a range of measures to mitigate adverse impacts that can be implemented afterwards during the onsite construction activities. The methodology is able to compare not only the overall environmental impact associated with the erection of various residential projects but also the absolute importance of a particular environmental aspect in the various projects being assessed.

3. Development of the methodology

In order to predict the severity of environmental impacts related to the construction process of residential buildings, the first step is to identify the environmental aspects related to the building construction process. Assessing the environmental aspects is the second step of the methodology and it includes (1) development of indicators, (2) formulation of the significance limits and (3) determination of the global environmental impact of a construction project.

3.1. Identification of environmental aspects related to the construction process

3.1.1 Literature review in environmental aspects related to the construction process

According to Chen et al. (2000), sources of pollution and/or hazards from construction activities can be divided into seven major types: dust, harmful gases, noises, solid and liquid wastes, fallen objects, ground movements and others.

Chen et al. (2005) considered construction impacts under eight categories: soil and ground contamination, ground and underground water, construction and demolition waste, noise and vibration, dust, hazardous emissions and odours, wildlife and natural features impacts and archaeology impacts.

On the other hand, Cole (2000) states that the environmental impacts of the construction process embrace resource uses, ecological loadings and human health issues.

March (1992) observed the construction industry’s environmental impacts under the categories of ecology, landscape, traffic, water, energy, timber consumption, noise, dust, sewage, and health and safety hazards.

Shen and Tam (2002) classified construction environmental impacts as the extraction of environmental resources such as fossil fuels and minerals; extending consumption of generic resources, namely, land, water, air, and energy; the production of waste that require the consumption of land for disposal; and pollution of the living environment with noise, odors, dust, vibrations, chemical and particulate emissions, and solid and sanitary waste.

According to Cardoso (2005), typical negative impacts of the construction activities include waste production, mud, dust, soil and water contamination and damage to public drainage systems, destruction of plants, visual impact, noise, traffic increase and parking space shortage and damage to public space.

3.1.2 Process oriented approach

As it can be seen, there is no single approach regarding the environmental aspects associated with the construction process in the literature. Eco-Management and Audit Scheme (EMAS) regulation provides a standardized and comprehensive list of environmental aspects covering almost all the previous mentioned environmental aspects. So finally, guidance provided in EMAS regulation was used to initially identify generic environmental aspects: (1) emissions to air, (2) releases to water, (3) avoidance, recycling, reuse, transportation and disposal of solid and other wastes, particularly hazardous wastes, (4) use and contamination of land, (5) use of natural resources and raw materials (including energy), (6) local issues (noise, vibration, odour, dust, visual appearance, etc.), (7) transport issues, (8) risks of environmental accidents and impacts arising, or likely to arise, as consequences of incidents, accidents and potential emergency situations and (9) effects on biodiversity.

However, environmental aspects coming from EMAS regulation had to be customized to the construction processes and for this reason an exhaustive preliminary analysis with a process-oriented approach (Zobel and Burman, 2004) was carried out. Environmental aspects provided in EMAS regulation were analysed for each construction process. 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. According to Roberts and Robinson (1998), these main construction processes were separated into smaller process steps, so that finally 219 stages and/or activities were considered in this initial environmental review.

3.1.3 Preliminary assessment of generic environmental aspects in each construction stage

According to Põder (2006) and along the lines of ISO 14004:2004, evaluation of the significance of environmental impacts can be facilitated by considering spatial scale (physical area influenced by a particular environmental aspect), severity (combination of quantity, toxicity, affected volume or surface or temporal extent), probability (likelihood of the event causing the environmental impact) and duration (persistence) of the environmental impact (Põder, 2006).

The severity of an environmental aspect depends on each specific building site as there is a correlation between the magnitude of the project (quantities and the toxicity of the materials involved, affected volume or surface and temporal extent) and the caused effects. On the contrary, other criteria are not dependant 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, ranging from 0 (none) to 3 (out of region), its probability of occurrence, from 0 (improbable) to 3 (very likely) and its duration, ranging from 0 (none) to 3 (superior to the time of the phase of work).

The significance rating of an environmental impact in a certain construction stage (Environmental Impact Degree, ID_{Ei}) is obtained by multiplying all these three significance components. An environmental impact for a specific construction stage was considered to be significant if its ID_{Ei} was higher than 3. The resulting matrix allowed us to distinguish potential environmental impacts for each construction stage. In order to make the future assessments controllable and effective, some environmental aspects were aggregated whereas others where disaggregated.

3.1.4 Environmental aspects related to the construction process

As a result of the process oriented approach, significant environmental aspects for construction activities were obtained and nine categories of environmental aspects were proposed (table1).

3.2 Assessment of the environmental aspects related to the construction process

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 remaining components of significance had to be considered: severity and potential regulatory and legal exposure.

In order to assess impact significance (S), 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 (S=0), non-significant impacts (S=1), marginally significant impacts (S=3) and extremely significant impacts (S=5).

3.2.1 Determining environmental indicators

To assess the severity of each environmental aspect, corresponding environmental indicators were developed (table 1).

As far as possible, direct environmental indicators were proposed. Direct environmental indicators are unequivocal so they will contribute to make the outcome of the process independent on the people conducting the assessment. The quantity of concrete used during the construction stage (expressed in m^3) is a good direct environmental indicator for the environmental aspect “Dumping of water resulting from the process of cleaning concrete chutes” included in the category of Water emissions. This parameter can be assessed from the information contained in the budget of the project. In the same way, the site occupation (expressed in m^2) is a good direct environmental indicator of the environmental aspect “Land occupancy by the building, provisional on-site facilities and storage areas” included in the category of Soil Alteration. This parameter can be assessed from the information contained in the Health and Safety Plan.

However, finding direct indicators is not an easy issue for some environmental aspects. On one hand, it has to be recognized that there is no universal measurement for widely different impacts (i.e. loss of habitat) (Johnston and Hutchison, 2000). On the other hand, the proposed methodology tries to assess the magnitude of the environmental aspects derived from the building construction process in advance (from the documents of the construction project), so finding direct environmental indicators becomes much more difficult.

When direct environmental indicators cannot be used, indirect indicators have to be proposed. Obviously, indirect environmental indicators have to be related to the environmental aspects that are going to be assessed. In addition, they should be measurable parameters already existing in the project documents. For example, the volume of excavated material (expressed in m^3) is a good indirect environmental indicator of an environmental aspect included in the category of Local Issues (referring to “Dust generation in earthworks activities and stockpiles”). This parameter can be obtained from the budget of the project. In a similar way, the length of the entrance to the site (expressed in m) is an indirect environmental indicator for the environmental aspect of “Opening construction site entrances with soil compaction” from the Effects on biodiversity category. This parameter can be easily found in the Health and Safety Plan.

The use of indirect environmental indicators facilitates obtaining an admissible order of magnitude, ensuring the objectivity of the evaluation process. Furthermore, indirect indicators allow continuing the assessment process with an acceptable approximation and without involving a high time consumption.

Table 1 Environmental impacts related to the construction process and corresponding environmental indicators.

ENVIRONMENTAL ASPECT		ENVIRONMENTAL INDICATOR [P]
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 $[m^3/m^2]$ · 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.
AE-2	Emission of VOCs and CFCs.	% of synthetic paints and varnishes.
Water emissions		
WE-1	Dumping of water resulting from the execution of foundations and retaining walls.	Quantity of thixotropic fluid per m^2 of floor area $[kg/m^2]$.
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 $[m^3/m^2]$.
WE-3	Dumping of sanitary water resulting from on-site sanitary conveniences.	Average number of workers per day.
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 $[m^3/m^2]$.
WG-2	Generation of municipal waste by on-site construction workers.	Average number or workers per day.
WG-3	Generation of inert waste.	Floor area $[m^2]$.
WG-4	Generation of ordinary or non-special waste (wood, plastic, metal, paper, cardboard or glass).	Floor area $[m^2]$.
WG-5	Generation of special (potentially dangerous) waste.	Floor area $[m^2]$.
Soil alteration		
SA-1	Land occupancy by the building, provisional on-site facilities and storage areas.	Site occupation per m^2 of floor area $[m^2/m^2]$.
SA-2	Use of concrete release agent at the construction site.	Use of concrete.
SA-3	Use of cleaning agents or surface-treatment liquids at the construction site.	% of facing brick closure. % of the floor area having discontinuous ceramic and/or stone surfaces.
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 $[m^2]$.
SA-5	Dumping of water resulting from the execution of foundations and retaining walls.	Quantity of thixotropic fluid per m^2 of floor area $[kg/m^2]$.
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 $[m^3/m^2]$.
SA-7	Dumping of sanitary water resulting from on-site sanitary conveniences.	Average number of workers per day.
Resource consumption		
RC-1	Water consumption during the construction process.	Water consumption per m^2 of floor area $[m^3/m^2]$.

ENVIRONMENTAL ASPECT		ENVIRONMENTAL INDICATOR [P]
RC-2	Electricity consumption during the construction process.	Floor area [m^2].
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.
RC-4	Raw materials consumption during the construction process.	Weight of structural floors, foundations, facades, partition walls, pavements and roofs per m^2 of floor area [kg/m^2].
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].
L-2	Dust generation in earthworks activities and stockpiles.	Volume of excavated material per m^2 of floor area [m^3/m^2].
L-3	Dust generation in activities with cutting operations.	% of facing brick closure. % of the floor area having discontinuous ceramic and/or stone surfaces.
L-4	Operations that cause dirtiness at the construction site entrances.	Floor area [m^2].
L-5	Generation of noise and vibrations due to site activities.	Time of activity, use of special machinery (road roller, graders and compactors, etc.).
L-6	Landscape alteration by the presence of singular elements (cranes).	Number of cranes.
Transport issues		
T-1	Increase in external road traffic due to construction site transport.	Floor area [m^2].
T-2	Interference in external road traffic due to the construction site.	Number of traffic cuts in non-instantaneous periods of time.
Effects on biodiversity		
B-1	Operations with vegetation removal (site preparation).	Site occupation per m^2 of floor area [m^2/m^2].
B-2	Operations with loss of edaphic soil (site preparation).	Site occupation per m^2 of floor area [m^2/m^2].
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].
B-4	Opening construction site entrances with soil compaction.	Length of the entrance to the site [m].
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.
Incidents, accidents and potential emergency situations		
AC-1	Fires at areas for storing flammable and combustible substances.	Floor area [m^2].
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].
AC-3	Breakage of receptacles with harmful substances. Storage tanks for dangerous	Floor area [m^2].

ENVIRONMENTAL ASPECT	ENVIRONMENTAL INDICATOR [P]
products.	

3.2.2 Obtaining significance limits

In order to establish numerical limits between non-existing impacts, non-significant impacts, marginally significant impacts and extremely significant impacts, it was assumed that a high proportion of construction projects involve a marginally significant impact.

Parameters used to calculate environmental indicators (both direct and indirect) were extracted from 25 new-start construction projects. In order to establish lower and upper limits for marginally significant impacts, a 68% interval confidence was calculated for each environmental indicator. Thus, if an environmental indicator does not exceed [$\mu-\sigma$], the environmental aspect is considered as non-significant. On the contrary, if the environmental indicator exceeds [$\mu+\sigma$], the environmental aspect is considered as extremely significant. Environmental indicators within [$\mu-\sigma$, $\mu+\sigma$] are considered as marginally significant. Significance limits for each environmental aspect can be consulted in Gangolells et al. (2008).

If after conducting the assessment, any environment aspect is found to be an extremely significant environmental impact ($Si>5$), related environmental procedures must be applied. Thus, the impacts that have been highlighted after the application of the methodology should be minimized.

3.2.3 Determining the global environmental impact of a construction project

The methodology sets to assess the overall significance rating of a construction project as show in (1).

$$R = \sum_{i=1}^{n} S_i \tag{1}$$

Where R = overall significance rating of a construction project; Si = significance of a specific environmental aspect i;

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

4 CASE STUDIES

After the design stage, two construction projects (P03 and P05) were studied in order to assess the environmental impacts associated with the erection of new buildings.

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.

The assessment of P03 showed 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.

Of the selected case studies, P03 had the highest overall significance rating (106), followed by P05 (100).

5 CONCLUSIONS

This paper has presented a methodological framework for predicting and assessing the environmental impacts associated with the erection of new buildings. The exposed methodology not only facilitates the identification of the most significant environmental aspects in a specific site but also allows the comparison of the absolute importance of a fixed environmental aspect in different construction projects. Overall significance rating of a construction project can also be assessed and therefore, compared to other construction projects.

The strength of the developed methodology lies in the fact that the assessment of the environmental aspects is made before the building construction stage. Thus, once extremely significant environmental impacts have been identified during the planning phase, corresponding environmental procedures can be applied during the on-site construction phase.

Another key feature in the exposed methodology is that when assessing the environmental impact of a construction project, no subjective judgements have to be made so the outcome of the process is not dependent on the people conducting the assessment.

Further research is needed in order to consider the main characteristics of the areas surrounding the construction site (mainly at population, community and ecosystem level). From an environmental point of view, L5 impact (Generation of noise and vibrations due to site activities), should not have the same relevance if the construction site is located in an industrial area or if it is located in a residential area, with nearby hospitals or schools. Moreover, local, regional and global concerns in reference to the environmental impacts should be also included in the proposed method by introducing a weighting system.

Besides these developments, further research is also needed to implement the method into a web-based information and knowledge management system with its databases in it. In this way, data already collected in previous assessments could be reused to refine the method, specially the significance limits of the environmental aspects.

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