Zurich, June 15-17 2016
Sustainable Built Environment (SBE) Regional Conference
Expanding Boundaries:
Systems Thinking for the Built Environment

THE ENVIRONMENTAL RELEVANCE OF THE CONSTRUCTION AND END-OF-LIFE PHASES OF A BUILDING: A TEMPORARY STRUCTURE LCA CASE STUDY

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Abstract

LCA can prevent shifting the environmental burden of a building to peculiar life cycle phases. Components production and demolition stages became much more relevant in new low-energy buildings. The same applies also to temporary structures, whose useful service life is generally limited to the duration of the related event. More attention must therefore be paid to the choice of the construction materials and the way they are assembled in order to reduce resource depletion, embodied energy and waste production. To achieve this goal, it is essential to act in the design phase of the building in order to include environmental problems in the early stages of the decision making process. The objective of our study is to assess the environmental impacts of the different life stages of a temporary structure to support the design phase of future ones. The reference case study is the Brazilian pavilion constructed in Milan (Italy) for EXPO 2015. The aim of the research is to evaluate how much the design phase of the building, the choice of the materials and the end-of-life scenarios can influence the environmental performances of the structure. Primary data for the whole lifecycle are considered and a sensitivity analysis on the materials sustainability is performed. LCA results confirm the importance of the design phase for temporary structures. The predilection of natural and recycled materials in the construction phase and the prevision of a second life significantly reduce the impacts of the building. Among the end-of-life scenarios the best environmental solution proves to be the refunctionalization on site. The priority must be therefore to foresee a second life of the components at an early stage of the decision-making process. Similar conclusions could be expected for low-energy buildings too.

Keywords:

LCA; temporary building; demolition phase; end of life

1 INTRODUCTION

IPCC recently reported that the building sector accounts for about 32% of global energy use and for about 19% of greenhouse gas emissions [1]. These numbers are constantly increasing and many countries started to adopt policies aimed at decreasing the energy requirements of the buildings during their use phase. However, the buildings' environmental impacts extend beyond the use phase, including the burdens related to the production phase and the end of life (EOL). In low-energy buildings these phases become more relevant compared to the operational energy, traditionally the main source of buildings' environmental impacts [2, 3]. The vast majority of LCA studies on buildings focus on the use phase, but several studies have been performed to assess the environmental impacts of the *minor* lifecycle stages: production and EOL [4-7]. The importance of the choice of the materials has also been assessed [8, 9]. Thorough low-energy buildings LCA are difficult to perform because of their EOL, hard to predict and with an allocation methodology of the impacts non-standardized [10-12]. A proxy for these buildings are temporary structures, whose useful service life is generally limited to the duration of the related event and whose EOL is very close in time and easy to predict [13, 14]. The LCA of a temporary pavilion built for the international exposition held in Milan (Italy) from May to October 2015 is performed in order to understand the importance in the choice of the materials and the design phase of the

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DOI 10.3218/3774-6_71, ISBN 978-3-7281-3774-6, http://vdf.ch/expanding-boundaries.html

building. Different scenarios for the temporary structure's EOL (refunctionalization, reuse of building components, recycling of building materials) are studied in order to determine the best solution to apply at the end of the international event. The results could be reasonably extended to new low-energy buildings.

2 MATERIALS AND METHODS

2.1 LCA

Methodology

The LCA study was performed according to ISO standards [15, 16]. Allocation rules for the input of recycled materials and the management of wastes refer to the General Programme Instructions for the international Environmental Product Declaration (EPD) system [17], in line with the Ecoinvent cut-off system model [18]:

- recyclable materials in input to the system: available burden free at the beginning of the recycling treatment processes
- recyclable materials in output to the system: the only burdens allocated to the system are the dismantling processes and the transport of the recyclable materials to the processing site
- wastes: the producer is fully responsible for the disposal of its wastes

Functional unit

The functional unit considered is the temporary pavilion built for the major international event EXPO. To pinpoint the most impacting phase of the structure's lifecycle, a study period equal to the duration of the event and the hypothesis that all the materials are sent to the recycling collection site at the end of the event were considered. Furthermore, to allow a comparison of different scenarios for the pavilion's EOL a reference study period of 10 years, according to the indicative design working life for temporary structures in [19], is considered.

System boundaries

The life of the building is divided in the stages proposed by the EN 15978 [20]. The processes considered, in a "cradle to grave" approach, are the following:

- Product stage: raw material supply, transport and manufacturing
- Construction stage: transport to site, construction and waste processing
- Use stage: operational energy and water use
- End of life stage: deconstruction, transport, waste processing and disposal

When the role that the choice of the post-event scenario, and all the building techniques related to this choice, plays in the overall environmental sustainability of the structure is investigated, a study period (10 years) longer than the required service life of the structure (6 months) is chosen. System boundaries are therefore extended from the first use of the building to a 10 year lifetime, including its second use. If the temporary building is not reused after the event, the same methodology considered in the EN 15978 is applied: scenarios for demolition and construction of an equivalent new building are developed. These scenarios provide for an extension of the service life which, when combined with the required service life of the object of assessment, is equal to or more than the reference study period. Another temporary building with the same characteristics shall be therefore considered to cover the reference study period.

Data quality

Primary data are considered for the materials employed: the vast majority of the data have been directly collected on site through the transport delivery notes and the remaining (about 5%) have been estimated from the building's drawings. HVAC system, water pipelines, kitchen and bathrooms' equipment and furniture were excluded from the system. When available, the environmental impacts of the production processes declared in the EPD certification of the materials used on site were considered. To these values, the impacts related to the transportation from the company gate to the construction site were added. When the EPD certification of the material was not available, we referred to the Ecoinvent database [18]. Information on transports' distances were collected on site and the Ecoinvent database was used to assess the emissions of the trucks. Primary data for the energetic and water consumptions during the construction phase were used. The average energy consumption of a pavilion, declared by the event's energy provider, was considered for the use phase (24 MWh per week). Finally, the energy needed for the dismantling process was assumed to be equal to the one used in the construction phase.

Impact categories

The impact assessment is carried out for the environmental impact categories recommended by EN 15978 (abiotic depletion (ADP), fossil fuels depletion (ADP fossil), global warming in a time interval of 100 years (GWP), ozone depletion (ODP), acidification (AP), eutrophication (EP), photochemical ozone creation (POCP)) with the characterization factors proposed by the CML institute.

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Impact category	Unit	Production	Prod. (no rec, no EPD)	Construction	Use	EOL (recycling)	Total lifecycle
ADP	kg Sb eq.	20.3	52.5	0.00	0.00	0.00	20.3
ADP fossil	TJ	36.3	53.4	2.55	4.89	1.01	44.8
GWP	kton CO2 eq.	2.96	4.69	0.17	0.36	0.07	3.55
ODP	g CFC11 eq.	254	315	30.9	47.1	12.3	344
POCP	ton C2H4 eq.	0.93	2.15	0.03	0.07	0.02	1.05
AP	ton SO2 eq.	13.4	23.2	1.04	1.47	0.58	16.5
EP	ton PO4 eq.	5.24	11.8	0.21	0.25	0.13	5.82

Table 1 : CML-IA Baseline results.

2.2 Building

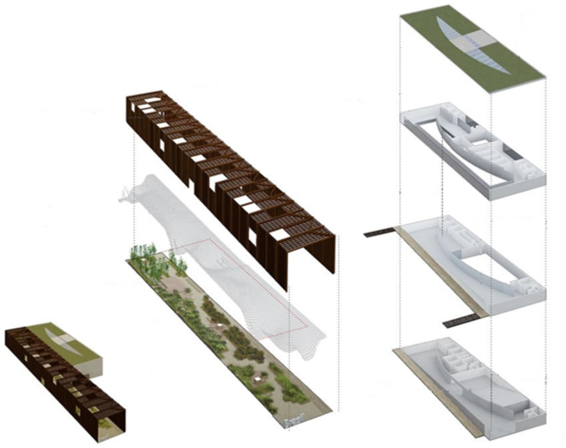

Fig. 1: Brazilian pavilion for EXPO 2015.

The building, shown in *Fig. 1*, is composed of two parts: a conventional covered structure on three floors (net surface area: 2802 m^2), and an open gallery traversed by an elevated net on which visitors can walk (net surface area: 1125 m^2). The total estimated mass of the building is about 5 kiloton (kton) and the materials used in the structure are presented in *Fig. 2*. Attention to sustainability has been paid by the designers in the selection of materials, choosing for many components materials with a high recycled content or with an EPD. Moreover, during the construction, dry assembly techniques have been used to allow an easy disassembling at the end of the event, guaranteeing therefore the possibility of reusing the components.

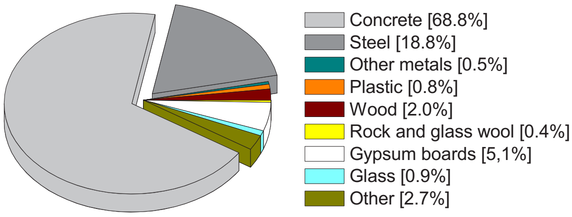

Fig. 2: building materials.

3 RESULTS

3.1 Life cycle phases

In *Table 1* the impacts of the different lifecycle phases of the pavilion are presented. Results point out that the pre-use phase of a temporary building overshadows the rest of the lifecycle, confirming the conclusions of Lavagna et al. in [13]. The pre-use phase contribution ranges from a minimum of 73.8% for the ODP impact category to a maximum of 99.9% for the ADP. The major contributor is the steel, used both in the covered structure (S355) and in the gallery (weathering steel). The impact of steel varies from 19.3% for ADP to 56.7% for ODP, with the latest due to the release of Halon gases in the fire-fighting and refrigeration systems in the production of oil and gas used to generate electricity consumed in the electric arc furnace (EAF) for secondary steelmaking. The highest share of emissions, responsible for most of the other environmental impact categories, derives instead from the combustion of fossil fuels used to produce electricity consumed in the production of steel. An important contribution to the ADP (26%) stems from the galvanized steel used in the dry floors, due to zinc depletion. The contribution of the transportation phase has a maximum of 5.3% for the ODP due, again, to the emissions in the oil production sector. Most of the building materials (85%) are sourced from a range lower than 350 km and just 7% from a range larger than 1000 km. It is worth noting that the latter represents only 1% of the total mass, but have a significant contribution to the whole transport stage impact (i.e. 12% of the GWP). The construction phase, including fuel consumption and waste disposal, has a maximum impact of 3.8% for the AP category, due to the sulphur dioxide emissions in the fuel combustion. The use phase reaches a maximum impact in the ODP (13.7%). Finally, the EOL phase, considering a scenario where all the materials are sent to the recycling collection site, contributes for a maximum of 3.6% (ODP) to the total lifecycle.

3.2 Construction materials

The second column of the production phase in *Table 1* show the impacts of an equivalent pavilion

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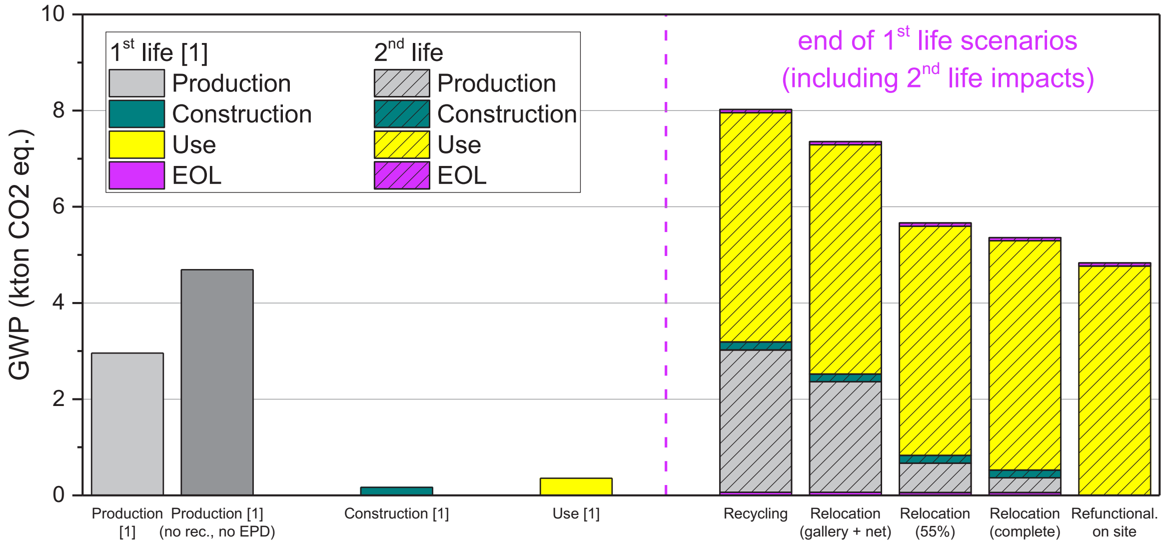

Fig. 3: GWP lifecycle stages.

made with standard construction materials: the recycled component of the materials in input to the system is substituted with virgin matter and the materials with EPD are substituted with standard materials from the Ecoinvent database. The use of recycled and sustainable materials leads to a reduction of the impacts in a range that goes from 19.4% of the ODP to 61.3% of the ADP. The reduction is mainly due to the lower impact of the production of steel from scrap in the electric arc furnaces, compared to the virgin steel produced in blast furnaces.

3.3 EOL Scenarios

A comparison among different EOL scenarios is assessed in order to understand the role this phase could play in the whole LCA. The scenarios considered are: refunctionalization of the pavilion on site, relocation of the structure elsewhere and dismantling with all the materials sent to the recycling collection site. Landfilling was not considered as an option because, according to the builders, all the materials used in the building could be recycled at the event. The last 5 columns in *Figure 3* show that, among the scenarios considered, the one with the highest impacts is the recycling option. The partial reuse of the pavilion (open gallery and net) in a different location (100 km away from the event's site) allows a reduction in the GWP impact, compared to the recycling option, of 6%. On the other hand, reusing the share of the materials that are easy to disassemble in the dismantling process (about 55% of the total) leads to a reduction of 21% of the GWP emissions. The ideal relocation case, considering a complete reusing of the building components, prevent the 23% of the greenhouse gas emissions. Results show, however, that the best solution for the options considered is the refunctionalization of the building on site. Extending the service life of the structure to 10 years guarantees a reduction of the GWP of 28%. The reductions are due to the avoided emissions generated in the production of the materials used for the post-event equivalent pavilion (as shown by the patterned grey stack in the columns in *Figure 3*).

4 DISCUSSION

The comparison of the impacts in the lifecycle stages of the pavilion highlights the role that the production of the building materials plays into the overall sustainability. Using *green* materials allows to substantially reduce the emissions in this lifecycle stage. Even though the EOL phase has a small impact compared to the whole lifecycle in terms of direct emissions, the study highlights that the planning of a second life for the pavilion could lead to important environmental benefits. Bearing this in mind, it is necessary during the design phase to foresee a possible second life and to allow the reuse of materials at the end of the event.

5 CONCLUSIONS

The goal of the study was to increase the awareness of architects and designers about the environmental impacts associated with the construction of buildings for temporary events. It is unthinkable nowadays to design disposable buildings, with a service life linked to the duration of the event. It is necessary to imagine a sustainable and adaptable structure during the design phase. This way of thinking, called Design for Environment (DfE), stresses the importance to consider, in the design stage, future needs of the community and the surrounding environment. The DfE includes the selection of materials and the use of dry construction techniques. The life cycle environmental impacts can be significantly reduced if the structural components of a building are designed to be durable and reusable.

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Additionally, using sustainable materials, either with a high recycled content or with an environmental declaration, would reduce the most impacting phase of buildings with a short service life. The same applies to low energy buildings, whose environmental burden is usually shifted from the use phase to the production of the building components. The design phase has a strategic importance for the overall environmental impact but especially for the EOL phase, highly influenced by the decisions made in the early stages of the work. The objective should be the refunctionalization of the structure, extending its service life as much as possible. The study highlights that a proper design of the structure could lead to a reduction of the environmental impacts, combining choice of the materials and service life extension, of more than 40% of the whole building lifecycle. It is important to highlight that the best environmental option can only be achieved with the intervention of the city organizing the event.

6 SUMMARY

The Brazilian pavilion built for the international event EXPO 2015 has been used as reference case study to understand the role that the design phase and the selection of the materials play in the lifecycle sustainability of the building. Choosing sustainable materials and foreseeing a second use for the building at the end of the event could almost halve the lifecycle environmental impacts over a lifespan of 10 years.

7 ACKNOWLEDGMENTS

The authors would like to thank the architecture and engineering studio Mosae and the construction company Mantovani group for all the information and the cooperation.

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