Environmental Profile and Building Process. Life Cycle Assessment application to experimental dry external wall Construction Systems

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ABSTRACT: We have addressed the theme of the impact of building products on the environment and the efficiency of covering systems within the framework of research on the application of the Life Cycle Assessment methodology in building and architecture, with emphasis on the energetic and environmental efficiency of solutions throughout the entire life cycle of buildings.

The envelope is a determinant factor in the energy consumption of buildings: the commitment by designers and producers must lead to the creation of energy efficient wall systems which give a solid answer to quality of life and to environmental policies.

In this work an experimental comparison between some dry covering systems has been carried out through specific methods of analysis. This could allow a more conscientious choice of the best solutions during the design phase, in order to reduce the environmental load to that associated. From this study, the impact assessment of the best external wall's solution built in a Italian case study building, during the service life, has been deduced. The aim is to highlight the role of the envelope and some directions for a project which answers to the eco-requirements.

The methodology used on the impact of the environment of building materials and components is the LCA, a methodology with indications of energy consumption and quantification of environmental impact.

Keywords: materials' life cycle, energy, sustainable architecture

1. INTRODUCTION

Over the last years the construction sector in Italy has been in constant increase: new buildings, periodical servicing, reuses and refurbishments. It is now the belief that the building industry must be aware of supporting the environment and must spread a culture of prevention and safeguard the construction and its effects.

Global environment deterioration has captured attention and has been the focus of constant mass media reports locally, nationally and worldwide [1]. The construction industry is responsible for high levels of pollution resulting from the energy consumed during the extraction, processing and transportation of raw materials. Also industrialized building methods, based on the widespread use of high-energy materials must now comply with new directives for the protection of the environment [2]. It is clear that actions are needed to make the building environment and construction activities more sustainable. Project development potentially contributes to the economic and social advancement of society, enhancing both the standard of living and the quality of life. The quality is reaching both improvements in projects and in building process, by means of a more closely integrated approach. During the design of buildings, the specification of building products is very important, because choices taken before the realization directly influence the environmental load of any building [3]. A different conception of architectonic project and design is necessary.

As concerns over the environmental impacts of residential house construction grows, nowadays in Italy, researchers are beginning to use life cycle assessment as a means method to quantify natural resources consumption and emissions on the environment. Usually, focus has been set on energy consumption during the service life of housing. With this approach, the energetic and environmental loads of construction materials are neglected. To understand overall impacts of the building, all life cycle stages should be inventoried [4].

The aim of this research is to identify the consequences of realization of light technological solutions - dry, low thermal transmitting - used in the covering of a residential building, during all phases of its life cycle. This paper has the objective of suggesting a strategic way to introduce the life cycle analysis in the building design.

2. METHODOLOGY

The procedures used in this study are standard life cycle assessment methodology, in accordance with standardisation ISO 14040. The analysis has been applied on the scale of building materials or elements, on the scale of vertical walls as technological system and on the scale of buildings.

The objects of study were four dry stratified coverings, built with eight different industrialized building elements, described in Table 1. One element, a stratified panel, was present in all four types. These covering's types were possible choices for a building project, actually under construction in Lodi, in Northern Italy. This building is an example of Structure/Covering technique of construction, using light weight building systems, with high thermal performances and with high level of recyclability. This is one of the singular examples of low energy buildings in Italy. The study was focused on the life cycle impact of the external walls, in three distinct phases: pre-use or manufacturing of building materials, use and end of life.

In the first phase the production processes of each material have been analysed. Due to difficulties in obtaining production processes' primary data from the companies, secondary data were selected to maintain a certain information uniformity. Different databases were used to support the completion of the processes and materials inventory, such as DataArchive (Holland, 1995), BUWAL 250 (Holland, 1997), ETH-ESU 96 (Zurich, Switzerland, 1996), IDEMAT (Holland, 2001), FRANKLIN US LCI (U.S.A., 2003), IVAM 2.0 (Amsterdam, Holland, 2000) and Ecoinvent (Switzerland, 2004), where the main semantics for the realization of an LCA has been looked up. In order to perform the damages characterisation, normalisation and evaluation, three methods were chosen: Eco-Indicator 99 (Hollandaise), EPS 2000 (Swedish) and EDIP96 (Danish) [5][6]. It is important to notice the limitations of such foreign methods for the Italian territory. In Italy neither a database nor a method exist, hence in order to perform an analysis we refer to the existing tools available in Europe. In all three methods damages are classified into major damages categories, grouped respectively in specific impact categories. Impact categories represent a good portion of the environmental problems, whatever the environmental element considered (water, ground or air). In the Dutch method the damage category considered are Human Health, Ecosystem Quality and Resources. Impacts are calculated given the best available scientific knowledge. EPS has similar ones, plus the Biodiversity category, related to species extinction. In the EDIP method other impact categories are present such as Global Warming Potential, Ozone layer depletion, Acidification, Ecotoxicity, Human Toxicity and the Depletion of reserves category, that actually is evaluated using a dedicated method, the EDIP 96 (resources only). This last method does anyway not completely evaluate the depletion of the primary resources. Through the characterization operation of the three methods, values associated to different unit measures are obtained, which become comparable after normalization and evaluation. This operation gives a dimensionless measure (Pt; Points) representing the product assigned impact measure.

EPS 2000 differs from Eco-Indicator 99 due to the different damages and impact categories, the characterization factor measure system and the different basic concept of economic origin. The specificity of EPS 2000 is in fact to estimate the damage depending upon the company willingness to pay in order to avoid a worsening of the considered conditions, hence assigning an economic value to the damage. What distinguishes EDIP 96 from others evaluation methods are: the different impact and damage categories, a different characterization factor measure system and a different basic concept, i.e. the attempt to evaluate the damage respect to a reference damage (2000).

For shortness in this paper only the Ecoindicators methods analysis results are presented.

3. ANALYSIS OF EXPERIMENTAL EXTERNAL WALL COVERING TYPES

This section shortly describes the Lodi building applied phase relative to the project strategy validation and the envelope types. The objective of this phase is to quantify the environmental damage for the realization and the maintenance of some envelope solution types. The external walls' covering types used for this building are classified as a ventilated wall, an opaque façade covered externally with slabs of various kinds, assembled by means of suspension devices and mechanical style fixings; these are considered experimental because they require the usage of particular industrial production. These components were already used as other functional components in buildings and, in this design project, they have a different role, with the needed technical modifications.

It is clearly evident that the thermal transmittance values of the covering behaviour is appraisable to that of a *Passiv Haus*, where an U-value of < 0,3 W/m^2K is foreseen for the external vertical walls, the energy consumption (for heating and for electricity purposes) is equal to 15 kWh/m^2 per year and the insulation thickness is between 25 and 40cm [7]: effectively these envelopes have an insulation of 25,5cm.

Table 1: External wall types for the residential low energy building in Lodi, Northern Italy.

Envelope	Thikness	Material/element	Element's thikness	U-value
type	cm	I/E	cm	W/m^2K
A	37,4	Sandwich panel (wood, EPS, wood)	17,4	0,109
		Stratified panel (polyurethane, embrossed aluminium panel)	12-16	
		Brick hollow flat block	4	
B	34,4	Sandwich panel (wood, EPS, wood)	17,4	0,110
		Stratified panel (polyurethane, embrossed aluminium panel)	12-16	
		Asbestos cement slab	1	
C	44	Cellular concrete blocks	24	0,146
		Stratified panel (polyurethane, embrossed aluminium panel)	12-16	
		Brick hollow flat block	4	
D	34,7	Gypsum board	2,5	0,125
		Glasswool slab	5	
		Hollow space	5	
		Glasswool slab	5	
		Asbestos cement slab	1	
		Stratified panel (polyurethane, embrossed aluminium panel)	12-16	
		Steel panel	0,2	

For the evaluation of the environmental damage a functional unit of 1 m^2 of the wall was chosen, considering an even transmittance (U-value = 0,109 W/ m^2K). In order to obtain this value the insulation thicknesses were modified. The system limits of the analysis are the production phase, from the retrieval of the raw material to the packaging, the company material transportation from its production site to the building site; it was defined the scenario for the end life recycle treatment. At first the life cycle for each covering type has been evaluated with detail, in order to highlight the impacts incidence for each single component and the impacts of the production phase respect to the transportation phase and the end of service life phase. For all four wall types, we may affirm that the production phase is highly incident with regard to the impacts respect to the transportation phase. A quantitative example for this: with the EcoIndicator99 the production phase of type A has an impact in Pt of 21,61, whereas the material transportation to the building site have an impact of 0,533 Pt.

In order to shortly describe the results, we may say that, in case of these stratified types, the high energetic content materials, such as aluminium, polyurethane and polystyrene, are important in assessing the impacts. Still in this study it is evident the importance of association between each material and the treatment at the end of life, after the demolition. For the components under examination, we have associated a recycling treatment, giving an advantage to those materials with high energetic content, that at the life end, thanks to their reuse, avoid the production of new products and so of a new high energy expense. In fact, a material can be produced with low environmental impacts, but if at the end of its life, it goes to the waste disposal, its initial advantage is compromised. It is true that determine today the waste treatment, that will come after some years, becomes only an attempt of foreseeing, since now we know only the actual treatment processes. Still in the future we could have a completely different scenario, thanks to the technological innovation or a deeper knowledge of the behaviour of the new in use materials. Anyway our opinion is that not taking into consideration the problem, due to uncertainty, can only bring to no action and to no experimental progress in the field.

From the comparison among the chosen components for these types of envelope it has been outlined that the synthetic insulation materials have more impact than the fiberglass insulant; among the wall cover materials, applied to the ventilated walls' system, the brick hollow flat blocks have higher performance than the fibrocement panel and the steel panel; the double stratified aluminium panel with polyurethane PUR insulation is highly incident on the environment respect to other components, because of the metallic ions water emission and because of a high energetic expense in the synthesis phase of the PUR.

4. LCA COMPARISON OF THE ENVIRONMENTAL PROFILE

The four coverings were compared to find a better choice of the highest performing solutions, on the same basis (functional and physical-technical). Type A stratified ventilated wall, covered in brick hollow flat blocks, has turned out altogether the more effective (Fig 1). This Type was applied to the assessment of the complete life cycle of the building, in the successive phase. Type C was the worst, as the cellular concrete blocks show a high level of fine powder emission (PM10), a substance harmful to human health in the production phase. The embodied energy has the following values: type A equal to 643 MJ, type B 733 MJ, type C 527 MJ and type D equal to -272 MJ. The latter has an advantage, shown by the negative sign, as it is just composed of materials, with a high content of energy, which through recycling even out the initial effects. Type A is overall the best but is also the one which requires more energy to be produced (Table 2).

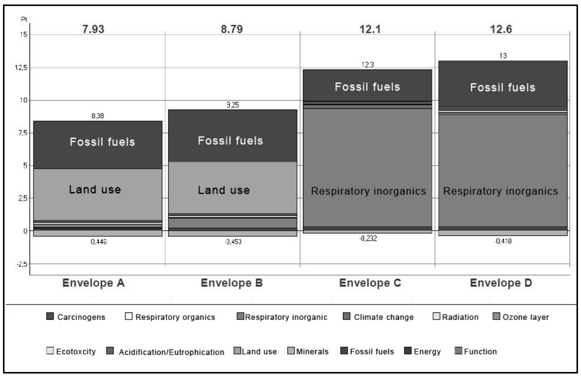

Figure 1: Comparison of environmental impacts of four experimental dry external walls with the EcoIndicator 99 method of evaluation. This method gives points as impact's value for each impact category (see the graph's legend)

Table 2: Characterisation of environmental impacts by method EcoIndicator 99.

Impact category	Unit	Manufacturing and transportation impacts			
Envelope		A	B	C	D
Human health	DALY	2,19E-05	4,65E-05	4,46E-04	4,19E-04
Carcinogens	DALY	1,11E-05	9,74E-06	1,36E-05	1,36E-05
Respiratory organics	DALY	2,05E-07	3,22E-07	6,72E-08	1,92E-07
Respiratory inorganics	DALY	1,08E-05	3,51E-05	0,000418	0,000396
Climate change	DALY	-2,75E-07	1,34E-06	1,46E-05	9,43E-06
Radiation	DALY	1,21E-08	1,20E-08	3,24E-09	4,26E-09
Ozone layer	DALY	1,84E-08	1,62E-08	-8,95E-09	-3,55E-09
Ecosystem quality	PDF*m2yr	65,68	66,25	9,178	23,26
Ecotoxicity	PAF*m2yr	18,3	19,2	5,57	19
Acidification/ Eutrophication	PDF*m2yr	2,65	3,03	2,95	2,46
Land use	PDF*m2yr	61,2	61,3	0,658	1,8
Resources	MJ surplus	57,14	62,41	38,96	56,03
Minerals	MJ surplus	-7,86	-8,09	-4,14	-7,47
Fossil fuels	MJ surplus	65	70,5	43,1	63,5
Enbodied energy	MJ	643	733	527	-272

Another important factor is the value of thermal mass: this parameter influences the heating load and the thermal comfort or cooling load. In this work it isn't carried out an evaluation about the role of mass on energy consumption for cooling, but some consideration has been emerged. These covering systems have low values of thermal mass: type A = 99,3 Kg/m2, type B = 67,37 Kg/m2, type C = 186,25 Kg/m2, type D = 77,5 Kg/m2. Any cooling system is planned for the summer comfort and it is probable a discomfort sensation. The problem is that these “light” materials have low values of thermal capacity and damp the solar gains too quickly than other “massive” components.

5. LCA OF THE COVERING IN THE BUILDING SERVICE LIFE

Increasing the limits of analysis from the production phase and transport to the building site, an evaluation was carried out on the environmental impact in the phase of usage of the whole covering of the building complex in Lodi. The functional unit, in this case, is the usable floor area (Su=505 m^2) and the time span is considered to be 25 years of building service life (estimate of the durability of the components of light covering). The form factor Usable floor area/ Usable building volume A/V is 0.584.

This evaluation has the following process inputs, included in the inventory: energy consumption for the heating of the building, the production process of the envelope with the end of life scenario (recycling), the production process of the reinforced concrete bed, as foundation, with floor and roof/ceiling, with relative end of life scenario (recycling), the production of the windows and doors and the use of ground in the life span of the building (hypothetical situation). Both the covering and the floor are dry assembled with lightweight prefabricated components.

The building site phases and the relative use of machinery are excluded, hypothesising that the high industrialisation of the products and the techniques chosen reduce the level of work, machinery and energy used at the building site. Therefore the impact of this phase, compared to the rest, has to be considered irrelevant.

For the quantification of the energy consumption requirements from the thermal heating system (gas methane) in order to maintain conditions of comfort internally in the building, in winter conditions in Lodi, over a period of 25 years and to contrast the thermal dispersions of 1150 m^2 of spread-out external surface, the software Recall 10, developed by ENEA, the Italian State Bureau for the new technologies, energy and the environment, was used. This is a simulation software, an authentication’s tool of Italian law for the standardized energetic requirements’ calculation. The dispersion due to ventilation and the solar heat gains through windows, optical properties of the glazing, shading effects from awnings and internal heating from other sources were considered in this evaluation. The efficiency of the furnace was also taken into consideration resulting in a value of thermal efficiency, η=0,766. The relative consumption of lighting and hot water production was not taken into consideration. The annual energy requirement of the building is 37 kWh/ m^2 per year. The objective was to verify the efficiency of the type of external walls used and the greater incidence between phase of production of the components or the phase of use with a precise U-value=0,1 W/m^{2}K (Fig. 2). The result in this specific case and for a time span of 25 years is that all processes preceding the phase of management of the building (from the sourcing of raw materials to the building site) determine a greater environmental impact compared to the single phase of the management of the building, with the impacts due to the fuel consumption for the heating system (Table 3).

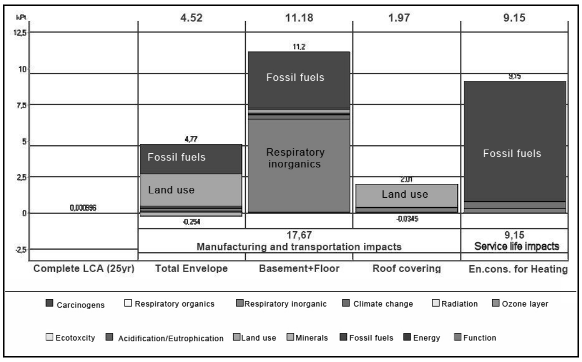

Figure 2: LCA of the case-study building with the scenario of 25 years of service life with the EcoIndicator 99 method of evaluation. The second, third and fourth columns show the manufacturing and transportation impacts; the fifth column shows the service life impacts.

Table 3: Characterisation of environmental impacts with the EcoIndicator 99 method.

Impact category	Unit	Building LCA with type A as envelope and a service life of 25 years				
Building’s system		Envelope A	Floor + Basement	Roof covering	Energy for heating	Total
Human health	DALY	0,0124	0,313	0,0134	0,0345	0,374
Carcinogens	DALY	0,0063	0,00177	0,00139	0,000675	0,0101
Respiratory org.	DALY	0,000117	8,43E-05	4,52E-06	3,34E-05	0,000239
Respiratory inorg.	DALY	0,00617	0,299	0,0133	0,0123	0,331
Climate change	DALY	-0,000157	0,0121	-0,00131	0,0214	0,0321
Radiation	DALY	6,87E-06	8,03E-06	4,04E-06	x	1,89E-05
Ozone layer	DALY	1,05E-05	1,48E-05	1,07E-05	9,20E-07	3,68E-05
Ecosystem quality	PDF*m2yr	3,74E+04	6,22E+03	2,57E+04	711	7,00E+04
Ecotoxicity	PAF*m2yr	1,04E+04	1,07E+04	6,04E+03	890	2,80E+04
Acidif./ Eutrophic.	PDF*m2yr	1,51E+03	1,00E+03	200	622	3,33E+03
Land use	PDF*m2yr	3,49E+04	4,15E+03	2,49E+04	x	6,39E+04
Resources	MJ surplus	3,26E+04	7,20E+04	362	1,49E+05	2,54E+05
Minerals	MJ surplus	-4,48E+03	1,14E+03	-112	48,6	-3,4E+03
Fossil fuels	MJ surplus	3,71E+04	7,08E+04	473	1,49E+05	2,58E+05
Enbodied energy	MJ	3,66E+05	5,69E+05	5,99E+04	1,73E+06	2,72E+06

These results differ if a time span of 50 or 75 years is used (Fig. 3, Fig. 4): two hypothetical situations were analysed for a life span of the building of 50 and 75 years, in which up keeping works and the substitution of the external walls and coverings were predicted. The impact of the construction phase remains unchanged, whereas those of the management phase increase, not only for a “double” consumption of fuel in the first situation, and “triple” in the second, but also for the impact due to the production of new components for the walls and for the roof. In these situations the management phase is decidedly more determining.

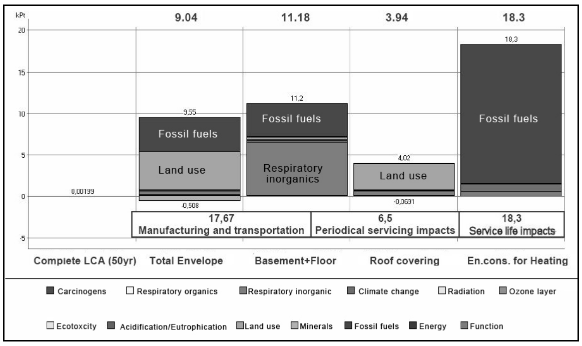

Figure 3: LCA of the case-study building with the scenario of 50 years of service life with the EcoIndicator 99 method of evaluation. The second, third and fourth columns show the manufacturing and transportation impacts and the periodical servicing impacts; the fifth column shows the service life impacts for 50 years.

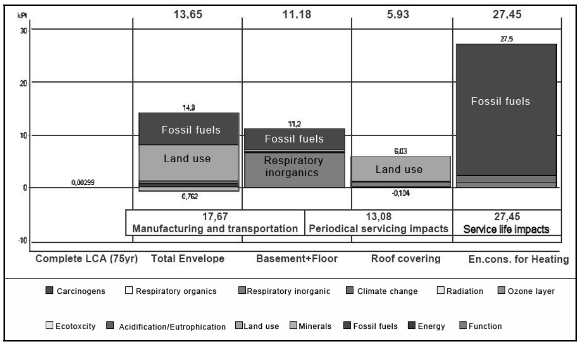

Figure 4: LCA of the case-study building with the scenario of 75 years of service life with the EcoIndicator 99 method of evaluation. The second, third and fourth columns show the manufacturing and transportation impacts and the periodical servicing impacts; the fifth column shows the service life impacts for 75 years.

6. COVERING AND ENVIRONMENTAL IMPACT OF THE 'CASE STUDY' BUILDING

At this point it is important to verify the presence of a minimal limit over which it is not convenient to increase the thickness of the isolating material to obtain an advantage of lower energy consumption. The thicknesses of the isolating material was varied for all four types of external walls. Four separate cases were verified for each type, with U-values of 0.06 W/m^{2}K, 0.1 W/ m^{2}K (base cases), 0.2 W/ m^{2}K, 0.4 W/ m^{2}K. For every case an estimate has been made: the LCA modified by the production processes of the materials, the new requirements of energy and, therefore, the total LCA in the situation of 25 years of service life.

It has been demonstrated that a minimum value exists of total LCA in correspondence with an U-value equal to 0.1W/mqK and that, with the materials used in the 4 types of masonry considered, under such value the reduction of the damage due to the energy consumption exceeds an increase of the damage produced from the production processes of the materials of the walls. An example is given here of external wall Type A estimated with the method EcoIndicator 99. The various greys of the lines in the table correspond to the columns of the diagram. The second and the third lines are constant values, not shown in the diagram.

Table 4: Evaluation of the minimal environmental impact for the Type A with the EcoIndicato99 method

Method Eco-indicator99					
Building LCA with type A as envelope and a service life of 25 years	unchanged impact (kPt)	Impacts of changed Envelopes (kPt)			
Insulation Thickness (cm)		48	25	13	5,2
Thermal transmission value (W/mqK)		0,06	0,1	0,2	0,4
Opaque Envelope Impact		6,2	4,52	3,65	3,23
Basement + Floor Impact	11,2				
Roof celing Impact	1,98				
Impact from energy consumption for heating		8,39	9,15	10,8	14,4
Total building impacts (25yr)		27,7	26,83	27,6	30,6

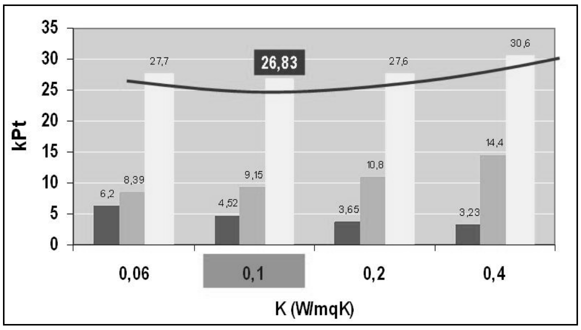

Figure 5: LCA comparison of environmental impact by material's manufacturing processes (with four different quantities of material for each U-value) and energy consumption for heating.

To this minimal value corresponds in Type A an insulation thickness of 25 cm: this is a peculiar case, where the covering is done with stratified components, mostly made with insulation materials. The outcome does not pretend to be an indication for an ordinary planning and building praxis. This analysis aims to show clearly how it is necessary an entire assessment, by LCA methodology, both of energy consumption, in the use phase, and of the production phase impacts of covering. Moreover this balance has to be considered in the planning phase in order to design and construct a building with a minimal environmental load.

7. CONCLUSIONS

The outcome of the study should be an indication of the basis of an environmental analysis in the planning process. This study demonstrates how the aspects to consider and not to underrate in the planning are always greater, if the tendency is "towards an overall quality". It is therefore correct to speak again about the complexity of the planning process and the variety of factors involved.

With specific reference to appraisals conducted during this research, it is not fair to assume that an architect, besides the customary verifications for the carrying out of a plan, can independently acquire such methodology and apply it in order to verify the minimum impact to obtain. It is also difficult to currently assume that on every project a similar analyses to this can be carried out, due to the current lack of certain figures necessary to the information process, the absence of an Italian methodology and of the high costs to support. Certainly, this practise could be used to support the decisional process of Public Administration offices for public works. The urgent condition remains however the improvement of quality in the sector of private building, which is the most widespread an widely decisive on emissions in the atmosphere. A decisive improvement is needed in quality construction in this sector.

The LCA Methodology does not want to announce complete accuracy but can definitely offer useful indications to compare the alternatives choices of materials and energy. It introduces a multidisciplinary approach, and so it is fundamental to have collaboration between experts in this methodology, pertaining to different disciplines, and field workers, more aware of the reality on a daily basis.

The LCA can be useful in the planning phase in order to preview the impacts and to optimize the choices, after a comparison between various construction systems (optimization of the quality of the project), and can be decisive on the entire building process, estimating the stages in which the damage to the environment can be minimized.

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