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ECODESIGN FOR DECONSTRUCTION IN THE LIFE CYCLE POST-OPERATIONAL STAGE TO IMPROVE CONCRETE RECYCLING IN BRAZIL

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ABSTRACT

The study presents *Ecodesign* as a tool that can help in the management of building deconstruction waste, through projects that use this waste as raw materials for the creation of new products that simultaneously meet the needs of its consumers and the environment, with the aim of reducing the use of non-renewable resources end minimizing their environmental impact in their post-production stage. All this with the aim of specifically bettering the recycling of concrete in Brazil. The study is characterized as exploratory research for its aim in providing information about *Ecodesign* applied to civil construction s in their post-operational life cycle phases; which is an under explored subject. In addition to presenting results of a case study of a residential building developed by the authors in Brazil.

Keywords: ecodesign, buildings, deconstruction, life cycle, recycling.

INTRODUCTION

The construction industry plays a key role when environmental issues are under discussion, as buildings are the main contributors to the environmental impact of human activity (Anderson *et al*., 2015). According to Lamé *et al*., (2017), to address this issue and reduce the environmental impact of human activity, a possible solution is the integration of environmental aspects into product development design, which is known as ecological design (ISO, 2002).

Given the current scenario of considerable exploitation of natural resources around the world, and despite growing discussion and search for more environmentally sustainable processes and solutions, the field of construction is still directly or indirectly responsible for causing major degradation processes and According to Tello and Ribeiro (2012), construction activities account for 40% of all waste generated by global society.

The increasing use of concrete in the construction of buildings around the world is evident. In 1950, between 2 and 2.5 billion tons of concrete were consumed, and in 2006, between 21 and 31 billion tons of concrete were consumed globally. They are used twice as concrete in world construction as the total of all other building materials, including wood, steel, plastic and aluminum (WBCSD, 2009). As a consequence, concrete constitutes a considerable part of the waste generated on the planet.

According to the report developed by the World Business Council for Sustainable Development - WBCSD (2009), concrete is the second most consumed material in the world after water. It is estimated that more than 900 million tons of waste from this material are generated annually in Europe, the United States and Japan, with quantities unknown elsewhere, including in Brazil.

For Durmisevic (2006) the main problem of conventional buildings lies in the fact that the materials used have no potential for recovery. Consequently, existing building methods use only a small percentage of the durability potential of building materials, considering the demolition process as the end of the building cycle. The main issue of sustainable construction is how to strike a balance between the changing dynamics of change, which is related to increased resource consumption and the fundamental principles of engineering for sustainability (such as: choosing natural resources, saving energy, reduction of waste, etc.). Many studies have pointed out that this goal can be achieved by extending the life cycle of buildings and their materials.

Barbosa (2010) states that attention to the life cycle of both the product and the building is the most direct way to guide each phase of the project with the sustainability guidelines:

> *During pre-fabrication, the choice of materials should be careful; in production, it is necessary to know labor relations and measure energy consumption; the distribution involves not only the transport, but the dissemination, the packaging; the use generates energy consumption, and the disposal produces another network of impacts not only on the environment, but also to the economy and society. Aiming at sustainable development, actions should qualify the context in which they will be inserted: uniting people, stimulating the sharing of tools and equipment. (Barbosa, 2010).*

In this perspective, structures that allow ephemeral aspects through assembly configurations and fixation of the components designed for this purpose can be the key to the balance between the contemporary dynamic changes in the way of life, the current demands of the market and economy, and environmental sustainability.

Thus, the principles of Ecodesign, conceptualized as comprehensive and complex by Yeang (2006), guide the contemplation of design solutions under environmental aspects, in a discourse aimed at minimizing waste, the use of material resources and energy, durability, modularity, reuse, recycling, among others. All of these aspects are included in the Design for Disassembly (DfD) guidelines. The concept of dismantling comes as a substitute for demolition, and guides the decision-making of the designer in predicting the useful life of the project, the components and the ease of dismantling the construction, aiming at the reuse of materials and possible recycling.

These principles can become allies in the design of projects and more rational constructive systems that aim at saving resources, rationalizing the durability aspect of the architectural concept and improving functional, aesthetic and human aspects.

The principles of Ecodesign are introduced in this context in an approach that aims to guide the designs of structures for the disassembly and recovery of components.

ECODESIGN

The concept of Ecodesign arose from the definition of "Design for Environment" (DfE), which arose when the electronic industries of the United States created an association, known as American Association of Electronics, with the concern of developing projects that were less invasive to the environment. At first, the benefits were given to the members of the association, but interest in the subject grew rapidly, and so the Ecodesign started to be used in other sectors such as environmental management and pollution prevention programs, including environmental issues in design of new products, processes or services (Nascimento; Venske, 2006).

Ecodesign is implemented in the creation of new concepts and in the emergence of new patterns of consumption. In addition to integrating environmental issues into industrial design, relating what is technically possible with what is ecologically necessary and socially acceptable, given the growing awareness of the need to safeguard the environment in a context of sustainable development (Annes, 2003).

The principles for the implementation of the Ecodesign have been defined by the United Nations Environment Program (UNEP) and comprise eight phases that serve as a guide for the implementation proposals by companies. UNEP uses the Ecodesign Strategies Web to evaluate the performance of various aspects related to a product, according to Figure 1 of Nascimento and Venzke (2006).

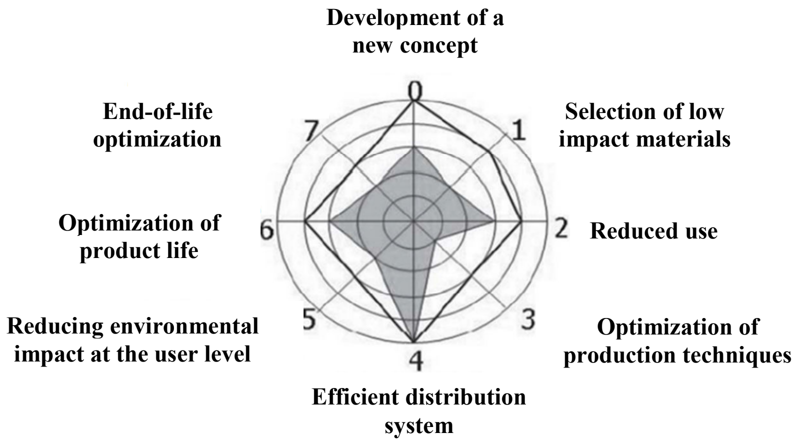

Fig. 1 - Ecodesign Strategies Web

In guiding the use of this tool to evaluate the environmental performance of a product, the user can assign a percentage for each circle, for example, the center of the circles corresponds to zero and, with a variation of 20 percentage points for each circle, we arrive at the outer circle with a score of 100%, that is, the center of the Figure represents an inadequate environmental performance and in the outer circle, optimal environmental performance. When performing an analysis of the probabilities of improvements, the environmental performance of the product is marked in the same rays after the application of the established measures (Nascimento and Venzke, 2006).

Ecodesign variables

The concept of ecological design is used and defined through variables for the development of so-called ecologically correct products. DfX - Design for x - where 'x' represents the variables, such as ease of maintenance, disassembly, services, etc., is used to demonstrate the specific characteristics of the product when the proposal focuses on ecological design (Annes, 2003).

According to Kindlein Júnior *et al*., (2002), the development of eco products depends on the decision-making by sets of elements which consider the relation with the Design for

Assembly (DfA), the Project for the Manufacture (DfM), the Design for Service (DfS) and the Design for Disassembly (DfD). In this way, it is possible to minimize the environmental impact generated by the product through the systematic application of the variables presented in the design practice in all spheres of the global production and use cycle. Table 1 describes the DfX variables used in the path to sustainability.

Table 1 - DfX variables

DfX variables	**Description**
DfA - *Design for Assembly*	It considers, during the development phase of the product, systems that facilitate the assembly of this product, that is, facilitate the manufacture. This directly implies the reduction of the assembly time and leads to an increase of production. More recent environmental considerations call for dismantling and recycling to be considered during product design.
DfM - *Design for Manufacture*	The selection of processes suitable for manufacturing includes: material selection, process selection, modulated component design, component standardization, multi-part parts development and targeted assembly for module minimization.
DfS - *Design for Service*	It is concerned with the maintenance services performed during the life of the product and its reconditioning, being important for those products that require service or periodic repair, such as machines, cars, etc.
DfD - *Design for Disassembly*	The development of the product design focusing on ease of disassembly includes advantages such as: reduction of the work required to remove parts of the product, reduction of maintenance time, separation of compatible and incompatible materials, and generates a greater interest in the final recycling of the product in Sorting Centers. This variable is also called DfR - Design for Recyclability because of the characteristic of providing a more practical recycling of the product.

Design for Disassembly (DfD)

The Design for Disassembly (DfD) is one of the lines of reasoning in the design approach of Ecodesign.

The practice of DfD is to facilitate deconstruction processes and procedures through planning and design (RIOS, CHONG, GRAU, 2015). According to Yeang (2006) the basic principle of design for dismantling (DfD) in construction is to achieve continuous reuse and recycling of the built environment before the end of its useful life and thus influence the way in which the various parts and components are assembled - together, fixed or connected. Figure 2 exemplifies the relevance of the design for disassembly.

For Taron (2016), since labor is the most costly aspect of screening a building in a series of waste streams at the end of its life cycle, pre-fabrication presents an opportunity to incorporate parts with the know-how of disassembly and self-class instead of resorting to demolition.

Considering this assumption by Taron (2016), the use of precast concrete slabs in the construction of the buildings can facilitate the disassembly and reuse of the pieces in new constructions, or, to allow the recycling of these plates, which can serve as matter for new uses in a "cleaner" way, since the pre-shaped plates can be removed without the building having to go through a demolition process, where all the materials that make up the building are mixed.

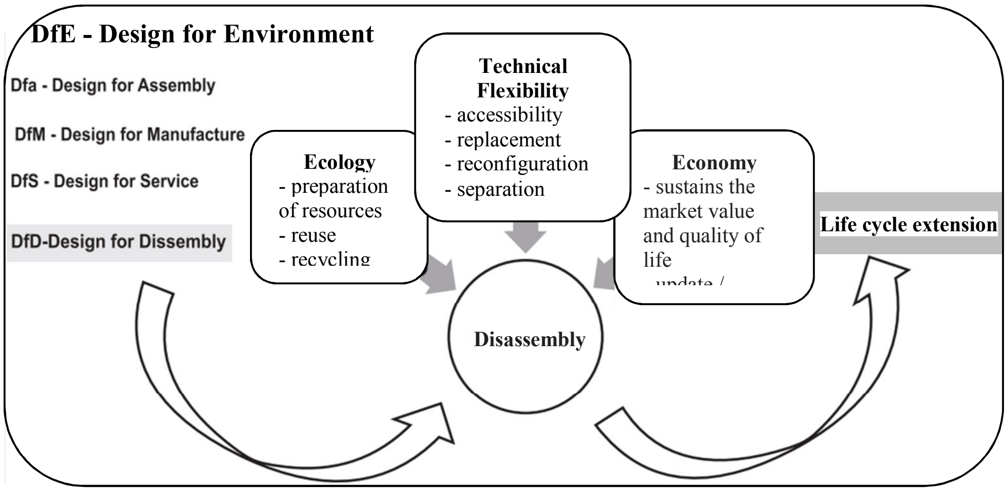

Fig. 2 - Relevance of the Project for Disassembly

According to Yeang (2006), a characteristic of DfD includes the use of simple clamps, pins and bolts, as most non-chemical attachments (with few connections that use glue, for example). If glue is used, it should be a water-based adhesive, strategically applied and with the minimum amount possible, not only to minimize the amount of adhesive used, but also to allow replacement by other materials. The most successful systems are those that use a small number of materials and components that can be easily dismantled, separated, rearranged, and reused.

Another characteristic of DfD pointed out by Yeang (2006) is to guide the design of products for the environment built to be durable or long life, with less need for elimination or replacement. In today's economy, when based on the sale of goods, the financial interests of the manufacturer become environmentally harmful and costly to customers. On the other hand, when this economy is based on DfD service and flow, it is in the interest of both the manufacturer and the customers to create long-life products using a minimum of energy and materials. Demand for labor (to do all disassembly, sorting and recycling) increases as waste is reduced.

Durmisevic's (2006) research assumes that the greater the capacity for transformation and dismantling of a building, the less environmental impact it will cause and, therefore, the greater the sustainability.

In this context, the environmental and use efficiency of the building may perform better with increasing dismantling potential, which can be achieved by optimizing the DfD aspects.

Ecodesign in the post-operational stage of the cycle of buildings

Strategy 7 of the Ecodesign Strategies Web (Figure 1) focuses on the use of the product after its useful life (post-operational phase), so that it does not cause environmental impacts when reaching this stage. According to Nascimento and Venzke (2006), in this strategy the following variables are considered: product reuse, reconditioning and remanufacturing, recycling of materials, clean incineration and energy reuse.

Generally, there is a discrepancy between the life of use and the technical life of the building materials. The combination of construction methods and current market activities, which result in shortening the time of use of buildings and systems and components, becomes a major challenge in the necessary reduction of waste, materials and energy use during the life cycle of buildings: "consequently, a complementary closed-loop approach is required in building design, improving the overall efficiency of building materials and waste throughout their entire life cycle" (Paduart *et al.*, 2015), as can be observed in Figure 3.

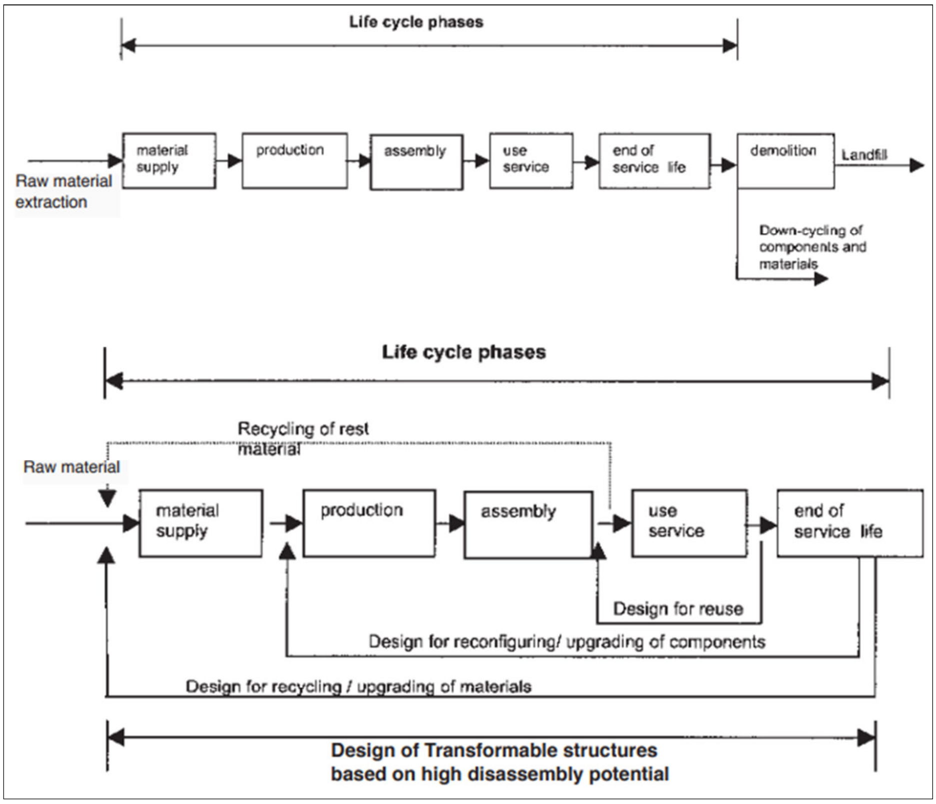

Fig. 3 - Standard linear life cycle model of materials and components of constructions (above) and closed life cycle model of materials and components of transformable structures (below)

In this way, a project for transformable buildings can help achieve long-term use of existing buildings and their components, as long as they anticipate changes during the building's lifecycle (Durmisevic, 2006; Debacker, 2009; Paduart, 2012). This strategy includes reversible fitting techniques that are combined with reusable building materials - so that buildings can withstand future changes and, consequently, prolonged use of the same components would enhance the environmental benefits during the building's life cycle (PADUART *et al.*, 2015).

The use of precast concrete in construction

Civil construction has been considered a lagging industry when compared to other industrial sectors. The reason for considering it is based on the fact that it generally presents low productivity, great waste of materials, slowness and low quality control. According to El Debs (2000), one of the ways to seek to reduce this delay, to minimize waste and to invest in the possibility of reusing these materials in new works is to combine techniques with the use of precast concrete elements. In this way, parts of the construction would be made under better conditions than the site and then assembled as part of the construction process.

Among the benefits of the use of precast concrete in construction, it is worth mentioning the reduction of construction time, better control of precast components and reduction of wastage of building materials, without the possibility of reusing parts of construction in new buildings. In buildings, precast concrete can be used in industrial, commercial and residential building structures, as well as in multipurpose urban equipment such as hospitals, road and rail terminals, among others. It should be emphasized that the application of the precast concrete is not restricted to the main structure and can also be used in the closures of the building encasement (El Debs, 2000).

Figure 4 below shows an example of construction with intensive application of precast components in buildings. This involves the expansion of the Madrid-Barajas airport in Madrid (Spain): a) execution of the precast concrete beam with mobile cramming; b) assembly of the honeycomb panels; c) view of the work under construction; d) work ready.

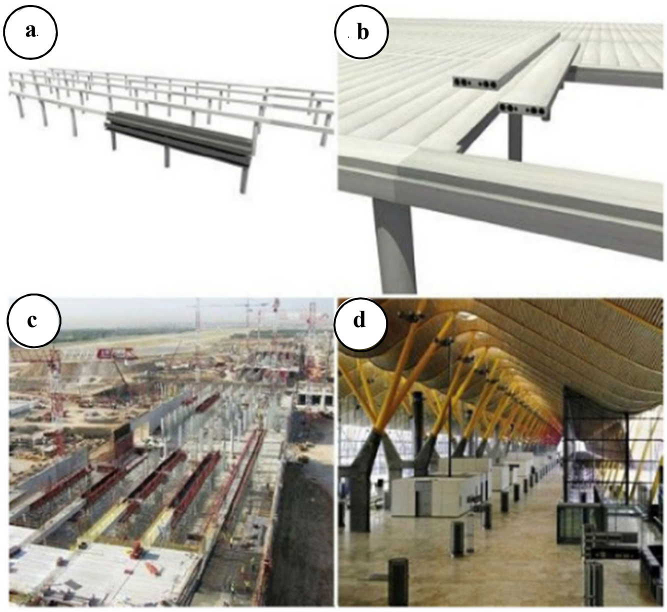

Fig. 4 - Enlargement of Madrid - Barajas airport, in Madrid (Spain)

For a long time, the precast concrete structures were considered very rigid in relation to the project, making the designers' freedom impossible. According to El Debs (2000), in fact until the end of the year 1970 there was intensive use of constructions with much repetition. Due to questions raised by this architecture, the projects are becoming more flexible and the manufacturers of precast concrete have tried to meet the demand for projects of this type. Figure 5 shows two representative examples of more flexible projects: the Bella Sky Comwell Hotel in Copenhagen (Denmark) and the Le Saint Jude Residence in the region of Quebec (Canada).

Precast concrete structures designed and built properly have durability and low maintenance, this feature is enhanced by greater quality control of precast elements made in factories (EL DEBS, 2000).

In view of the growing concern with the post-operational phase of the life cycle of buildings, projects should consider ways to maximize re-use possibilities, or at least enable recycling of the structure and its components. The use of precast components, in this case, can meet this current need of civil construction. An example of this can be seen in Figure 6, where the deconstruction of old precast concrete silos in Copenhagen was performed for reconstruction for residential use.

Fig. 5 - Examples of precast concrete application in more flexible designs

Fig. 6 - Example of deconstruction of old silos in Copenhagen for reconstruction for residential use

RESULTS

Considering a previously developed case study in Brazil by the authors, concerning a residential building with 1.385,84 m², it was observed that for the purpose of calculating the energy consumption in the post-operational phase of the life cycle of the building, it was necessary to consider two main aspects, those being the consumption of energy to remove the waste from the demolition site, and the energy consumption to demolish the building, summing up to the total energy consumption for the demolition of a building.

Only materials with the highest amount (m³) were selected for the analysis according to the results obtained in the quantitative material. In Table 2, the materials and their respective amounts in m³ are described. To obtain the mass of debris in kg, the specific weight of each material was determined.

Table 2 - Materials adopted for calculation

Materials	**Quantity** (m³)	**Specific mass** (kg/m³)	**TOTAL** (waste mass - kg)
Steel	2,75	7.800	21.450
Masonry*	663,05	2.100 - 2.300	1.732.015
Concrete	283,3	2.100 - 2.300	651.590
Wood	30,22	600	18.132

* Masonry sum acquired (m³) by summing the volume of the building's mortar/plaster/rough-cast.

In this study, the transport distance traveled for the removal of the waste to the recycling plant is 47 km. Another important aspect is that the energy consumption for the removal of waste is divided into four other processes, including loading, crushing, transporting and unloading the waste at the place of recycling or storage.

In order to verify the energy consumption in transport for each related material in Table 2, the number of trips (back and forth) of the truck to transport the residues of each of the materials was verified. Then, multiplying the number of trips by the energy consumption of the truck (399,21 kWh), the total consumption in kWh was obtained to transport each material. To reach the total consumption in kWh / m², the consumption in kWh was divided by the total area of the building, 1.385,84 m². The results are shown in Table 3.

Table 3 - Use of energy for the transportation of waste

Materials	**Number of truck trips**	**Total consumption** (kWh)	**Total consumption** (kWh/m²)
Steel	1,07	428,15	0,31
Masonry	86,60	34.571,87	24,95
Concrete	32,58	13.006,06	9,38
Wood	0,91	361,92	0,26

It was verified that the energy consumption for the transportation of the waste is of 34,9 kWh / m², being that this value is related only to the use of the truck.

For the process of loading the waste into the truck, a height of 1,5 meters was assumed and for discharging, a height of 1,0 meter. A total of 2.423.187 kg of waste was considered in the loading and unloading processes, including masonry, steel, concrete and wood. For the crushing process, a total of 2.383.605 kg of waste including masonry and concrete was considered.

In order to make better use of each trip made by the trucks, it was assumed that the grinding of the large wastes was done at the demolition site itself. An amount of of 55 kW was considered for the power of the crusher. The materials considered for crushing were masonry and concrete, disregarding the other materials. The results for each of the processes are shown in Table 4.

Table 4 - Energy consumption for other removal processes

Process	Energy consumption (kWh)	Energy consumption (kWh/m²)
Loading	9,90	0,0071
Crushing	2.184,97	1,5766
Unloading	6,60	0,0047

It has been found that the energy consumption for the processes of loading, crushing and unloading of waste is 1,59 kWh / m². In view of these values, the total energy consumption of waste from the demolition site is 36.49 kWh / m².

In addition to energy for the removal of waste, there is also the demolition energy. According to the report developed by the World Business Council for Sustainable Development (2009), the energy consumption for demolition is estimated at 92 MJ / ton. For demolition energy consumption, the total amount of masonry, steel and concrete, was 2,405,055 kg, resulting in 44.35 kWh / m².

Figure 7 shows the total energy consumption for demolition, relating the energy consumption for demolition and waste removal to the recycling plant.

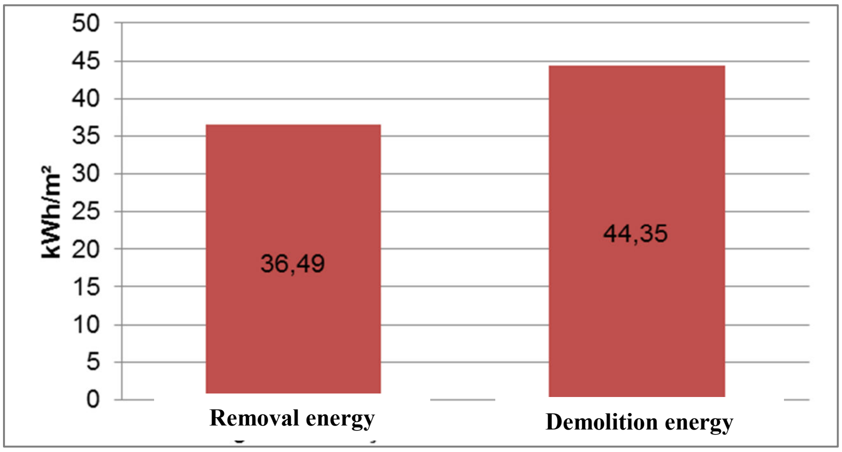

Fig. 7 - Total use of demolition energy

The total demolition energy consists of the sum of the demolition energy plus the energy for removal, resulting in 80,84 kWh/m².

CONCLUSION

Considering the reuse of concrete from demolition in the construction of new buildings, it would be possible to save 1,72 kWh / km·m² (total demolition energy / distance to the recycling plant = specific energy consumption per kilometer) from new buildings, considering (kWh / m²) and the distances for the transportation of debris from the demolition of buildings (km).

In order to obtain better effects from the application of Ecodesign in civil construction, specifically in the post-operational phase of the life cycle, it is necessary to consider the flexibility of the architectural design from its conception; this could improve the useful life of the building and allow future adaptations, making feasible the reuse of the materials used. Deconstruction of a building in such circumstances would make it possible to reuse virtually all materials.

The project designed for future reuse enables a lower energy consumption, since the only additional energy required is transportation, while in the recycling process, sufficient energy is needed to divide a compound and reconstitute a complete material, which requires energy in most cases. Reuse of components, such as structures, technical services and façade coatings avoids the consumption of virgin raw materials and reduces the generation of waste.

To effectively integrate Ecodesign into the concrete reuse or recycling process, companies responsible for this building industry may have to significantly change some of the practices and habits of all stakeholders involved, along with the organization, and productive and constructive techniques.

Within a life cycle analysis, the use of recycled concrete can reduce significant environmental impacts. When you stop using recycled materials you increase the volume of waste deposited in landfills, along with the associated environmental and health costs. In addition the use of virgin materials is promoted. In some cases, transport needs for recycled concrete may also be lower when compared to virgin materials and therefore fuel consumption, CO_2 emissions and the use of roads and vehicles can be reduced.

In view of the above, it is possible to conclude that if the Design for Disassembly is adopted as a practice in conventional projects, it will allow existing constructions to serve as a source of raw material for new constructions, rather than to extract resources from the natural environment. In order to move towards such scenarios, it is necessary to change the perception of the designer regarding the technical composition of the building, the transition from permanent and fixed structures to mutable and flexible structures.

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