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Design for Disassembly

A sustainable option for the construction industry

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Abstract

This paper is about Design for Disassembly, a concept that has been used in the electronic and automotive industry as a way to ease the disassembly of products and increase the possibilities to reuse and recycle the materials and components. In the construction industry it is important to consider that the residues from construction, maintenance and demolition are responsible for a large part of environmental pollution. To prevent this, it has become such an important issue that a lot of companies, universities and governments are searching for better solutions. At the end of the life of a building, a lot of materials and components that are still in good condition and could be reused or recycled end up as residuals and go to landfills . Most of the time this happens because when the building was designed, the end of its life and its deconstruction wasn't considered , so it is more difficult to separate the materials and components. During the design of a building it's important to think about the lifecycle of the whole building, its components and materials, It´s also very important to consider the different life cycles and the end of its life. Nowadays, in Brasil, demolition is the most common solution at the end of a buildings life. This has serious consequences for the environment, the large amount of waste results in pollution of rivers and other places that are not prepared to receive these materials. This article reports on a common demolition in Brasil, which didn't consider concepts for Design for Disassembly. This helps to understand how it is done, to see what materials and components can be disassembled for future reuse or recycling, also to observe the obstacles that hinder better results. Design for Disassembly can increase the possibility to reuse and recycle the materials and components. It can also contribute to making the process faster and rental more economical. Some design solutions such as the way the components and materials are connected can make the process easier, faster and more attractive.

Keywords: design for disassembly, sustainable architecture, demolition, deconstruction.

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1. Introduction

This article aims to discuss the environmental impact of building demolition in Brazil and argue about the concepts and importance of considering Design for Disassembly (DFD).

Nowadays the most common system of construction here in Brazil is a structure with reinforced concrete, brick walls, timber structure roof and ceramic roofing tiles. At the end of its useful life, usually the building is demolished, some of the materials are separated for future reselling, but most of them are treated as demolition waste and go to landfill or an illegal place.

Demolition has terrible consequences for the environment. Most of the residuals go to landfill or are disposed in illegal places such as rivers or unoccupied lands. The Construction Industry is responsible for a lot of the solid waste in the cities. Demolition causes a lot of material waste, so it's fundamental to look for strategies to minimize it, such as facilitating the reuse and recycling of the materials and components (Heriqson, Rocha and Sattler 2008).

This practice results in a lot of material waste, pollution and environmental damage. It is fundamental to reach for solutions to relieve the situation. The concept of Design for Disassembly can assist in reaching better solutions. By using this tool the disassembly during the design of the building, can contribute to a better deconstruction with more possibilities to reuse and recycle more materials and elements. Therefore contributing to the environment. Nowadays, the way the buildings are designed and constructed results in a large amount of material waste such as the large consumption of primary materials that are extracted with considerable environmental damage (Gorgolewski 2008).

To Design considering the end of life (EOL) of the building also contributes to reducing the consumption of raw materials. The expanding economy and population are increasing the demand for materials, as a consequence this consumes a lot of natural resources (Gorgolewski 2008). It is also very important to consider the lifecycle assessment (LCA) of the building from the design stage, to ease the disassembly and maintenance of different elements and materials during the lifecycle and end of life.

The Design for Disassembly is an important tool to optimize the reuse and recycling of the materials and components from a building that reaches the end of its useful life. It is not usual for the designer to consider the end of life of the building and what to do after that. They are designed to be used for decades, but after that, the most common solution is demolition.

2. Research Method

The paper uses multiple evidence sources: literature review, field research and interviews with some people involved on the case study. It began with a literature review of sustainable development in construction and the environmental impact caused by demolition. The Design for Disassembly concepts are also based on literature review and LCA.

Subsequently, a case study is presented about a common demolition of a one floor commercial building, to analyze what materials could be or not be disassembled and the reasons for that. A thin kind of construction was chosen because it is very usual in Brazil and it would be possible to verify what are the barriers to disassemble the elements to achieve better results.

Finally, this paper talks about the relation of demolition, LCA, DFD and how it can contribute to better results for future reuse or recycling of the materials and the reduction in environmental impact.

3. Demolition and Sustainability

According to Tessaro, Sá and Scremin (2012) the construction industry is a very important sector in society's progress, however, it causes serious environmental impact. Construction and demolition consume large amounts of materials and also generate a lot of waste. Comparing to last century the economy and population have grown a lot, along with them, the consumption and waste of materials.

According to Alves (2010) the population grew 7 times (1 billion to 7 billion) from 1800 to 2010, and the economy has grown about 50 times. That fast growth results in soil, river, lakes and ocean pollution, also deforestation and a large consumption of fossil fuel. This shows how important it is to look for a more sustainable development.

It is important to reach for solutions to sustainable development in the construction sector. The environmental aspects of sustainable development require that we reach for a balance to protect the environment and natural resources and use it in a way to provide a good quality of life (CIB and UNEP-IETC 2002).

In Brazil, during recent years, there has been a fast growth of large and mid-sized cities, so the Construction and Demolition Waste (C&D Waste) has also been growing fast (Nunes, Mahler and Valle 2009). Finding ways to improve the reuse and recycling of materials, subsystems and elements helps to reduce the waste and consumption of raw materials.

Most of the C&D Waste is not recycled in Brasil, but to try and encourage change, the government creates federal regulations to oblige municipalities to implement better solutions to increase recycling. One of the initiatives from the Brazilian government was the creation of the resolution CONOMA 307, which established directives, criterias and procedures for waste management, so municipalities must have a plan to reduce the waste (Nunes, Mahler and Valle 2009). The production of documents that intend to reduce environmental impact is very positive and forces the construction industry to pay more attention to construction and demolition waste (Couto, Couto and Teixeira 2006).

Only 0.2 % of Brazilian municipalities (12 from 5,507) have C&D waste recycling centers installed or under construction (Nunes, Mahler and Valle 2009). For the authors, most municipals are far from reaching the CONAMA resolution.

Nunes, Mahler and Valle (2009) have made some suggestions in arguing for the recycling of C&D Waste:

- The government could be a better example, as it is the biggest consumer of construction materials, by adopting policies that encourage the consumption of recycled materials
- Reduction of taxes and provision of loans with lower interest rates
- The prices of recycled material need to be lower than the conventional materials, especially in Brazil that has a low price of raw construction material
- Motivate construction of private recycling centers

When considering the life cycle of the building, its components and materials need to have better results in future reuse and recycling, this is also one of the concepts that makes up part of DFD. It is essential to look for solutions during the design process with sustainable concepts, besides technical and functional issues, in a way to reduce the environmental impact (Gouvinha and Romeiro Filho, 2010).

4. LCA

The LCA (life cycle assessment) is an important tool to plan and reduce the consequences of our actions (Crowther, 2005). It helps to indentify the output, the inputs and the whole cycle to help the designer take sustainable decisions.

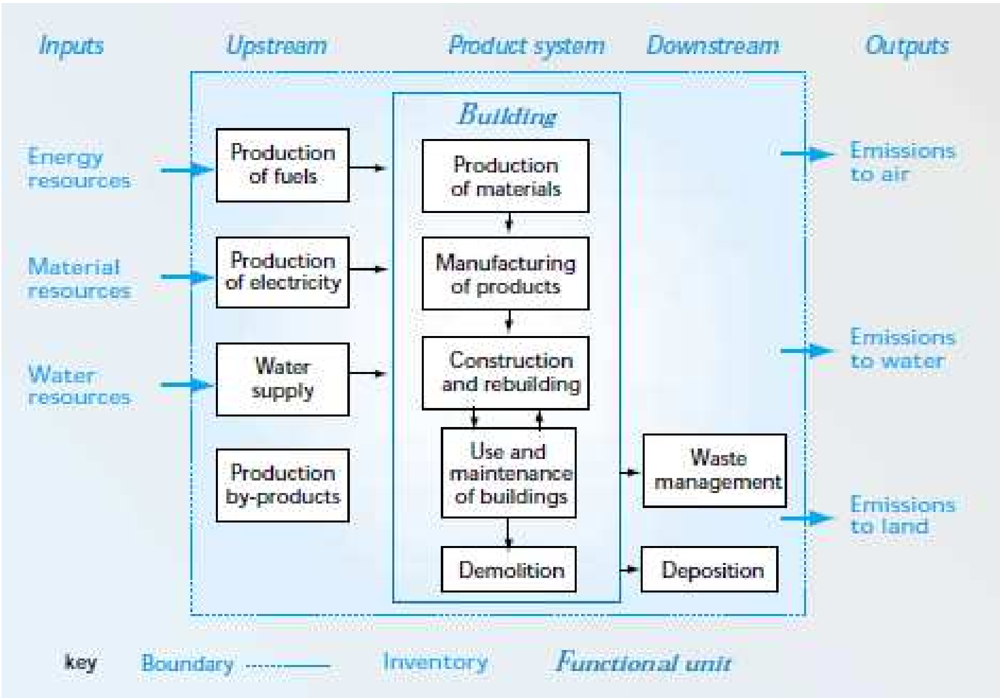

Figure 1: Application of LCA to construction products (Edwards and Bennett 2003)

Finding solutions for material waste is critical in creating a “closed loop” production model for sustainable development (Rocha and Sattler 2009). It is important to consider a cyclic view of the build environmental during the project, so there are more options in its end-of-life (Crowther 2005).

The figure 1 shows the usual procedure of LCA for construction products. It is important to realize what is necessary to produce materials and products for the construction. All phases of the product are important to considerer the environmental impact. From the extraction of raw material to production, use and discard. In this way it makes it possible to realize the critical points and search for solutions. The usual model of industry production is to extract material from the environment, process, manufacture, use and dispose. In the construction industry it also works that way, most of the time (Crowther 2005). This is considered a linear cycle. The concept of DFD collaborates to change that, because it contributes to reuse and recycling.

Some designers have the idea that the building should last as long as it can, so they don't even consider what to do at the end of its useful life. This causes serious consequences to the environment. Sometimes the government needs to intervene with regulations to encourage better solutions.

In Brazil there are regulations that consider the LCA, one of them is the ABNT NBR 15.575, which argues for the consideration of the cycle of the building and the components during the design. The table below shows how long a project should consider the lifetime of the building's components, for residential buildings of up to 5 floors.

Table 1 Life expectation (ABNT NBR 15575, 2008)

System	Years
Structure	>40
Internal Floor	>13
External Vertical Seal	>40
Internal Vertical Seal	>20
Roof	>20
Hydrosanitary	>20

It is possible to note that a lot of new buildings won't last more than 40 years, and if they do, they will need maintenance. This makes clear the importance of finding solutions for the end of their life.

The next table is about the maintenance of the buildings and their life cycle. It is interesting to note that between 30 and 50 years is considered long time usage.

Table 2: Construction processes and the lifetimes (Soares et al, 2000 apud European Commission, 1997)

Life Expectation	Processes of a specific building
1 to 3 years	Design and construction of building / civil engineering work
3 to 5 years	Maintenance time and use
10 to 15 years	Average length of use and partial renewal
30 to 50 years	Long time usage and Renovation

80 to 120 years	Lifetime structural systems of buildings
More than 150 years	Lifetime of monuments

It also shows that most buildings don't last as long as most people think. The designers need to consider this so we can have more options at the end of life and not choose only demolition. Crowther (2005) talks about four end-of-life scenarios:

- · Relocation or reuse of the building
- · Relocation or reuse of the components
- · Reuse of the materials
- · Recycling the materials

Considering this important phase of the building and the life cycle is very important to finding better solutions for reuse and recycling, also in reducing the demotion waste and the environmental impact caused by this industry.

5. Design for Disassembly

The project is the starting point of the building, so a large part of the solution to reduce the environmental damage should come from the designer, who is responsible for this phase (Degani and Cardoso 2002). Design for Disassembly can contribute to finding better solutions at the end of life of a building and facilitate the reuse and recycling of materials.

Nowadays demolition is the most common practice, but it results in a lot of waste and environmental degradation. Disassembly of the buildings to facilitate the reuse of materials and components is not usual in the modern construction industry (Crowther 2005).

The deconstruction valorises the reuse of elements and materials that would be treated as residuals without any value, in addition to contributing to recycling, reuse, innovation of technology, sustainability and the market of used material (Couto, Couto and Teixeira 2006).

Many designers don't pay too much attention to the end of life of construction and don´t consider ways to dismantle the building. However, there are some buildings that were constructed to be disassembled and assembled again, even relocated, such as the portable colonial cottages of nineteenth century Australia and London's crystal palace of 1851 (Crowther 2005). History can supply designers with some successful references.

According to Crowther (2005) there are three broad themes for DFD: consider a model for sustainable design; think about the different layers of the building; and a hierarchy of different types of materials and components that will be recycled.

To understand the building as a composition of components and materials and the relation of different parts, helps to find better solutions for reuse of those parts (Heriqson, Rocha and Sattler 2008). The authors have some definitions of layers:

- Parts: products that compose the building
- Materials: with no specific function (cement, sand, paint, boards, steel profile)
- Components: products with defined functions (windows, locks, handles)
- Elements: materials with components that are a part of the construction (wall, door)
- Subsystem: materials with components and elements that have a function (sanitary modules, facade)
- System: subsystems that have a complete solution for the building (structure, roof)

Thinking about the layer of the building also helps to design for disassembly, so it's possible to consider ways to ease the dismantling without compromising other parts of the building. Usually the buildings are designed as a unit that is conceived, used and disposed. But the building can live longer if it can be changed during time, for example, the structure can be the same and the internal layers changed (Crowther 2005).

With performance building deconstruction, it is possible to have better results for the reuse of bricks, windows and tiles, differently from traditional demolition. The demolition is connected to the process of building. The way that it is constructed, the types of components and materials, the connection and relation between different layers have an influence on the way to disassemble and reuse (Heriqson, Rocha and Sattler 2008).

There are some other points that should be considered when designing for disassembly to gain better results. Based on Heriqson, Rocha and Sattler (2008), who have some suggestions on how to improve the demolition:

- Use resistant and durable materials and components
- Use screws and connections that don´t damage the elements
- Avoid chemical connection
- Independent relation with different layers
- Facilitate access in all parts of the building
- Reuse materials and components to stimulate the practice

It's also important to think about why, what, where, and when to disassemble, and how to design for better results (Crowther 2005). The author mentions some principles for DFD:

Table 3: Based on the Principles of Design for Disassembly (Crowther 2005)

Principles	Description
Use recycled and recyclable materials	To encourage industry and government to develop new technologies
Minimize the number of different types of materials	Simplify the process, reduce transport
Avoid toxic and hazardous materials	Reduce the potential of health risks
Avoid composed materials and make inseparable subassemblies from the same material	Large amount of one material won´t be contaminated by a small amount of a foreign material
Avoid secondary finishes to materials	To not contaminate the base material and difficult recycling
Provide standard and permanent identification of material types	Provide information about material type, place, time, etc

Minimize the number of different types of components	Simplify the process and make the component reuse more attractive
Use mechanical connections rather than chemical ones	Makes the separation easier and reduces damage
Use an open building system where parts of the building are more freely interchangeable and less unique to one application	Allow changes without damage
Use modular design	Makes easier to reuse the materials and components in another system that is compatible
Use construction technologies that are compatible with standard, simple, and 'low-tech' building practice and common tools	Better to disassemble because the user is more used to it
Separate the structure from the cladding, internal walls, and services	To facilitate parallel disassembly
Provide access to all parts of the building and to all components	Makes the disassembly easier when there is access to different parts of the building
Make components and materials of a size that suits the intended means of handling	Better for assembly, disassembly, transport, reprocessing and re-assembly
Provide a means of handling and locating components during the assembly and disassembly procedure	Facilitate the handling of different elements
Provide realistic tolerances to allow for manoeuvring during disassembly	To handle the repeated assembly and disassembly process
Use a minimum number of fasteners or connectors	Easy and quick disassembly
Use a minimum number of different types of fasteners or connectors	More standardized process
Design joints and connectors to withstand repeated use	Minimize irreparable damage or distortion
Allow for parallel disassembly rather than sequential disassembly	Components and materials can be removed without disrupting other components or materials
Provide permanent identification of component type	Work in a co-ordinated way with material information
Use a structural grid	Makes the most efficient use of material type and allow coordinated relocation
Use prefabricated subassemblies and a system of mass production	To reduce site work and allow greater control of quality and conformity
Use lightweight materials and components	Makes handling easier and quicker
Permanently identify points of disassembly	To avoid confusion and make the process faster
Provide spare parts and on-site storage for them	To replace broken or damaged components
Retain all information on the building construction systems and assembly and disassembly procedures	Retain and update the information

The table above shows a lot of concepts inserted in Design for Disassembly, this can work as a guide for designers to improve the solutions for having better results when dismantling the building.

Because it is most used in the automotive and electronic industry, there are a lot of challenges when applying this concept in the construction industry. According to Brewer and Mooney (2008), when applying the DFD principles to the construction industry there are a lot of challenges because of the differences between construction and manufacturing.

- Lack of identification for most of the products to recycle
- Use of generic and composed materials
- Differences in design specifications and the particle build
- Lack of responsibility in coordinating points to facilitate the reuse or recycling
- Some products can become hazardous to health or environment

There are also technical barriers to success in the recuperation of the materials for reuse or recycling. Design for future reuse and recycling has a lot of environmental benefits such as reduction in material waste and energy consumption, but it can also have some consequences that are not so good such as the energy used to recycle and some toxic materials to improve durability (Crowther 2005). It is important to considerer the life cycle of the building and what to do with the material and components at the end of its life from the design stage and also the way it will be reused or recycled.

Design for Disassembly can help to reduce the demolition waste and, as a consequence, reduce the environmental damage caused by the construction industry. However, it is also important to consider the life cycle, how reuse and recycling could be possible, to reach better results.

This study case can assist in understanding how a large part of demolitions in Brazil are being performed. By analyzing, it is possible to note what can be disassembled for future reuse and what cannot, and then explore the reasons for this.

6. Study Case of a Demolition

This demolition was a commercial building of one floor, built with reinforced concrete and bricks, as many constructions are in Brazil. The owners decided to demolish to build another commercial building with an open plan and a different facade.

During a week, four workers disassembled some parts of the building to separate what could be used in another construction for a future resell. The table below shows what they could select for a future reuse:

Table 4: Materials for future sell

	Separated for future sale	Went to landfill
Timber	X	
Glass (common)		x
Glass (tempered)	X	
Electrical System		x
Hydraulic System (PVC Tubes)	X	
Water Tank	X	
Metallic Panel	X	
Ceramic Tiles (Roof)		x
Ceramic Tiles (floor, wall)		x
Structural System (Reinforced Concrete)		x

Plaster (ceiling, wall)		x

After they had separated the materials, in one morning they demolished what was left and took all the waste to the landfill. There was a coordinator, two workers cleaning the ground with hand tools, one man to operate the wheel loader and one man to drive the truck to take the demolition waste.

It was possible to note that the demolition was related to the construction. The workers executed the inverse order of the construction. They first disassembled the roof, then doors and windows. After that, they demolished the wall and structure, as there weren't separate layers. During the demolition or disassembly some parts of the building were also damaged.



Figure 2: Inside of the demolition; Figure 3: Wood being separated; Figure 4: Hydraulic system separated (Mattaraia 2012)


Figure 5 and 6: Mixed materials during demolition (Mattaraia 2012)


Figures 7 and 8: Finishing the demolition and cleaning the ground (Mattaraia 2012)

7. Conclusion

With this case study it was possible to note that with demolition as is practiced today it is possible to separate, for future reuse, only a few materials and elements. Most of them go to landfill and result in pollution and environmental impact.

This shows how necessary it is to reach for solutions at the end of the life of buildings and find ways to improve the disassembly to have better materials for future reuse. One way to do that is to look for better choices during the design phase.

In this study it was possible to see what materials could be removed without seriously compromising their quality, so they can be reused, and which had to be demolished by a machine and eventually removed just as rubbish. As seen in the literature some characteristics such as chemical bonds, designer not thinking about the EOL, mix of materials, related layers and non-resistant materials, can contribute to a poor recovery in materials and elements.

On the other hand, some points from DFD can contribute to better results. For example, the timber used in the roof structure was connected by nails and screws, this facilitates the disassembly and the material was in good condition for future reuse. They are also easy to handle and transport.

Design for Disassembly is an important tool that can be used to reduce the environmental impact caused by the construction industry and contribute to reuse and recycling of materials and elements. By observing and interviewing the people involved it is possible to note that the concepts in DFD would really contribute to better results.

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