Designing [for] the future: Managing architectural parts through the principles of circular economy

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Abstract. The environmental impact of the construction and demolition industry is enormous, therefore the management of architectural "waste" and the existing building volume became of crucial importance for the design of sustainable buildings and cities. Considering the principles of circular economy, two possible approaches emerge. The first concerns the existing architectural stock and its future use, not as a whole but as upcycled separate modules. The second is oriented towards the incorporation of future management of architectural parts in the design of new constructions, also known as design for disassembly (DfD). The research highlights the capabilities of each material and the potential ways of reusing it. In the case of design for disassembly, the connectivity of construction elements is of equal importance to the materiality of the projects. Moreover, the observations include the logistics of reuse in a new construction, the incorporation of a former architectural part, whose function sometimes differs from its role in the original building. In the existing residential fabric, upcycling emerges as a practice of creative reuse of building elements. Nonetheless, each case should be individually evaluated. Though these processes have not been yet used at a great extent, this theoretical framework is a reminder that the creation of a new building is not a permanent condition, but an aggregation of materials that temporarily serve a given purpose.

1. Introduction
Building materials already represent half of the solid waste generated each year worldwide and about 35% of global waste [1]. In total, over 11 billion tons of waste are generated from the construction and demolition industry [2]. Moreover, the construction industry is responsible for 40% of the materials produced worldwide [1], while 10 billion tons of sand and rock are used worldwide for concrete production [2]. Additionally, even if the average lifespan of a building often exceeds 75 years, the average lifespan of the world's tallest buildings before demolition is 39.8 years (according to the Tallest voluntarily demolished buildings list) [3].

The above problems are still to exacerbate if we take into account the increase in housing needs due to rapid population growth. The majority of people are being relocated to urban centers, a phenomenon which according to the United Nations will also intensify in the future [4].

1.1. Scope
As a result the environmental impact of the construction and demolition industry is enormous, therefore the management of architectural "waste" and the existing building volume become of crucial
importance for the design of sustainable buildings and cities [5]. Considering the principles of circular economy, two possible approaches emerge. The first concerns the existing architectural stock and its future use, not as a whole but as upcycled separate modules. The second is oriented towards the incorporation of future management of architectural parts in the design of new constructions, also known as design for disassembly (DfD) [6].

1.2. Methodology
To clarify the research case, a critical qualitative bibliographical research was conducted, together with the study of upcycling and DfD techniques. Case studies from a broad geographical distribution were selected, as well as best practices from architectural offices which couple sustainability theory with praxis. Furthermore, the research includes the analysis of architectural examples of variable scales, which illustrate the aforementioned techniques.

2. Current approach on the built environment
Recycling is now considered to be the most environmentally friendly waste management strategy. In the case of construction and demolition waste, it refers to the process of converting the used construction materials into reusable materials. In architecture, the term recycling is relatively new. In the past this practice was not necessary, as construction and demolition waste mainly consisted of natural materials. Also, recycling requires energy both for the transport of materials and for its processing, while at the same time, during these processes, pollutants are inevitably produced. The most efficient recycling method is the one that requires the least product processing, since that way less pollutants are created while saving energy. However, the best way to manage waste would be not to waste it.

According to the European Commission: "The circular economy is emerging as an alternative to the linear economy (ie construction, use, disposal) in which raw materials remain in use for as long as possible, their maximum value is extracted during use, while, at the end of their life, these products shall be recovered and re-used" [7].

As far as buildings are concerned, Circular Economy, according to Danish architect Jensen Guldager and his colleagues, refers to the holistic design strategy that closes open material flows and material life cycles, leading to less building waste, less carbon dioxide and minimizing resource consumption [8]. Therefore, a key element of the relationship between the building as a being and the circular economy is none other than its approach. Unlike the usual approach of a construction, the main concern of the circular design is the contact with the future of the building.

Bearing that in mind, the following sections will study architectural practices that enhance the action of the circular economy, and show how these can be applied to both existing buildings and new constructions.

3. Second use of existing architectural parts - Upcycling
According to the Cambridge Dictionary, “Upcycling” is the activity of creating new objects, from old, or used objects, or waste. Other researchers include in the definition the environmental value of new products and the change in how they are used. Particularly interesting is the approach to the term in “The Cannibal’s Cookbook” [5]. Matter design uses the term ”cannibalism” without referring to its common use. Instead, they frame it in the data of the city and refer to the inanimate matter that consumes itself, in an on-site reuse.

Although the practice of upcycling seems to be emerging as a new practice when it comes to the built environment, the reuse of older building materials is an ancient practice that had been present in almost all historical periods. Examples date back to prehistory and the criterion for upcycling had been both the availability of material as well as the demonstration of strength among stakeholders. The future approach to the reuse of parts of buildings aims at a more specific practice of waste exploitation.
For a better understanding of upcycling, examples in which this technique is applied will be studied, casting light to the materiality of upcycled architectural parts, their connection and the produced aesthetical results.

3.1. Examples

The examples are divided into two categories. These include experimental prototypes, which represent smaller-scale applications, and larger scale buildings.

*Matter Design* created the “*Cyclopean Cannibalism wall prototype*” [9] from demolition debris, inspired by the Inca masonry techniques. To create it, the stocks of the demolished building are scanned and after undergoing minimal carving, they are placed in such a way as to create the "new" load-bearing masonry. At the same time, the masonry models of *Vandkunsten Architects* [10] offer a special variety of materials. Examples selected include the reuse of concrete elements, tiles, metal pipes, wooden elements and glazing.

*Figure 1.* Prototype projects that employ existing architectural parts in second use, (a) Cyclopean Cannibalism wall prototype, Matter Design, (b) Prototype from sliced concrete slabs, (c) Brick Facade cladding made from roof tiles, (d) Metal Facade cladding made from used spiro ducts, (e) Wood Indoor walls made from used wood, (f) Prototype built from glass bricks, (g) Prototype of glass interior wall with ornamental wedge fixations, Vandkunsten Architects.

Overall, it is observed that the reused materials of the constructions are used in a new role, different from their original function. In fact, five out of seven projects studied are repositioning the original units to create masonry. However, in some cases, these may not function as load bearing elements. Except for the tiles and some glazing that are used in their initial form, in all other cases milling or resizing takes place. Of particular interest is the fact that only two examples provide for the future repositioning of already reused members.

The next category of applied upcycling examples includes larger-scale projects that now go beyond the experimental nature of prototypes. At the first level, it becomes obvious that architectural offices around the world are dealing with this technique, aiming to demonstrate how architectural members are reused in practice.
After studying the projects demonstrated in figure number 2, the conclusion was drawn that all the basic construction materials have the potential to be reused, as the projects analyzed consist of bricks, concrete, metal and wood. Materials such as bricks and metal have essentially the same function in the new construction, either as load-bearing elements or as filling parts. Concrete, in some cases, such as in Project Middleburg [11], is reused for construction purposes, while in other structures, such as the London Olympic Park [12], it is reused in a different way than the original, i.e. as paving. In the case of both the Resource Rows and the Vegan House, wood as a material is repositioned in new locations in the respective residences.

It is also noted that half of the examples are directly related to a recent demolition, the waste of which was reused. The rest of the projects, are exploiting parts of pre-existing abandoned constructions. Finally, it is obvious that no building is made of 100% reused materials while at the same time there is no prospect of future reuse.

This method can be applied on buildings that have been constructed without any prior consideration in this practice. Nevertheless, the integration of the upcycling methodology in the design process could conclude to very interesting results.

4. Sustainable treatment of new buildings and complexes through "DfD"

The aforementioned idea gave rise to the technique of Design for Disassembly (DfD). This technique is not related to reused materials and components by definition, but is a prerequisite for facilitating future reuse, as a strategy of architectural design. The basic idea is that the building should be considered as a temporary aggregation of building materials. Therefore, it is important to design how the structure can be separated and rebuilt using, to a large extent, the same materials.

4.1. Basic DfD aspects

The design of life cycles of the building as a whole, as well as its individual elements is subjected to this technique. The idea that buildings are made up of sub-parts and components with different lifespan was introduced by Durmisevic and Yeang [6]. In the life cycle of a building, each system requires replacement at a different time. In order to facilitate the monitoring of materials and systems, the so-called "passports" of materials are proposed. Through them, access to all relevant information describing the characteristics and quality of a unit is allowed.

In order to better understand the application of disassembly design, architectural examples will be analyzed.

4.2. Examples

The selection of examples aimed to cover a wide range of projects in order to observe the usual scale of DfD constructions, the materials used and their aesthetic result. The first category includes units with an area of less than (or equal to) 100 m², which operate mainly as pavilions. The second category includes buildings of much larger scale.
Figure 3. Pavilion projects ≤100 m² that employ Design for Disassembly, (a) Circle House, Lendager Group, Vandkunsten Architects, 3XN Architects, (b) The Circular Building, Arup Design, (c) ICHouseTM, William McDonough + Partners, (d) Nest We Grow, College of Environmental Design UC Berkeley, Kengo Kuma & Associates.

Although the project Nest We Grow [13] is not mentioned in the literature as a DfD construction, the dry mechanical visible connections, the logic of interlocking the frame elements, the prefabricated members connected on the spot, but also the visible skin of the building, are design features that lead to easy disassembly. Therefore, it was considered appropriate to be included in this section as the architects seem to realize the ephemerality of their intervention.

Overall, from the examples studied, which are presented in figure 3, we observe that concrete, wood and metal products are used for the frame, usually in the first use of material, without being recycled or reused. In all cases, the frame is assembled with the help of metal connectors, either with clamps, as in the case of Arup’s Circular building, or with screws and bolts, as in other cases. Also, a feature of the design for disassembly is the connection of the building elements with simple integration in the construction. Often, in this subcategory, plastic-based materials are also used as additives. Of great interest is the fact that although all the examples are designed with the ability to be disassembled, only in the case of the Circle House [14] is the exact repositioning of its members provided. The following section includes buildings of larger scale.

Figure 4. Projects larger than 100 m² that employ Design for Disassembly, (a) NASA Sustainability Base, William McDonough + Partners, AECOM, (b) Bullitt Center, Miller Hull Partnership, (c) Rio Olympic Handball Center, Lopes Santos and Ferreira Gomes Architects, OA Architects, (d) Triodos Bank, RAU Architects, (e) Wooden Nursery, Djuric Tardio Architects.

It is observed that in the case of large-scale constructions (figure 4), mainly metal and wooden frames are chosen, while concrete has been used only in the case of the Bullitt Center [14]. These materials are usually used for the first time, with the exception of the wooden beams in the restaurant area in the Triodos office building. Where a specific connection method is mentioned, screws are used, both to assemble the frame itself and to adjust the filling elements. The latter usually consist of metal, wood or even biosynthetic panels. At the same time, some materials are re-used, mainly wooden elements, on the skin of the Olympic Handball Arena and in some parts of Triodos Bank. Although all examples can be disassembled, only for two there is an accurate reuse program provision. However,
while the *Olympic Handball Arena* was planned to be converted into school buildings, this conversion never took place.

With regards to smaller scale examples, it is observed that less details are known about the construction of the buildings. In many cases it is stated that the frame can be disassembled, however, the way of its connection is not presented in detail.

A pattern seems to emerge through the study of buildings that are designed considering DfD specifications. The visible metal frame and the prefabricated front panels are key elements of the disassembly technique. Nevertheless, this entails the risk of producing a very specific performance-oriented type of architecture, that often overshadows its aesthetic value.

5. **Combining design for disassembly with upcycling**

At this point it is now clear that the action of upcycling concerns the reuse of existing structures and buildings, while DfD is defined as the design of new elements with the ability to be disassembled. These two methods could be combined in cases of reuse of parts or shells of old buildings by strengthening them with new structures that meet the design requirements for dismantling. No combined research of these two methods was found in the literature, however, while searching for information for DfD techniques, two examples were found which seem to combine both methods.

5.1. *Examples*

![Figure 5. Projects that combine Design for Disassembly and Upcycling, (a) 3XN Architecture Offices, 3XN Architects, (b) Quay Quarter Tower, 3XN Architects.](image)

In the projects demonstrated in Figure 5, it is observed that the two constructions use different materials. In the case of the *3XN Architects office* [14], both the reused material and the new material is timber. On the other hand, in the *Quay Quarter tower* [8], while concrete elements are being reused, both the new frame and its filling elements are metal. In both cases the new constructions are in the same location from which the reused elements were retrieved. In the case of the tower, the pre-existing skyscraper is used almost completely, without being demolished, while only some components of it are cut and placed in other parts of the new construction. Partially, this technique could perhaps be compared to shell reuse. Undeniably, since this is a design for disassembly, it has been foreseen that the individual parts of the construction will have the possibility to be disassembled, while the connection of the elements is done mechanically.

6. **Conclusions**

Finally, observing the percentages of solid waste generated by the construction and demolition industry, it is clear that there must be some change in the way both building stock and new construction are managed. In previous times the motivation for the second use of architectural members was mainly the limited availability of materials, whereas nowadays the environmental impact is predominant.
Figure 6 presents the combination of sustainable building management strategies analyzed in this paper. “Design for disassembly” is the predominant practice of redesign based on the circular economy. It essentially integrates reclaim practices in the design process. In existing buildings, upcycling emerges as a practice of creative reuse of building elements. Hence, these materials, instead of being turned into waste, regain value, which has a positive effect on the environment. The goal is to reuse as much as possible. Of course, as such methods are not yet widespread, public opinion remains skeptical about their application. So far, the most environmentally friendly building waste management action is recycling. However, it is not the most effective method. For this reason, it is proposed to use it as an auxiliary, ideally on site, as this would save energy and the costs of transport, storage and processing of materials. The goal is the least possible rejection of architectural components, aiming to reduce or even eliminate waste.

It is considered important to evaluate each case individually. If the process of acquiring, transferring and processing an architectural member has a greater environmental impact than creating and using a new element, then reuse is not appropriate. Similarly, if the carbon dioxide emissions during the construction of dismantled structures and their subsequent transport and modification exceed those of rebuilding, the design for dismantling is also contraindicated. Also, it is very important to take into account the cost of the whole process.

The design of buildings and complexes based on their future use is a practice that directly concerns architects and all other stakeholders. Environmental policies and regulations should further motivate such design practices. Nonetheless, it is important to take the overall feasibility of a project into consideration. Although it may sound compelling as an idea, often times practice shows the opposite, as in the case of the Olympic Handball Arena in Rio. In this particular case study, although the arena was created to be converted into school complexes after the end of the Olympic Games, the plan was eventually abandoned.

Finally, an interesting issue that arises is the development of new technological media employed for the techniques of upcycling and DfD, both in terms of design and construction. As we have seen in the examples analyzed, most of them involved the use of digital media directly or indirectly. The study and analysis of technologies that can facilitate environmentally friendly architecture is an ever-growing research question, which will most probably concern all architects in the years to come. After
all, technological means have the potential to create a course of thought when it comes to material use, as well as spatial transformation [8].

Altogether, how does one design [for] the future? Certainly, many factors must be taken into account, such as environmental, social and economic ones. However, Matter Design's vision for a city that is being reborn by itself could be applied through the principles of circular economy and become a future reference point in design matters.

Even if DfD or upcycling proves to be practically unprofitable, the underlying theory of these techniques is extremely useful, as it reminds us that the creation of a new building is not a permanent condition. A construction is nothing but a collection, a storage of materials that temporarily serve a certain purpose.

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