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Design for disassembly as an instrument for the preservation of water resources in civil construction industry

Projeto para a desconstrução como instrumento para a preservação de recursos hídricos na construção civil

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ABSTRACT

With concerns related to the consumption of natural resources, changes in urban space, and the generation of waste by civil construction, strategies were created and developed to promote environmentally sustainable development. One of these is the design for deconstruction, as an alternative for minimizing solid waste, extending the useful life of materials, preserving embodied energy, and reducing areas for landfills and the consumption of natural resources. Due to the changes in the consumption profile and the records of the concern with facing a new water crisis, this study aims to identify the design guidelines for deconstruction that contribute to the preservation of water resources. For the development of this study, a narrative literature review was carried out with documentary research in the Scopus and Google Scholar databases, using keywords related to the topic. It was found that there are phases in which water consumption in civil construction is neglected, with less explored phases and an absence of available data and information. To achieve the proposed objective, information on water consumption in the sector and deconstruction guidelines were compiled and related. The linkages between the design guidelines for deconstruction and information on water use in the life cycle phases of buildings were demonstrated and analyzed with flowcharts. From this analysis, it was verified that deconstruction contributes to environmental preservation by considering the building in full, in all phases of existence.

Keywords: demolition; water resources; civil construction waste; construction life cycle; water footprint.

RESUMO

Com as preocupações relacionadas ao consumo de recursos naturais, alterações no espaço urbano e a geração de resíduos pela construção civil, estratégias foram criadas e desenvolvidas para a promoção do desenvolvimento ambientalmente sustentado. Uma delas é o projeto para a desconstrução como alternativa para a minimização dos resíduos sólidos, o prolongamento da vida útil de materiais, a preservação da energia incorporada e a redução de áreas para aterros e do consumo de recursos naturais. Diante das mudanças no perfil de consumo e dos registros da preocupação com o enfrentamento de uma nova crise hídrica, este trabalho visa identificar as diretrizes de projeto para a desconstrução que contribuem para a preservação de recursos hídricos. Para o desenvolvimento deste estudo foi realizada revisão bibliográfica narrativa com a pesquisa documental nas bases Scopus e Google Acadêmico fazendo uso de palavras-chave relacionadas ao tema. Com as buscas, verificou-se que há fases em que o consumo de água na construção civil é negligenciado, com etapas pouco exploradas, e ausência de dados e informações disponíveis. Para atingir o objetivo proposto, as informações sobre o consumo de água no setor e as diretrizes da desconstrução foram compiladas e relacionadas. Os vínculos entre as diretrizes de projeto para a desconstrução e as informações sobre o uso da água nas fases do ciclo de vida de edificações foram demonstrados e analisados com fluxogramas. Com base nessa análise, foi verificado que a desconstrução contribui para a preservação ambiental por considerar a edificação de forma integral, em todas as fases de existência.

Palavras-chave: demolição; recursos hídricos; resíduos da construção civil; ciclo de vida da construção; pegada hídrica.

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Introduction

With the growth of cities, the lack of space, and the aging of buildings, there is a need for changes in the forms of occupation of urban space around the world, for example, the verticalization process and the new usage needs with the dynamics of society (Akhtar and Sarmah, 2018). Buildings that have become obsolete and reached the end of their life cycle are chosen for alterations and requalification of urban space. According to Tatiya et al. (2018), when considering the life cycle of a building, the design, construction, period of operation, renovation/renovation, and removal for reconstruction are included.

Camillato (2018) pointed out that considering the life cycle of buildings and durability is essential for making more assertive decisions and choices regarding sustainability. Hence, by extending the useful life of buildings, the demand for new materials and components is reduced.

Akinade et al. (2015) pointed out two possible activities for a building that reaches the end of its useful life: demolition and deconstruction. Demolition consists of removing the building with less concern for the recovery of materials, and deconstruction seeks to recover and reuse materials, avoiding the need for disposal in landfills. According to Akhtar and Sarmah (2018), demolition is the process chosen in most cases due to economic aspects and the agility of execution.

The construction industry produces large amounts of construction and demolition waste (CDW) and consumes 40% of natural resources and energy. As an example, in China, the volume of CDW generated is equivalent to 30–40% of the total urban solid waste, and there are predictions that these values will reach 90% in the coming years, given that the demolition activity generates 39 times more waste per m² than construction (Ding et al., 2016).

Akhtar and Sarmah (2018) presented a global perspective of CDW generation in 40 countries, which together reached more than 3 billion tons per year in 2012. The countries with the highest CDW production rates are China, India, and the USA, which together account for an annual generation of more than 2 billion tons. In the data presented by Su et al. (2021), China alone accounted to generate CDW of approximately 2.36 billion tons per year from 2003 to 2013.

According to data from the Brazilian Association of Public Cleaning Companies and Special Waste (ABRELPE, 2020), published in the 2020 Solid Waste Panorama, 79 million tons of municipal solid waste were generated in Brazil, and it is estimated that of this amount, 55%, equivalent to 44.5 million tons, is CDW.

Civil construction faces several challenges to balance productivity with sustainable development. Examples of these are the reduction of waste generated, the optimization of energy and water consumption, the preservation of the natural environment, and the quality of the built environment (Santos et al., 2015).

Illegal dumping and inadequate disposal of CDW are some of the consequences of excessive waste generation. The undue deposition of CDW causes soil, water, and air contamination that can be observed by the silting of water resources and effects on the fauna and flora. In addition to contributing to the deterioration of surface and groundwater, it can also lead to the proliferation of vectors (da Paz et al., 2020).

The consumption of natural resources in the construction sector takes place throughout the life cycle of products, since extraction. The raw material undergoes transformation through industrial processes in which energy is consumed and greenhouse gas emissions are generated. After use, with maintenance, alterations, or renovations, there are associated environmental impacts due to the transportation of a large mass of materials and construction waste (Costa and Qualharini, 2018).

Marques et al. (2017) pointed out that civil construction has high water consumption directly and indirectly, i.e., directly with the use of water in the processes of execution of works for the production of mortars, concrete, among others, and indirectly with the use of water incorporated by the industry in the manufacture of various products, such as blocks, coatings and extraction of aggregates, used in construction.

Zeule et al. (2020) argued that water is used in many activities in the construction industry, which makes it difficult to measure. Some of these activities are as follows: production of materials, extraction of raw materials, cleaning of tools and equipment, dust abatement, hydrodemolition, concreting, among other processes in different stages.

Sustainability in the construction industry is inevitable. This includes reducing the carbon footprint and contributing to the conservation of the natural environment and resources that are crucial for human development. There are ongoing studies concerned with the depletion of the natural recovery of sources, but avoiding the appropriation of natural resources is not possible, and therefore it is necessary to consider sustainability during the planning of different projects and at all stages (Akhtar and Sarmah, 2018).

The construction sector's contribution to the depletion of natural resources is significant. Thus, it has an influence on their preservation through the adoption of conservation measures (Santos et al., 2015).

Many strategies are being developed and implemented with the objective of minimizing the impacts caused by this sector of great economic importance. One of these is the Design for Disassembly or Design for Deconstruction, which, if applied in the design phase of building projects, aims to apply strategies for planned disassembly, which enables the reuse and recycling of materials, and the increase of their useful life, in addition to reducing the amount of waste generated and sent to landfills, as well as the need to extract raw materials and use natural resources in the production of new materials (Li et al., 2022).

Deconstruction allows the recovery, reuse, and recycling of materials and components as it is a systematic disassembly, used as an alternative to conventional demolition (Silva et al., 2021).

Da Paz et al. (2020) pointed out that recycling products that would be discarded in the environment is a way to reduce impacts, as it contributes to reducing the volume of waste generated and the consumption of certain materials.

Given this context, the objective of this study was to characterize the aspects of deconstruction that influence the sustainable management of water, pointing out the practices that, when implemented correctly, bring benefits to the management and preservation of water resources. Based on this bibliographic research study, the aim was to list gains in relation to the reduction and preservation of water consumption with the adoption of design strategies for deconstruction, making the advantages of this practice more visible.

Materials and Methods

For the development of this study, a narrative bibliographic review was carried out with documentary research to gather information and data about the process of deconstruction of buildings and the characteristics of this process that interfere with the preservation of water resources.

The research was carried out with the help of the Internet in October and November 2021 and started with the use of a search string in the Scopus database. The Scopus database is the largest multidisciplinary, peer-reviewed database of abstracts and citations of literature, with over 22,000 titles, as per Scopus Quick Reference Guide (Capes, 2016).

The research development stages are mentioned in the flowchart shown in Figure 1.

For the construction and definition of the string, a search was carried out in the Scopus database in order to identify keywords related to the theme of this study with only two descriptors ("design deconstruction" AND "water"), considering that the resulting documents contain some of the words searched in the titles of the articles, in the abstracts, or in the keywords, but no documents were found.

Then, the Boolean operator "OR" was added to expand the scope of the search, and more descriptors were used (("DfD" OR "Design for disassembly OR deconstruction") AND ("water" OR "hydric")). A total of 146 resulting documents were analyzed by reading the titles, keywords, and abstracts, and the need for more descriptive terms was identified to obtain results consistent with the investigated subject.

The descriptors used in defining the search strings used in the Scopus database are shown in Table 1.

Due to the difficulty of finding information on the subject, sources of documents found with searches carried out on the Google Scholar were used, such as articles from the Scielo Brasil database, which is a free access digital library, and course completion works available in university repositories.

The documents found through the Google Scholar search engine, which is a search engine focused on academic literature, were located using the descriptors: "demolition of buildings and water consumption," "use of water in the demolition and recycling process," "water crisis demolition project," "water deconstruction project contributions," and "project for deconstruction and the water crisis." Even so, no information was obtained from studies carried out specifically on this topic. Then, for the formulation of results and conclusions, information about water resources in the civil construction life cycle and aspects of deconstruction that contribute to the preservation of water resources was related and analyzed.

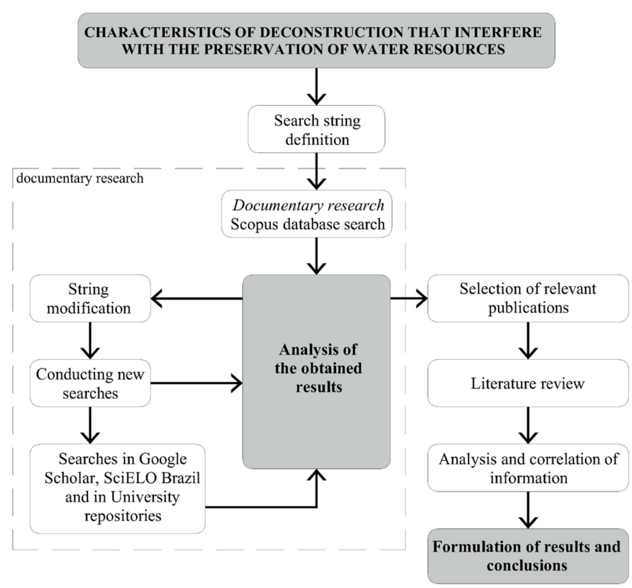

Figure 1 – Flowchart of work development stages.
Source: Prepared by the authors (2022).

Table 1 – Descriptors used in the research.

Related to the design for deconstruction	Related to civil construction	Related to water
design for deconstruction	construction industry	water
design for disassembly	architecture, engineering and construction industry	water security
project for disassembly	AEC	water resources
project for deconstruction	building	water crisis
DfD	civil construction	
demolition selective deconstruction		

Source: Prepared by the authors (2022).

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For the conception of conclusions, the information collected is divided into three sections presented below. These are the references and data found on the use of water in the civil construction sector, deconstruction, and the guidelines of two guides for deconstruction used as a reference for this study.

Results and Discussion

The search for specific literature on the topic began with the use of the string: ((“design for deconstruction” OR “design for disassembly” OR “project for disassembly” OR “project for deconstruction” OR “DfD”) AND (“construction industry” OR “architecture, engineering and construction industry” OR “AEC” OR “Building”) AND (water OR “water security”)). Using these descriptors with Boolean operators (*or*, *and*) linked, the themes project for deconstruction and the civil construction industry with water and water security.

After performing the search using the aforementioned string, 12 results were found (Table 2).

Some of the articles resulting from the search expose broad considerations related to design for deconstruction, the environment, and CDW production. However, characteristics and guidelines that must be taken into account in the design phase are not presented in the scope of sustainable water management, which is the objective of the present investigation.

Considering the applied search strategy, with the small amount of results obtained regarding the topic, new searches were carried out in order to complement the investigation. New strings were formulated in search of information that could provide the answer to the research question.

Searching the Scopus database with terms related to water resources, water crisis, and civil construction (“water resources” OR “water crisis” AND “civil construction”), 16 results were found.

Table 2 – Search results with the first string in the Scopus database.

Document Title	Authors	Year	Source	Cited by
An agent based environmental impact assessment of building demolition waste management: Conventional versus green management	Ding et al.	2016	Journal of Cleaner Production	60
Optimizing urban material flows and waste streams in urban development through principles of zero waste and sustainable consumption	Lehmann, S.	2011	Sustainability	48
Design for disassembly analysis for environmentally conscious design and manufacturing	Li, W., Zhang, C., Wang, H.-P. Ben, Awoniyi, S. A.	1995	American Society of Mechanical Engineers, Manufacturing Engineering Division, MED	21
Resource recovery and materials flow in the city: Zero waste and sustainable consumption as paradigm in urban development	Lehmann, S.	2011	Journal of Green Building	11
Whole-life design and resource reuse of a solar water heater in the UK	Saint, R.M., Pomponi, F., Garnier, C., Currie, J.I.	2018	Proceedings of the Institution of Civil Engineers: Engineering Sustainability	4
The metabolism of the city: Optimizing Urban material flow through principles of zero waste and sustainable consumption (Book Chapter)	Lehmann, S.	2013	Designing for Zero Waste: Consumption, Technologies and the Built Environment	4
Optimizing Urban material flows and waste streams in urban development through principles of zero waste and sustainable consumption (Book Chapter)	Lehmann, S.	2012	Sustainable Solid Waste Management	2
Systematization process in studies of water well level in areas of geoseismic surveys | [Sistematización de procesos para estudios de aforo de pozos de agua subterránea en áreas sujetas a la adquisición de datos sísmicos]	Pineda, N., Jaimes, E., Mejías, J., Mendoza, J.	2004	Interciencia	1
Green building/infrastructure system with manufacturing/ distribution strategy	Fisk, P., Faulkner, B.M.	2019	Sustainable Mediterranean Construction	0
IOP Conference Series: Earth and Environmental Science	[No author name available]	2018	IOP Conference Series: Earth and Environmental Science	0
Anti-collapse drilling fluids for the Cretaceous scientific drilling in Songliao basin, China: A case study	Cai, J., Wu, X., Gu, S.	2012	Applied Mechanics and Materials	0
Do we really need to do that every time?	McGrail, D.M.	2004	Fire Engineering	0

Source: Scopus (2021).

Notably, 14 distanced themselves from the topic of civil construction, and 2 presented data and information related to the scope of this study.

In a new complimentary search, another set of strings was used (*"demolition selective deconstruction" OR "design for deconstruction" OR "design for disassembly" OR "project for disassembly" OR "project for deconstruction" OR "DfD") AND ("water"*), which resulted in 19 documents. However, most of the results obtained were, again, not related to civil construction, and only one document was used in this study, which is the article by Akhtar and Sarmah (2018) with the presentation of a global overview of CDW production.

Water resources in the civil construction life cycle

Water consumption in the construction industry takes place in different processes and stages, which include extraction, production, and manufacture, during the building execution process and even for cleaning before delivery to the owners. In many of these stages, there are no policies to rationalize the use, leaving the requirements focused on the use of operational water in the built environment (Marques et al., 2017).

Crawford and Treloar (2005) showed that water and energy consumption are incorporated in buildings in addition to the operational stage. These are also consumed in the stages of extraction and processing of raw materials, in the manufacture of materials and construction products, in the execution of the building, in the renovations and maintenance, as well as in the removal/demolition.

Based on data presented by Crawford and Treloar (2005), Barreto (2015), and Napomuceno and da Paz (2016), some examples of activities that use water at different stages of construction are presented in Figure 2.

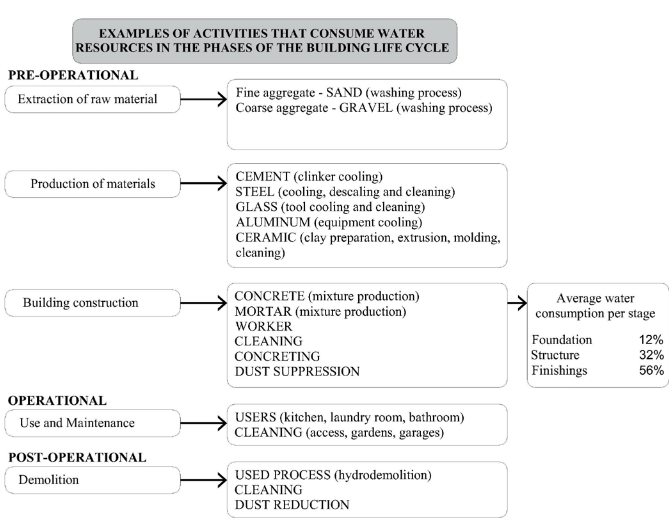

Figure 2 – Activities that consume water in the phases of the building's life cycle.

Marques et al. (2017) argued that the water consumed during execution and incorporated during the manufacturing process of goods and services often does not receive attention in terms of rational use. This is because the volume is smaller when compared to the total volume of water used throughout the life of a building. However, even if this consumption is punctual, during the execution of these processes, the volume consumed is high and should not be underestimated.

A tool pointed out by da T. Silva et al. (2021) as promising in relation to sustainability in civil construction is the life cycle assessment, because it allows knowing the impacts caused at different stages of processes, from the extraction of raw materials to the final disposal of the products.

With the scarcity of water resources, studies on water consumption in civil construction are expanded in stages that were previously disregarded. In the work found through the first string, studies on water consumption at the construction site are presented.

Santos et al. (2015) and Marques et al. (2017) pointed out that water consumption in the construction phase represents less than 3% of all water consumed when considering the life cycle of materials. In addition, this value varies according to the characteristics of the work and policies adopted by the executing companies.

In the survey by Santos et al. (2015), carried out in Recife/PE, it was identified that the highest percentage of water consumption at the construction site is intended for employees, for human consumption. The information shows that in construction activities, 57.9% of the water is intended for the use of employees, 25.19% for the cafeteria, kitchen, and cleaning equipment, and 16.91% is used directly for the execution of the construction. These data reveal that the awareness of those involved with the activity is essential to succeed in relation to conscious consumption.

Silva and Martins (2017) stated that environmental education is a tool that contributes to the formation of employees' ecological awareness, by aiming at the balance, rationality, and sensitivity of those involved in all processes about the importance of environmental preservation. Arousing conscious consumption and demystifying the idea of abundance and the infinity of natural resources.

Also related to water consumption at the construction site, Zeule et al. (2020) proposed a list of good practices for the rational use of water. In summary, the items are as follows: capture of rainwater and ash for treatment and reuse; drinking water facilities separate from rainwater collection; wastewater technologies; reservoir for decanting water with particulate material; periodic maintenance of facilities; consumption reduction with the installation of devices and awareness strategies; frequent instructions and guidance to workers; and install water-reducing equipment in temporary installations (tap with automatic shut-off, aerator, flushing box with fractional actuation).

Although water consumption occurs throughout the life cycle of the most diverse types of projects (e.g., roads, ports, and airports), it is noted that the literature gives a special focus to the issue of projects in the area of buildings. Buildings are usually designed with long life cycles in mind. In Brazil, NBR 15575 (ABNT, 2013) — performance for housing — establishes that the minimum project life for structures is 50 years. Due to this characteristic of civil construction, in order to guarantee sustainability, it is necessary to propose strategies that integrate those involved in all phases of the building's life cycle, with the use of strategies in the pre-operational phase, following and integrating the operational and also in the post-operational phase (Camillato, 2018). The phases of the building's life cycle are represented in Figure 3.

Even so, for the post-operational phase, which is when the building reaches the end of its useful life, there are no measures and action requirements that must be taken so that the demolition/dismantling process takes place in an appropriate and environmentally responsible manner (Camillato, 2018). According to Longo (2020), the practice of conventional demolition is usually adopted, even if the building has elements and materials in good condition. With the adoption of deconstruction strategies, there are many environmental gains, such as the preservation of energy and raw materials incorporated in the production processes of building components, as well as the reduction of the consumption of more natural resources, such as water, for execution.

Crowther (2001) proposed a hierarchy of organization of end-of-life scenarios of construction. In this hierarchy, the most beneficial strategy for the environment is prioritized, as shown in Figure 4, listing first the reuse or reallocation of the building, second the reuse or reallocation of components in a new building, third the reuse of materials in the manufacture of new components, and finally, recycling materials into new materials.

Olivo et al. (2021) emphasized the need for single legislation for the integrated sustainable management of solid waste, with guidelines, accountability, inspection, penalties, and incentives that are easily understood by users, and the availability of manuals and instructions by local governments with guidelines that involve the generation, segregation, reduction, and reuse of waste.

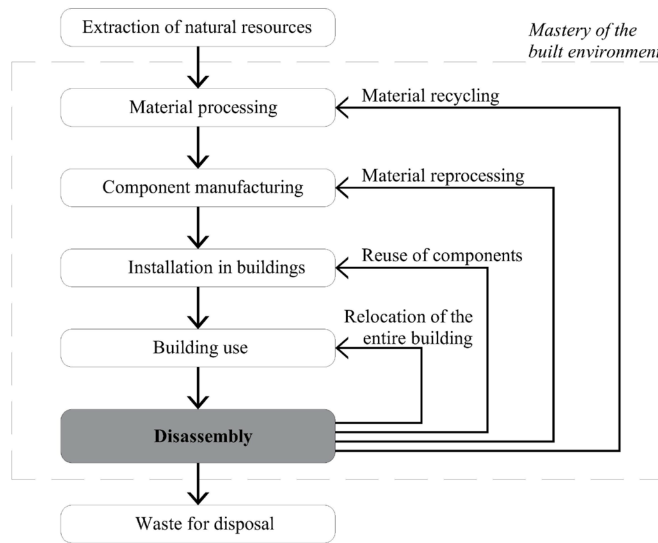

Figure 4 – Possible end-of-life scenarios for buildings.
Source: adapted from Crowther (2001).

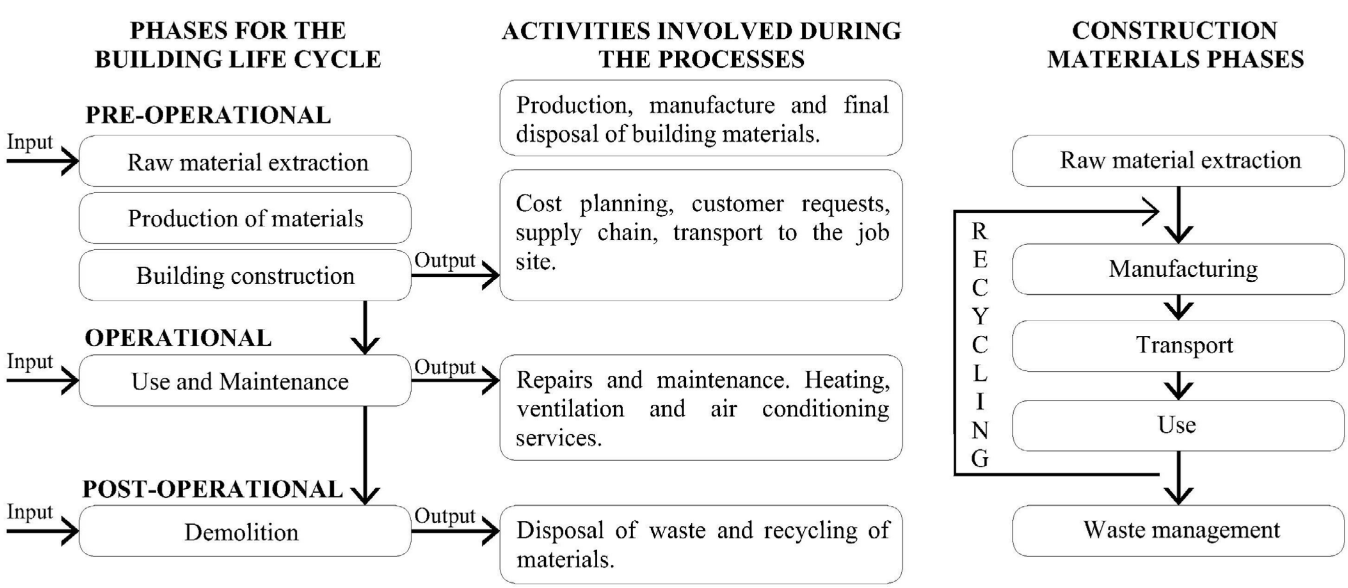

Figure 3 – Representation of the phases of the building's life cycle.
Source: adapted from Ortiz et al. (2009).

Few studies were found in relation to water consumption linked to the demolition process or in carrying out deconstruction. One of the studies by Akhtar and Sarmah (2018) observed the total loss of water from 102 demolition projects, comparing the use of conventional practices with green practices. The result of a 1,000 simulations carried out showed that with the adoption of green deconstruction practices, the loss of water decreases by 97.58 million tons, reaching a reduction of 51.97% in relation to conventional demolition practices.

Deconstruction

Silva (2020) argued that, in carrying out bibliographic research on deconstruction, two words are found which refer to the same intention, i.e., *Design for deconstruction* (DfD) and *Design for disassembly* (DfD). The two expressions refer to the same concept, which emerged in the 1990s and which represents the act of designing a building in advance for the process of deconstruction or disassembly.

With applications of DfD concepts in the design phase, it is possible to increase the chances of the reuse of materials and elements due to the characteristic of predicting and facilitating the process of removal or clearance without causing damage (Longo, 2020).

Camillato (2018) pointed out that there is a great demand for resources beyond the construction phase, which are also consumed for remodeling, renovations, and even for the execution of demolition. With the forecast of disassembly, it is possible to close the cycle of materials and with that the environmental impacts of civil construction are reduced.

To plan and predict in the design phase the fate of the building when it reaches the end of its life cycle, and how it will be deconstructed or dismantled causing minimal or no waste, it is necessary that several variables and definitions are considered. These affect sizes, functions, types of materials, and maintenance. The benefits go beyond reducing environmental impacts and are also social and economic (Kanters, 2018).

Applying aspects of DfD in the design phase avoids carrying out conventional demolition. Deconstruction must be prioritized to minimize or reduce to zero the generation of waste and its impacts on the environment (Akhtar and Sarmah, 2018).

The disassembly project provides guidance to improve the performance of the deconstruction process of a building that reaches the end of its useful life. This happens with the presentation of techniques and management methods that make it possible to reuse materials and elements (Longo, 2020).

The buildings are made up of a wide variety of materials and are designed to last for a lifetime of 50–100 years. These characteristics make it difficult to predict the resale value and how to extract certain materials. Applying design concepts to the deconstruction of buildings is a challenge, but the benefits are much greater (Martins, 2017).

Deconstruction and the contribution to the preservation of water resources

For the analysis of characteristics of deconstruction that contribute to the preservation of water resources, guidelines for deconstruction cited in three studies were listed: first by Camillato (2018), second by Longo (2020), and the third by Saraiva (2013). The three authors congruently cite two manuals and guidelines as a database, the Silk Guide prepared by Morgan and Stevenson (2005), in Scotland, and the Principles of Deconstruction by Philip Crowther (2005), in Australia.

The Silk Guide is composed of seven principles, and Crowther's work lists 27 principles divided into 5 generative fields (Camillato, 2018). The principles that compose them will be presented in the form of a table and, afterward, the considerations related to the contribution to the preservation of water resources.

The coincident guidelines and principles presented in the two manuals chosen for this study, Silk Guide and Crowther, were connected and grouped as presented in the study by Longo (2020), in which the author gathered and summarized the equivalent DfD guidelines and concepts from different authors (Table 3).

Table 3 presents the DfD guidelines with an indication of authorship and grouping the similar guidelines of the two manuals.

According to the guidelines presented in Table 3 and according to Kanters (2018), the essence of DfD is both the prevention of waste generation and reuse. The author also pointed out that attention to these practices has grown due to the interest in implementing the circular economy model, which seeks to preserve finite resources and not produce waste.

Morgan and Stevenson (2005) showed that the benefits of DfD go beyond the environmental ones which offer economic advantages for customers and building owners by increasing the flexibility of adaptation, maximizing the value of a building that has a short period of use, reducing maintenance and modernization costs, reducing impacts throughout the life cycle, and reducing the need for landfills.

Metin and Aydin İpekçi (2015) presented a flow scheme in which the design principles for the deconstruction of different authors were grouped and synthesized. Based on this, they presented their relationships with end-of-life management scenarios and environmental impact indicators and categories.

Figure 5 shows that all design principles for deconstruction are linked to environmental impact indicators. Water consumption, the focus of this study, is linked to the consumption of resources in the environmental impact category.

The DfD principles presented in Table 3 and Figure 5 show that the construction system is of the type known as dry construction. In this system, there is no need for water for execution and the fixings are with fittings and screws, which makes it possible to carry out maintenance and renovations in the operational phase of a building, without compromising the integrity of parts that have a longer life cycle, due to the easy removal and replacement of elements and parts.

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Table 3 – Guidelines for the Silk Guide (Morgan and Stevenson) and Crowther's DfD.

Guidelines and principles	Authorship
Design in a sustainable way	Crowther (2005)
Design structures that can be reused	Morgan and Stevenson (2005)
Separate structure and compartments	Crowther (2005)
Layout that allows change of use. Adaptability	Morgan and Stevenson (2005)
Facilitate access to all parts of the building	Crowther (2005); Morgan and Stevenson (2005)
Consider the different layers of the building	Crowther (2005); Morgan and Stevenson (2005)
Make systems compatible	Crowther (2005)
The way in which the building is constructed influences the deconstruction	Crowther (2005); Morgan and Stevenson (2005)
Seek to make connections with screws and fittings	Crowther (2005); Morgan and Stevenson (2005)
Avoid chemical bonds	Crowther (2005); Morgan and Stevenson (2005)
Identification of materials and components	Crowther (2005); Morgan and Stevenson (2005)
Use screws and connections that do not damage the elements	Morgan and Stevenson (2005)
Use strong and durable materials and components	Morgan and Stevenson (2005)
Consider the different life cycles of building materials and components	Crowther (2005)
Consider the hierarchy of different types of materials and components	Crowther (2005)
Understand that the building is a composition of components and materials	Crowther (2005)
Consider materials that can be reused	Morgan and Stevenson (2005)
Allow components to be disassembled simultaneously	Crowther (2005)
Use parts that are easy to handle, transport and store	Crowther (2005)
Use elements compatible with the human scale	Morgan and Stevenson (2005)
Consider insulation and air pressure in separate building layers	Morgan and Stevenson (2005)
Consider the outer "skin" of the building as a separate layer	Morgan and Stevenson (2005)
Keep services (water, heating, lighting, power, cooling, security systems, etc.) separate from other elements	Morgan and Stevenson (2005)
Use common areas of buildings and make the user participate in the process	Crowther (2005)
Safely save the project *as built*	Morgan and Stevenson (2005)

Source: adapted from Longo (2020).

In the post-operational phase, when the building is removed, dismantled, or deconstructed, the DfD principles allow closing the life cycle of materials and optimizing the use of energy embodied in the phases of extraction, processing, manufacturing, assembly, and use of the construction.

By adopting DfD strategies, it is possible to reuse materials due to the easy separation of the elements without damaging them and preserving their original form and function. With the project planned for deconstruction, disassembly is facilitated by the standardization of the dimensions of the components, by the fastening that does not use chemical processes and in adequate quantity, and by the easy access to the connections (Metin and Aydin İpekçi, 2015).

The advantages of the project for deconstruction are in the reduction of waste generation, which leads to a reduction in the need for transport and areas for landfill. With the possibilities of reuse and recycling of materials, i.e., the increase in the life cycle, the consumption of raw materials, energy, and water for the production of a new material is also lower.

Vasconcelos and Mota (2020) pointed out that urban sprawl, human activities, and different sources of pollution directly damage water resources, such as water quality, soil permeability, vegetation cover, natural resources consumption, grounding of water courses, deforestation, disposal, and dumping of residues in water bodies. The practice of DfD contributes to the reduction of the damage presented, as its key element is the reduction of waste production, which culminates in the reduction of the need for landfill areas and the consumption of raw materials.

Relating the end-of-life scenarios presented in Figure 4, in which Crowther (2001) inserted the disassembly strategy in the post-operational phase, with Figure 3, which presents the phases of the usual life cycle adapted from Ortiz et al. (2009), it is observed that the adoption of disassembly/deconstruction strategies closes the materials cycle, preserving the energy embodied in other phases of the building.

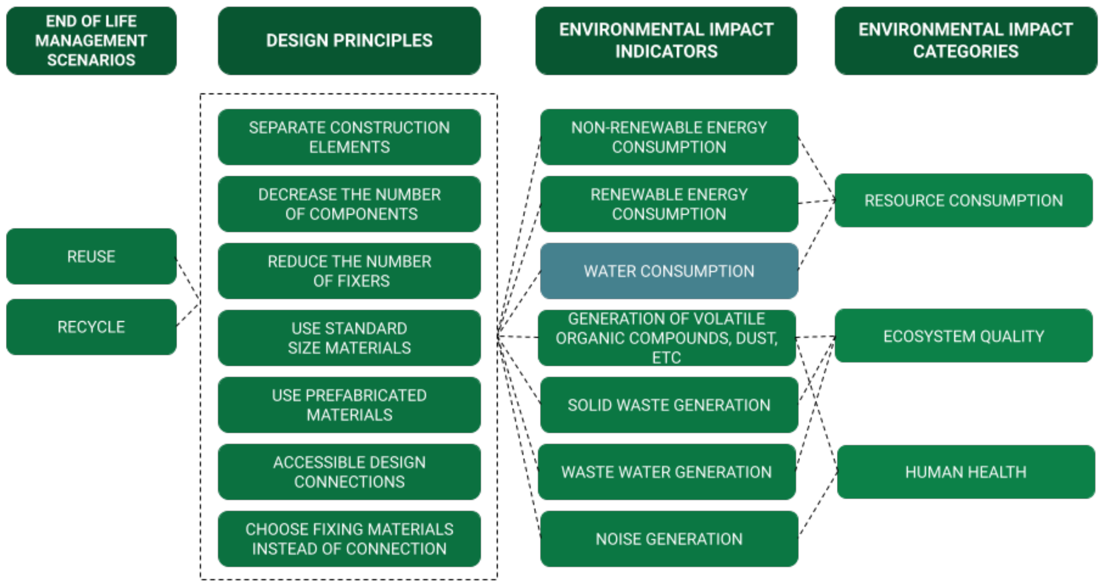

Figure 5 – Architectural deconstruction project approach.
Source: adapted from Metin and Aydin İpekçi (2015).

Figure 6 shows the preservation of embodied energy by adopting the deconstruction/dismantling strategy in the post-operational phase. This is due to the reallocation, reuse, reprocessing, or recycling of components and materials, making it unnecessary to extract raw materials and use more natural resources.

According to the study by Akhtar and Sarmah (2018), which presents the results of simulations on water loss comparing the adoption of conventional practices with green deconstruction practices, they showed that with DfD there is a decrease in water loss by more than 50%.

Among the benefits of DfD are the ease of maintenance, the possibility of reuse or recycling of materials, the reduction of the amount of energy and water consumption, as well as the reduction of noise in the execution of the processes due to the type and amount of fasteners, the reduction of dust and solid waste generated (Metin and Aydin İpekçi, 2015).

Conclusions

With the analysis of the characterization of design guidelines for deconstruction related to water consumption, it was observed that it is possible to reduce the consumption of this resource mainly through the reuse of materials and components, since it makes the energy and raw materials incorporated into the products have a prolonged life cycle, reducing the need to extract and use more natural resources.

The presented characteristics and objectives of the DfD show that the construction systems indicated are of the type known as dry construction. This constructive system does not use water for the execution, since it makes use of fasteners, such as screws and fittings, and avoids chemical bonds, such as mortar in the laying of bricks.

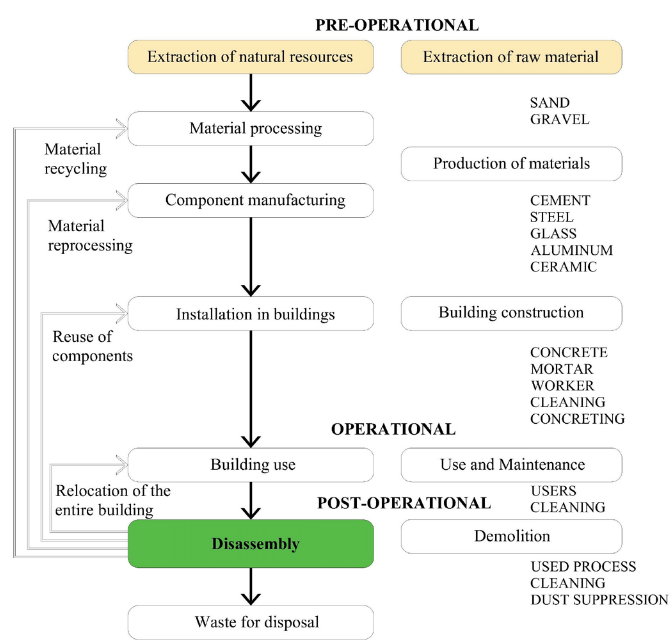

Figure 6 – Deconstruction in the phases of the building's life cycle.
Source: adapted from Crowther (2001) and Ortiz et al. (2009).

The adoption of this guideline contributes substantially to the economic and environmental preservation of water resources.

Through the search in the literature, it was possible to perceive that the consumption of water resources in the civil construction is neglected in some phases, in the execution of the works, and at the end of life of demolition/deconstruction buildings. Policies and requirements on conscious consumption are concentrated in the operational phase of the work, of occupation of inhabitants.

Taking into account DfD principles and guidelines enables sustainability issues to be developed and integrated throughout the construction, maintenance, and deconstruction process. This is an important strategy to achieve sustainable objectives in the sector.

In future studies, more investigations and surveys on the use of water resources in little-explored stages, such as the post-operational phase of the building, are suggested. Studies on the embodied energy in the different phases of construction and strategies to make the proper use of all potential and life cycle of products and elements.

Contribution of authors:

SPADOTTO, A.: Conceptualization; Data Curation; Formal Analysis; Investigation; Methodology; Resources; Software; Visualization; Writing — Original Draft; Writing — Review & Editing; GADDA, T. M. C.: Conceptualization; Methodology; Supervision; Validation; Visualization; Writing — Review & Editing; NAGALLI, A.: Supervision; Validation; Visualization; Writing — Review & Editing.

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