Potentials for the Reduction of Construction Waste in the Architectural Design Stage

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Abstract. In this article, we propose the correspondence of Construction and Demolition Waste, CDW reduction and architectural design as a central concept to redefine the role of Architecture in the context of the Circular Economy, as applied to the construction process. To raise this question, 1) a State of the Art discussion was elaborated, a series of interviews was conducted with various relevant actors in the public and private spheres; 2) a Case Study of works carried out in relation to these principles was prepared; and 3) surveys were applied among professionals in the construction sector to assess the perception, experience and willingness to incorporate principles of waste reduction in professional practice. These activities made it possible to elucidate the potential of waste reduction strategies in the design stage, to identify the main barriers and opportunities, and to propose measures and instruments for a better implementation in practice.

1. Introduction: Construction and Demolition Waste in Chile. Circular Economy and the Built Environment

In Chile, Construction and Demolition Waste (CDW) in Spanish Residuos de Construcción y Demolición, RCD (UBB-CITEC 2017) or RESCON (Sepúlveda and Cortés 2012), are considered part of industrial waste. A 61% of the total solid waste is classified as industrial, and out of this, a 56% comes from construction (MMA 2012). Between 2000 and 2009, there was a 72% increase in the production of waste from the construction sector (CChC, 2014), with a generation rate estimated at 0.8 kg/day-inhabitant (Muñoz et al, 2011).

Within the framework of the National Strategy for Sustainable Construction (Estrategia Nacional de Construcción Sustentable, ENCS), the Code of Sustainable Construction (Código de Construcción Sustentable) establishes four categories of sustainability: Energy, Water, Waste and Health and Well-being (MINVU-BRE, 2014). Despite the importance that the State has given to the subject, the figures show that the reuse and recycling of materials in the construction industry, the main sector in the generation of waste, is in its beginnings in Chile.

A strategy to address the problem of CDW is to analyse them from the perspective and principles of Circular Economy (Pearce and Turner 1990), and apply them to the built environment, understanding that everything we design, produce and use is part of a continuum that does not start in the extraction of raw materials or ends with waste disposal, but includes the use of resources at all stages of the life cycle and in several sub-cycles or non-linear phases, which can be differentiated and intervened, to improve the production process of physical space.
2. Relevant Issues: Regulation, Classification, Quantification, Data
The problem of CDW RCDs is scarcely addressed in political debates or in regulatory frameworks, despite the fact that in the last 20 years serious environmental problems made the issue visible in Chile. For the first time in 2000, the Environmental Health Service (Servicio de Salud del Ambiente) estimated that 93% of the waste was disposed of in illegal landfills (CChC 2014; Muñoz et al 2011; UBB-CITEC 2017). The huge amount of debris generated in the 2010 earthquake was managed informally, being disposed in urban and rural areas or near roads, causing pollution and damages to public and private property (García 2016).

On the other hand, the legal and regulatory framework is not specific but fragmentary (García 2016), and generally does not consider the issue of construction waste. The current regulation refers to the differentiation between Hazardous Solid Waste (MINSAL 2003) and Non-Hazardous, mainly regulated by the Ministry of Health (MINSAL 1989; MINSAL 1999; SEGPRES 2001). In recent years, the issue has been addressed under the pressure of several stakeholders, generating standards, such as NCh3562 “Construction and Demolition Waste Management: Classification and Guidelines” (about to be published), and specific regulation projects.

According to the technical literature, the Reduce, Reuse, Recycle (RRR) scheme is only partially present in the building industry, recycling is possible only for few materials produced in large volumes (Ulloa 2013) and reuse is not yet regulated. A recent study by the Universidad del Bio-Bio (CITEC-UBB 2017) synthesizes knowledge and introduces international references for the cataloguing of construction waste and its quantification. In it, conversion factors are proposed for the units (m², m³, kg, etc.) of a resource in the amount of waste generated, but the available data is scarce, they are representative of only a part of the existing construction typologies, and there are few buildings examined and not all construction stages considered, generating heterogeneous results. Various studies (CCHC 2014; Muñoz et al. 2011; Sepúlveda and Cortés 2012) raise different values, ranging from 0.14 m³ waste / m² built to 0.46 m³ / m². The Ministry of Environment (Ministerio del Medio Ambiente, MMA) recognizes the importance of the lack of reliable and public sources that provide quality information to validate any estimates made in the sector (MMA 2012).

3. Design as a Tool for Reduction: Conceptual and Instrumental Platforms, Parameters
With the objective of obtaining practical references for the development of construction projects where parameters applicable to concepts of Circular Economy can be applied, we analysed platforms and tools that encourage or propose actions for waste management at the design stage. Several of them contain actions applicable to the following stages of construction, operation, etc., and have been generated internationally or in Chile.

3.1. International Platforms
The review of international platforms focused on those relevant for the industry, such Life Cycle Analysis (LCA) or the LEED Certification, as well as other concepts that are currently not massively incorporated into the design processes including RRR strategies.

ReSOLVE Framework is a simple system that companies, and governments can adopt to move towards a transition to the Circular Economy; through 6 actions it allows a project to be evaluated and directed towards circularity (Ellen MacArthur Foundation 2015):

- Regenerate
- Share
- Optimise
- Loop
- Virtualise
- Exchange
Originally, LEED focused on building energy and water performance issues. As of its fourth version, it incorporates sustainable waste and material strategies within its requirements, opening to concepts of Circular Economy and RRR strategies for architectural works.

The main limitation of the Life Cycle Assessment (LCA) is the availability of databases or inventories of materials relevant to the project or cycle to be analysed. In Chile, when conducting LCA it is necessary to simplify it substantially, due to the lack of a specific inventory, using international databases and estimate the characteristics of the materials available in the market (Cárdenas et al. 2014). Given the performance of a building (construction process, operation, energy balance, various use regimes, etc.), LCA methodology applied to the construction sector needs considerable adaptation, and the development of specific tools.

Ecodesign (Ecodiseño) considers actions aimed at the environmental improvement of a product or service at all stages of its life cycle. Divided into 8 clusters, it proposes concrete strategies according to the different stages of project development (White et al, 2013).

Brand-ARUP’s layered construction model differentiates seven layers or skins (7S) in a building, each with a different lifespan: System, Site, Structure, Skins, Services, Space, Stuff. Building in layers means that each element can be separated and disposed of, which facilitates reuse, remanufacturing and recycling. Thus, the façades or heating systems can be designed and adjusted as independent entities, integrated with other construction systems and not intertwined with the building structure.

3.2. National Platforms

At national level these platforms are in different stages of development and have different ways of being applied in the stages of the life cycle of a construction project.

The Certification of Sustainable Building (Certificación de Edificio Sustentable, CES), allows to evaluate, qualify and certify the environmental behaviour of buildings (new or existing) for public use in Chile. It is based on the fulfilment of a set of variables disaggregated in mandatory and voluntary requirements, which deliver scores. To be certified, the mandatory requirements must be met and have at least 30 points out of a maximum of 100. The system was developed with the goal of encouraging the design and construction of buildings under sustainability criteria and of stimulating the market to value this type of building. It does not incorporate mandatory CDW or RRR points, but a voluntary point can be chosen by incorporating a “CDW management and valorisation plan”.

The Sustainable Construction Standards (Estándares de Construcción Sustentable, ECS), develop specific indicators for the reduction, recovery, reuse and recycling of waste, and about the impact that materials production and building construction processes have (MINVU 2016). It also provides guidelines and indicators so that a house can meet sustainability standards, differentiated for stages of Design, Construction and Operation. An interesting aspect of the Sustainable Construction Standards is that they establish specific guidelines for the design stage, accompanied by calculation methodologies and traceability spreadsheets to measure project performance.

“ECOBASE Construction” seeks to evaluate and report on the environmental impacts of construction materials, using LCA methodology, thus providing the construction industry with information on the environmental sustainability performance of the materials used, supporting decision-making from design to investment, and incorporating sustainable attributes required by the market to strengthen its competitiveness (IDIEM and CDT 2013).

The ABACO-Chile project is a platform of cost-base (Open Access) that links construction costs and sustainability indicators for different categories of environmental impact, using an LCA approach, referred to the energy cost and emissions of CO₂ (Carbon Footprint). In successive phases it will extend to the quantification of waste generation, its classification, water footprint and ecological footprint, among others.

The National Waste Declaration System (Sistema Nacional de Declaración de Residuos, SINADER) obliges generators and recipients of waste, who valorize or dispose of more than 12 tons per year, as well as all municipalities, to declare their waste through the Registry of Emissions and Transfers of Pollutants (Registro de Emisiones y Transferencias de Contaminantes, RETC). However,
according to the breaches survey conducted by Construye 2025, even though it is mandatory, 50% of construction companies recognize they do not declare on SINADER on-line platform.

4. Gaps and Opportunities in Chile: Interviews and Surveys
In order to establish gaps and opportunities in Chile, the research sought to retrieve qualitative information from first-hand sources, both from the perspective of the research problem and of possible users, through 12 interviews and an online survey, with actors related to the construction industry, from the public and private spheres, with some relation to the themes of CDW.

4.1. Interviews
In the systematization of the interviews, a classification by keywords was used, organized around 10 previously defined relevant topics: construction process; waste assessment; regulations; pre-existing elements; participation; circular economy; implementation; opportunities and benefits; difficulties; typology and volume; indicators; cost/benefit ratio; and organizational culture. From the answers, it can be concluded that the Circular Economy related to the built environment is a recent issue in Chile, which unifies the point of views of different Ministries, but is in the early stages of implementation at both the regulation and company levels. In addition, the implementation of these strategies depends on a hierarchical chain of actors who value waste management comprehensively.

In answer to the question: How is your organization's approach to Circular Economy and RRR strategies? it can be concluded that in Chile the approach to these concepts is mainly linked to the issues of waste, recycling (recycling, recyclers), construction and management (fig. 1), which are related to the construction stage, where waste is visible and potentially managed through recycling. On the other hand, reuse and reduction obtained less relevance, these two categories being closer to the design stages and the ones with the greater potential impact on the waste management pyramid.

The interviews collected at the institutional level (Housing, Environment or Public Works Ministries, CORFO, Construye 2025) suggest that work is being carried out in conjunction with the concepts of Circular Economy. However, the work developed so far has not incorporated the early stages of the problem. In the words of Alejandra Tapia, Technical Coordinator of Construye 2025, “we are addressing different fronts, where there are some that we have not collected with enough depth, as could be the case of architecture”. There is thus a shortage both in the implementation of reduction and reuse strategies and in the depth with which this issue is addressed from the design stage.

In the early stages of ideation, management and design, two concepts can be concluded from the answers: first, the economic recovery of the waste and its relation to productivity: "waste is seen as synonymous with low productivity, poor planning or poor design" (Katherine Martínez, Deputy Manager for Sustainable Construction, CDT). The management of waste tends to be seen as a cost by companies, rather than a benefit. According to the interviewees, this vision is changing recently, especially in companies that seek an increase in productivity and greater efficiency. Some of the mentioned strategies mentioned often towards this aim are: standardization of measures in building materials; and the industrialization and prefabrication of components. Both are directly associated with the architectural design stage.
Figure 1. Hierarchy of answers to question 2: “How is your organization's approach to the Circular Economy and RRR strategies?”

Secondly, the interviewees mention that for architectural projects and the following stages in the value chain (construction, operation, disposition) there is no clear regulation or incentives for waste management within the industry (fig. 2). Today there is an atomized regulatory framework, and the regulations do not promote a minimum standard in waste management and reduction.

Figure 2. Hierarchy of answers to question 2: “How is waste management implemented in the industry today and how is it projected in the future?”
4.2. Survey

Once the interview process was completed, an online survey was developed on issues related to the problem of CDW in Chile. A total of 260 responses were received, segmented by different actors in the design, construction, and waste management industries, among others. Quantitative information could be obtained, with a much greater scope, which could validate to some extent the opinions obtained earlier from the interviews. Regarding their role within the institutions, there is a large majority of professionals in the construction area, namely architects, engineers and contractors, with 196 responses. In the other categories the responses were very few, thus less representative to compare with the former, except “others”, which groups varied origins, with 42 responses (fig. 3).

It is interesting that the responses from private companies are relatively even in number with government entities, resulting in a good tool to have a comparative look in both work environments. The territorial coverage covers practically all the Regions in the country, the main ones being the Metropolitan (Santiago), with 39 participants, Atacama (north) with 28, Los Lagos (south) 18, and Aysén (extreme south) with 16.

Within the total of responses, trends and patterns were recognized favourable to the hypotheses generated during the research, which is expressed in the high level of agreement on certain key aspects. In general, there is a high percentage of agreement regarding the importance and need to address the issue of CDW (fig. 4); however, when asked about its implementation, only 50% of the interviewees declare to have put into practice waste management or reduction strategies (fig. 5). On the other hand, one aspect on which unanimity is achieved is the importance that is given to collaborative work and the formation of multidisciplinary work teams, confirming the need to develop networks and address the problem with a more holistic vision in order to provide effective solutions (fig. 6).
**Figure 4.** In my projects or works I consider relevant the reduction of waste generated in the construction processes.

**Figure 5.** In my professional activity I implement strategies to reduce construction waste.

**Figure 6.** I consider it important to build alliances between various organizations for the management of CDW.
In the detailed response segmentation, the Project and Design stage occupies 69 responses, representing 26.5% of the total universe. Within this group, 50% declare to implement strategies for the reduction of CDW in their works, such as standardization, prefabrication, modulation or eco-design, and more than 80% express a high interest in implementing these concepts in their future projects, confirming a growing awareness on these issues and an opportunity for the incorporation of related tools in the design process.

5. Conclusions
Sustainable construction in Chile today, specifically associated with CDW management, is being approached in initial stages by State actors through the joint work of Ministries and CORFO, among others. National strategies have been developed for both the design and construction and operation stages (National Sustainable Construction Strategy, Construye 2025). During the last years, however, these programs and actions have focused mainly on Recycling during the Construction stage, with a lack of actions towards the concepts of Reduction and Reuse. Reduction is accepted widely as the waste management strategy that has the greatest impact; therefore, it is essential to focus efforts on developing these actions mainly in the design stage: waste generation is related to “bad planning or bad design”.

![Figure 7. Classification of platforms and tools in the design stage.](image)

The review of existing platforms and tools shows that there are different initiatives to apply concepts of RRR and Circular Economy in Architecture projects. All of these are voluntary and lack of an architectural dimension with a focus on design. According to the methodology and the concepts based on which each one operates, it is possible to group them into 5 different groups: 1.- Building
Certifications: in this group we find LEED, BREEM, CES among others. They characteristically seek to understand the development of the entire project in a sustainable way, incorporating mainly issues of energy, health, territory, etc.; 2.- Product Life Cycle Analysis: based on ISO14040 and ISO14044 standards for analysing environmental loads. These are derived from EPD (Environmental Product Declarations), PCR (Product Category Rules), and Databases such as Ecoinvent, Ábaco, or Ecobase; 3.- Timing and Phases: Refers to the relationship that the project or contrition process has over time, both its parts and components and the life cycle of the entire building. It is aimed at understanding the stages of the work from the idea, the location within its territory, the design, the regulations that apply, the construction, deconstruction and operation among others (value chain); 4.- Design Parameters: Among them Eco-design (Ecodiseño) delivers strategies related to the optimization of resources, understanding of the life cycle, impacts during use etc. The initiative developed by MINVU Sustainable Construction Strategies for Housing (Estrategias de Construcción Sustentable para Viviendas) can be included in this group, as it defines the parameters that must be met to design, build and operate a sustainable home; 5.- Circular Economy Toolkits: Specifically refer to the package of 6 parameters which we can apply for projects and buildings.

In Chile, CDW and RRR issues are becoming increasingly important in the private sphere. We find a high interest in professionals to incorporate these strategies (over 80% in the surveys). Despite this, there is currently only a small or medium implementation of them. On the other hand, there is a gap between the declared interest of incorporating CDW management strategies in projects, and the current implementation of these actions in practice. Among architects, professionals linked to the design stage, we find a current panorama of fewer actions (50%) and a high declaration of interest to incorporate RRR strategies (more than 80%). Both national and international platforms that address CDW and RRR do so in a rather disperse manner and with different degrees of depth and relevance. All of these are voluntary and address also other concepts that appear with greater relevance. We can thus relate the growing interest in implementing RRR strategies at the design stage and the lack of a specific instrument that systematically integrates these concepts, an opportunity to develop a specific tool that addresses Reduction in the design stage.

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