CHALLENGES FOR THE PRACTICAL USE OF RECYCLED CONCRETE AS A SUSTAINABLE ALTERNATIVE IN CONSTRUCTION IN THE MEXICO CITY METROPOLITAN AREA

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ABSTRACT
Concrete is a building material that generates a large amount of CO_2 and consumes a lot of natural resources. Therefore, people seek to replace it with some type of sustainable concrete (SC). One type of SC is the one made with recycled coarse aggregates (RCA), which come from the demolition and subsequent crushing of concrete elements, commonly used in Mexican construction. This paper analyses the situation of the practical use of this type of concrete in the Mexico City Metropolitan Area, one of the largest and densest cities in the world. Four main challenges to be faced in the application of this type of SC were found: (1) lack of quality control, (2) flexibility in the regulations or their non-existence, (3) time required to safeguard on site, and (4) the social acceptance of the main players in the construction industry. In conclusion, the use of concrete with RCA is a constructively feasible option, however, it requires prior training of the personnel who manage it, in addition to awareness campaigns among the population that increase demand, or else, to be enforced under a mandatory regulation.
Keywords: sustainable concrete, recycled coarse aggregates, construction, Mexico City.

1 INTRODUCTION

The main economic model has been that of producing, consuming and discarding. This model generates a linear system, where resources are extracted, produced, distributed, consumed and discarded. These linear models of production and consumption cause a greater generation of waste, which, since it is not used, requires a final disposal site where it can be deposited once its useful life is over [1]. These construction works are part of a sector that transforms and produces noticeable changes in our environment, contributing significantly to the negative impacts that degrade it. To mitigate them, the use of conventional materials can be replaced by more sustainable ones, or by actions such as reusing and recycling the waste generated. These options are feasible, and recycling techniques can even be implemented on the same site, but some aspects need to be considered to facilitate their execution.

Construction and demolition waste (CDW) are defined as materials, products or by-products generated during construction activities such as: construction, modification, remodelling, expansion, adaptation, rehabilitation, restoration, repair, infrastructure substitution, conservation, maintenance, installation, demolition or others; as well as the product from the excavation when it has been altered in its original physical, chemical and biological conditions [2].

Most of the waste generated in this sector is not typical of construction processes, but is the product of sub-activities such as demolitions carried out during construction. Although, in the product life cycle of concrete, the main source of carbon emissions is the cement

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production process (cement is added to aggregates to make concrete) [3] and not in its aggregates, recycling them is a way to reduce the environmental impact of this material.

To explore this phenomenon, the case of Mexico is used, where 12,003,359 cubic metres of CDW are generated annually [4], and only the Mexican capital generates 7,000 tons of this waste daily [5].

The Metropolitan Area of the Valley of Mexico was chosen, as it is the most representative due to its size and urban population. The construction rules and regulations applicable to the management of CDW were reviewed, in addition to the observation and analysis of nine areas of accumulation of this waste distributed in the study area with active construction works. As a result of the qualitative and current legislation analysis, the four main challenges facing the practical use of sustainable concrete (SC) using recycled coarse aggregates (RCA), mentioned in this document, are supported. It is worth mentioning that a technical feasibility study, tests or trials that determine the resistance to compression, tension, bending, cutting or any other force necessary to support the loads induced in the concrete are not shown.

2 METHODOLOGY

This document is one of the outcomes of a broader research on the recycling of RCA in concrete. For the presented case study, qualitative scientific research techniques such as participant observation, interviews with strategic actors and analysis of applicable current legislation are used to discover the data of the study area. Glaser uses the word ‘discover’ to describe what the researcher does in the field to underpin their position, as the use of this term indicates that data exist in the field, waiting to be discovered through the method of constant comparison [6].

The section is divided into two parts: Mexican standards review and field study. The field study, in turn, is subdivided into two subsections, according to the area studied. The same researcher who collected the data was in charge of analysing them, through a process of interpretation based on the triangulation or integration of: interviews, documents and normative elements. For this, criteria of perception, comparison and ordering of categories were applied. The confidentiality of the people interviewed or responsible for the sites visited, with whom prior agreements were signed, was respected.

2.1 Mexican standards review

The main standards that regulate the construction works with concrete elements and CDW were consulted, reviewed and analyzed, highlighting that there is only one environmental standard applicable for the recycling of CDW. These standards are: official Mexican standards (NOM) of mandatory compliance, Mexican standards (NMX) of voluntary compliance but necessary for the NOM, environmental standards (NA); the Construction Regulations of Mexico City, the only document of its kind in the study area; and the National Development Plan 2019–2024 and its National Programs.

2.2 Field study

2.2.1 CDW generation sites

Nine concrete waste accumulation sites were selected in the study area, following the criteria of location (different municipalities or boroughs), construction phase and type of waste. Criteria such as size, type and age of the work, regulations, procedures and CDW mix were excluded. For two months, structured and semi-structured interviews, observation and active participation were applied to obtain data on: type, storage time, perception, final destination, materials and quality tests of the CDW.

2.2.2 Visit to recycling plant

In October 2022, the CDW recycling plant in Miguel Hidalgo, Mexico City, was visited, where the aggregate transformation process was observed: reception, separation, selection, testing, crushing, screening and finished product, mainly types of gravel or SC made with RAP. The characteristics of the machinery and equipment used were recorded. The plant receives waste from Mexico City and the State of Mexico, mainly within a radius of 10 km.

Semi-structured interviews were conducted with strategic personnel from the plant, obtaining data mainly on the demand and perception of the waste.

3 SUSTAINABLE CONCRETE MADE WITH RECYCLED COARSE AGGREGATES

Conventional concrete is a material that hardens when it sets, and is used in construction. It is obtained from a combination of four essential elements: water, Portland-type cement, coarse aggregates (also called gravel), and fine aggregates (also called sand). Coarse aggregates are those that are retained on the No. 4 or 4.75 mm sieve, and fine aggregates are those that pass the sieve [7]. The proportions of these elements vary depending on the required strength. On the other hand, a SC is that concrete that modifies or adds elements in its mixture with the aim of reducing negative impacts and emissions to the environment, but without altering the strength attributes provided by conventional concrete.

Bakens [8] reports there is probably no sector with a greater potential to contribute to sustainability than construction. However, this transition from conventional concrete to SC involves many variations. In this case, we only refer to the replacement of coarse mine aggregates with RCA, without modifying another material or using ecological cements. Ecological cements are those that reduce their carbon footprint from their manufacture, through alternative to traditional processes.

There are several and diverse methods for transforming the residue into gravel. Therefore, methods that can produce RCA of acceptable quality with little impact on the environment need to be discussed [9], although, it is not the purpose of this research; processes that involve chemical alterations, mortar removal or similar are excluded, as they would increase the energy required and the time to obtain the RCA. The technique analyzed is by a physical process of crushing and grinding, and then screening to obtain the required size; the most common coarse aggregates used in the sites visited are 3/8" and 1/2". An important previous step is the identification and separation of waste at the source of generation, to achieve the use of a large part of it.

The type of machinery used in the RCA recycling procedure should be analysed, mainly during crushing or grinding, complying with low noise and vibration emissions, with energy-saving motors to increase the sustainability of the system. High transportation cost of waste disposal forces companies to consider waste recycling [10], so, the system must be modular and be placed in a specific area within the site in such a way that its transportation is minimized.

Cuchí and Segura [11] report that the energy intensity in the manufacture of one kilogram of aggregate is 0.1 MJ, without considering transportation (in Spain, the aggregate is known differently than in Mexico, therefore, it could be translated differently depending on the country of destination). If RCA is used in the same work where it is generated, the transport of the material is avoided, which implies a saving of fuel and emissions. Assuming that a cargo vehicle consumes 3 l/km and that the calorific value of the fuel is 38 MJ/l [12], it is

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estimated that it is reduced by 114 MJ/kg of recycled aggregate for each km that is not travelled. This value may vary depending on the type of machinery used in the process of obtaining the RCA.

4 SUSTAINABLE CONCRETE IN URBAN CONSTRUCTION PROJECTS IN MEXICO

Construction is an essential economic activity, since the development of any nation depends on having the necessary infrastructure to maintain sustained economic growth.

In Mexico, this industry is one of the most important in the Mexican economy, representing about 7% of the gross domestic product. In addition, being a labour-intensive economic activity, it is an important source of job creation [13]. It is also diverse and presents noticeable differences between its regions, while on their coasts the design considers the severity of the average weathering due to salinity; to the north the risk of freezing and thawing must also be considered. There are even changes between urban and rural areas due to the availability of adequate infrastructure to carry out the RCA recycling procedure and different degrees of building density.

The Metropolitan Area of the Valley of Mexico, located in the centre of the country, is formed by the 16 municipalities of Mexico City, the 59 municipalities of the state of Mexico and one municipality of the state of Hidalgo. It is the largest and most populated region of the country. The construction systems of this area are mainly made of reinforced concrete elements.

The main actors identified in construction can be divided into four sectors: academic, business, public and civil society. However, the focus is on civil society, seen as a demander of new materials, and on businesses, which function as suppliers.

According to the particularity of the field work, some of the intentions indicated in the design stage can be changed and adjusted, especially when there is a lack of adequate knowledge or experience. Considering this, the following challenges facing the recycling of RCA were found:

- Quality control;
- Flexibility in the regulations;
- The time required to safeguard on site;
- Social acceptance.

4.1 Quality control

The materials used in the construction procedures must comply with specific parameters determined and with physical and mechanical characteristics established in the Mexican regulations, through the performance of tests and trials. Otherwise, the risk of failures in the element increases. However, RCA regulation still do not have established parameters that delimit their applications and their useful life [2]. This can deteriorate the load capacity and represent an imminent risk for human safety.

We could subject the aggregates to the appropriate treatment until they achieve the quality to meet the requirements [7] as mentioned in the regulation, however, this is intended only for new aggregates. There is also no adequate regulation for its management, mainly during the work, even being the place where they are generated and reused or recycled1

4.2 Flexibility in the regulations

Strategies to minimize CDW are based on having an appropriate comprehensive management plan, as well as regulations that indicate the steps to follow. The official Mexican Standard NOM-161-SEMARNAT-2011 is an instrument for the classification of Special Management Waste (including CDW) and establishes the obligation, by large generators, to establish management plans for their prevention, reduction, use and recovery, leaving the baton to the generators [14].

Another relevant regulation is the Environmental Standard for Mexico City NACDMX-007-RNAT-2019, which sets out the classification and specifications for the integrated management of construction and demolition waste in Mexico City [2]. This is the only standard of its kind in the Mexico City Metropolitan Area, and it serves as a model for other states because of its proximity and the lack of other similar legal instruments. However, this standard has some inconsistencies and legal gaps, as it is relatively new. For example, it does not specify the lines of action, the specific sanctions or the control mechanisms for the generators of CDW. Moreover, although this standard aims to harmonize the management and promote the recycling of CDW, it does not define clear procedures or require tests on the material to be recycled. This can lead to confusion, non-compliance or abuse by the obligated parties (individuals or entities). Furthermore, this standard only applies in the capital of the country.

4.3 The time required to safeguard on site

Demolition and removal works are the first tasks that are carried out in a construction project, so the concrete blocks to be recycled must be stored from the beginning and until their use in new elements. However, as they are currently only considered for non-structural uses, such as concrete pavements, sidewalks and other elements, which correspond to the final phases of the critical path in a construction procedure, the storage will last for a long period. According to the active observation carried out, this implies conditions to be modified in a work: a fixed place must be allocated during almost 70% of the construction duration; a space is required for the physical treatment and transformation into CDW; the cost of the specialized machinery for the transformation must be considered; the transfers of the waste and the risk of mixing with other types of CDW must be avoided.

In addition to being a key success factor for a waste-efficient project, the result of the factor analysis suggests that waste segregation is an underlying measure for achieving other waste minimization practices, for instance, on-site materials' reuse could be largely influenced by how well the different waste categories are properly segregated [15].

4.4 Social acceptance

The unfavourable perception of recycled concrete in the construction industry has a substantially negative impact on the sector's confidence in it and approval of recycled concrete for construction work, especially for large-scale projects requiring strict quality control procedures [16].

For the use of SC with RCA to increase, it is necessary that there is a greater demand for this type of construction material by civil society. However, the lack of public policy and educational programs that promote the recycling of CDW makes it difficult for the population to adopt an environmental awareness and prefer this type of material. The National Development Plan (PND) 2019–2024, which is the document where the Government of

Mexico establishes its objectives and strategies for the 6-year term, does not address at all the issues related to this article [17].

Also, the supply of the recycling plant is variable, as it depends on the quantity and quality of the demolished elements that are sent for recycling. This prevents estimating accurately the potential volumes of concrete that could use the RCA. However, the effort required to coordinate all the actors involved and achieve the objectives proposed by sustainable development in construction is recognized.

5 CONCLUSIONS AND FINAL COMMENTS

There is no single optimal solution in this transition towards more sustainable constructions. It is a process that requires time, proximity with the population and the creation of public policies aimed at contributing to the Sustainable Development, generating a circular economy in this industry, but also matching the environment and the particularities of the Mexican territory.

To do this, the four interrelated challenges that were identified and that hinder the use of recycled materials in construction in Mexico must be addressed in a transdisciplinary way, being the most significant contribution of this study. The strategic regulation on the subject is synthesized, with the expectation that the current study will be useful for both professionals and academics in this field, as well as for decision makers to face the limitations of the current legislation.

Finally, an approximate estimate of energy saving of 114 MJ/kg of recycled aggregate for each km that is not travelled is included, as one of the environmental benefits of increasing this practice. However, it is recommended to use a more rigorous methodology that determines the saving of electrical energy.

As future lines of research, it is suggested to carry out a life cycle analysis of SC using RCA, compare the different variants of SC mixtures including economic indicators supported by unit prices and indicators that measure circularity in the construction sector, such as total energy consumption.

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