Sustainable Concrete Application in the Manufacture of University Urban Furniture

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Abstract. It is clear that construction and demolition wastes (CDW) are constantly increasing throughout the world and these wastes can be used effectively to minimize the consumption of natural resources in the manufacture of more sustainable concrete. The CDW occupy an important segment of world waste production and its generation reached approximately 3 billion tons in 2012 in 40 countries [1]. Although this topic has been studied in the world, it is still valid for the reuse of waste that is constantly increasing, and although in many countries there are already examples of its use this type of concrete in Colombia and in the Medellìn city lacks applications. This project proposes the application of a sustainable concrete made with CDW and coal ash in the Medellín city for its implementation in the construction of urban furniture. A university community diagnosis of the needs in terms of furnishing was made. With the design reached, a modular chair was proposed to enable spaces within the university. The mechanical characteristics of the concrete and the design of the chair are evaluated and a simulation is done through finite elements to evaluate the viability of the proposed concrete, finding that with these properties is possible to manufacture durable and sustainable furniture that serves as an example for the application of sustainable materials

1 Introduction

The Incorporation of the most possible quantity of recycled products in the concrete manufacturing, it is a on going and necessary alternative towards the development of sustainable material. Currently_ this is a priority in the construction industry, taking into account that concrete is one of the most consumed material in the world [2] [3].

In this context, the green concrete has been developed, and in the same trend the ecological mortar [4][5]–[7]. Both materials aim to reducing the emissions of gases through by the substitution of some of their components such as Portland cement, promoting the implementation of alternative raw materials (fly ash , blast furnace slag, biomass ash, alternative and recycled aggregates) strengthening the obtaining of materials with high performance and sustainability in their life cycle. [4], [8][9].

Construction and demolition waste (CDW's) is a promising by-product for its reuse as an alternative aggregate in the manufacture of concrete[10]–[13]. The use of this waste to produce composite materials promotes the conservation of natural resources and minimizes the disposal of such waste in landfills [8], [14].

In the Area Metropolitana del Valle de Aburrá (Department of Antioquia - Colombia) where this research was developed, approximately 8,000 tons/day of solid waste is generated. Almost 70% of these (5,500 tons) are CDW, particularly in the case of urban solid waste recovery of 13% is achieved, meaning that the recycling potential of these materials is still being wasted [15].

There is enormous potential associated with recycling, which can be exploited using appropriate management strategies and introducing innovative technologies that allow recycling of CDW according to its quality and use. One of the strategies proposed by this research is to apply an alternative concrete through the implementation of sustainable furniture focused on the needs of the Institución Universitaria Colegio Mayor de Antioquia located in the Medellín city.

2 Diagnosis and furniture design

Figure 1 show the methodology used in the diagnosis was developed in three stages, which are listed below:

Step 1 - Specification of variables: this stage was to define a few variables to analyze the conditions of University furniture in the local context, understanding the particularities that present the furniture as a component of the University infrastructure, in addition to the features not only the object, but the interaction with their environment. Additionally performs a verification in field of related premises with chips of systematic observation, in order to check the variables with the physical conditions of the same.

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At this stage a survey was also designed for the academic community of the institution where we included all sectors to take a sample that would allow us to make decisions as soon as the type of furniture to be developed and its location. Additionally, defined variables for the systematic observation of exercises, among which are: design, ergonomics, function and modularity. Connectivity. Lighting. Accessibility, materiality, ornamental, comfort, color and texture, and people adaptability.

Stage 2: in this stage of the diagnosis results are processed, analyzed data on projections that the institution according to the physical space has to generate new University securities based on the principle of sustainable urban development, as well as the sample estimation of the survey to determine what kind of furniture is pertinent to develop. This diagnosis also yielded results about the location preferred by the University community for the furniture, as well as, the type of furniture that is considered most needed to be implemented.

Stage 3 - Furniture design: at this stage, the results of the survey, are analyzed in order to define the guidelines of the furniture design. It is for this stage, aspects such as the University community opinion in relation to the provision of furniture within the institution, type of furniture is considered more suitable for its implementation on the campus.

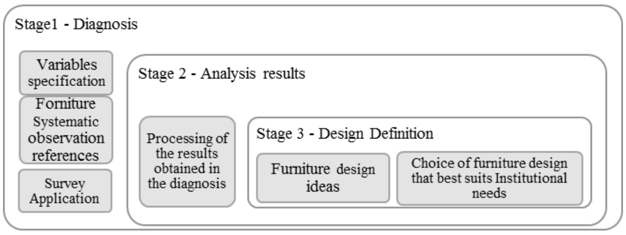

Figure 1. Methodology for the diagnosis and design of university furniture.

2.1 Furniture feasibility

In relation to the data obtained, the interest in the furniture required by the university community needs have been identified and it is found that elements such as chairs and tables have preference (Figure 2), therefore an authentic design is proposed seeking to generate an institutional identity with the design and relate necessary variables such as ergonomics, modularity (Figure 3).

Likewise, it was sought to comply with the requirement of using alternative materials in the furniture (Figure 4) by proposing an alternative concrete as will be shown in the following chapter, since due to the conditions of durability to the external environment that is where interest is found for implement the furniture (Figure 5) this material adapts easily.

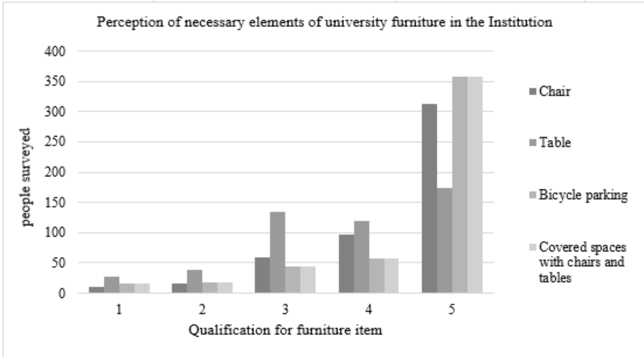

Figure 2. Response importance of university furniture in the institution.

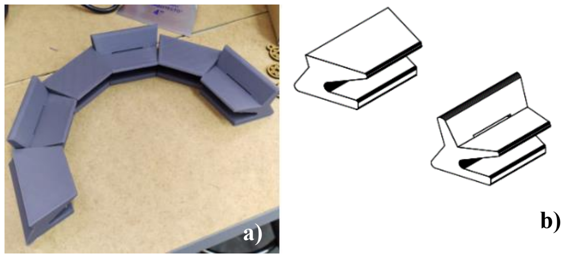

Figure 3. Design proposal for university furniture. a) articulated furniture scheme printed in 3D. b) Chair design with backrest. c) Backless chair design adaptable to table.

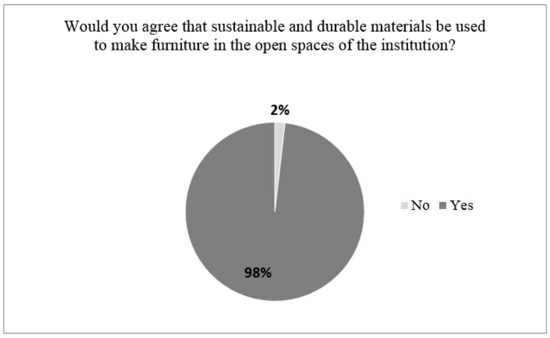

Figure 4. University community interest in the use of alternative materials applied to furniture.

Figure 5. Location map of the possible sectors of intervention of University.

Regarding the stage of search for furniture references in the universities, it was found that the elements that were part of the universal furniture complied with variables such as ergonomics, lighting and connectivity, however with respect to the use of alternative materials or that used some type of urban waste no references were found.

3. Evaluation of alternative concrete

3.1 Materials

The cement used was a gray Portland cement for structural use (PC), in accordance with the Colombian Technical Standard NTC-121 Cemex brand, since its setting time is shorter compared to general-purpose cement and its early strengths are greater, which It allows a quick release of prefabricated elements and an early development of resistance. The coal ash came from carbom combustion for paper supplied by the local company in Medellín.

The recycled aggregate (RA), is directly taken from the materials laboratory university, after the concrete practices carried out by the students this type of waste is generated. The cylinders are passed through a crushing process and are classified into different particle sizes. The glass used as an addition to the white concrete mixture is conventional, coming from recycling green glass bottles with an approximate size of 3mm to change the aesthetic appearance.

The crushing process was done manually with the help of a hammer**.** Structural synthetic fibers (macro fibers) were used according to ASTM C-1116, for type III (Syntetic Fiber - Reinforced Concrete Shotcrete), composed of polypropylene / polyethylene, monofilament, which self fibrillate when incorporated in the concrete mix.

3.2 Methods

Granulometry: The granulometry was determined to the samples of Natural Aggregate (NA) and Recycled Aggregate (RA) according to the specifications of ASTM C 33 and ASTM C136.

Setting times: Taking into account that the cement will be replaced by coal ash, setting time was measured using a Vicat´s needle (according to ASTM C266) in pastes with replacement percentages of 10, 20 and 30% respectively to analyze how these variations affect the time of decoupling of the concrete pieces.

Mixtures design: After considering the dosages to be studied, the design of the concrete mixture is defined, and according to the methodology proposed by the ACI 211, the quantities of each of the components of the mixtures to be studied (table 1). At the time of mixing, moisture correction was made for the water content of the aggregate, and all quantities of the mixture corresponding to these modifications were determined.

Table 1. Concrete mixture design.

Components	**Amount**
Water (kg/m^3) ratio a/=0,45	225
Cement (kg/m^3)	500,00
Fine aggregate (kg/m^3)	540,28
Coarse aggregate (kg/m^3)	1032,54

Compressive strength: The samples to compressive test were manufactured to 28 age days and was curing in water immersion, and were tested to failure in accordance to standard test ASTM C39. For each dosage were taken three samples as seen in the Table 2 and compression resistance was reported.

Table 2. (%) Composition of alternative concrete evaluated.

Samples	**Portland Cement (PC)**	**Water**	**Coal Ash (CA)**	**Natural Aggregate (NA)**	**Recycle aggregate (RA)**	**Fibers (F)**	**Plasticizer additive (%)**
PC+NA	21,87	10,95	-	67,14	-	-	-
PC+CA +NA	17,52	10,95	4,38	67,14	-	-	-
PC+CA+NA +CDW	17,52	10,95	4,38	52,06	15,08	-	-
PC+CA+NA +CDW+F	17,52	10,95	4,38	52,06	15,08	0,69	0,13

Static analysis in finite elements: In order to validate approximately that the chair can withstand the loads to which it could be subjected, a finite element simulation was performed using the commercial package. Two possible scenarios were simulated, in which it is intended to reproduce the most critical conditions of use of the piece. The simulations was carried out using the designed model of the chair and the material proprieties taken of the samples evaluated under compression in the laboratory.

4. Results and analysis

Figure 6 shows the granulometric distribution of both aggregates, the ranges established by the standard limit the maximum and minimum sizes of the aggregates. The sample of NA presents a finer granulometry while the RA presents a thicker distribution. The adjustments of the granulometric curves were made through the Fuller method and the percentages of aggregate to be used to take advantage of the existing distributions are determined.

After analyzing the distribution of particles of the natural aggregate, its fineness module was found in 2.76. This classifies it as a medium gradation sand suitable for mixtures employed in the forniture prefabricated. The maximum size of the aggregate was 9.5 mm, which is also a requirement for the prefabricated texture will be smoother.

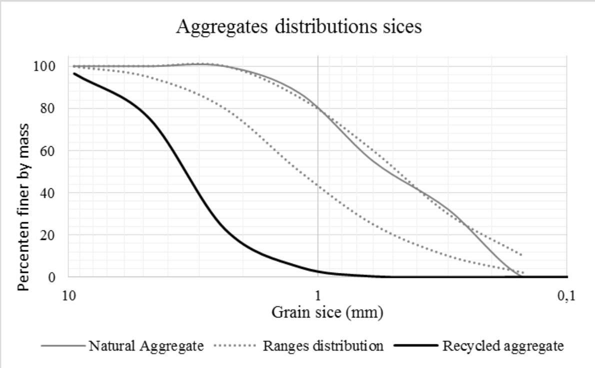

Figure 6. Gradation distribution of NA and RA.

Setting times: Figure 7 shows the incidence of the different coal ash replacements for Portland cement in 10, 20 and 30%. It is possible to identify that the ash increases the setting time, with 30% replacement of ash the paste takes to harden an additional 2.5 hours with respect to the control sample, likewise the replacement of 20% ash increases 1.6 hours the setting, however It is decided to work with this substitution to reduce the cement percentages within the prefabricated piece of furniture.

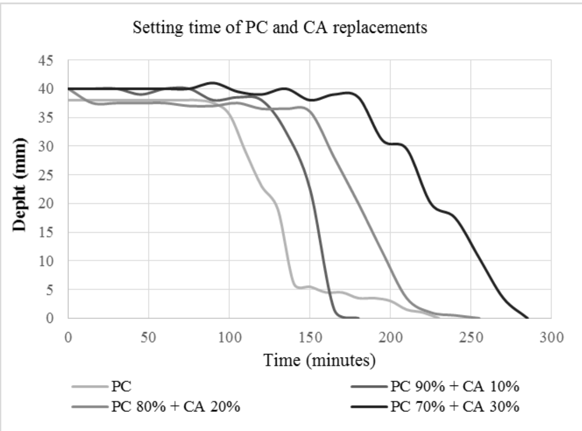

Figure 7. Setting time of cement with different percentages of coal ash.

Concrete compression strength: Figure 8 show the compressive strengths of different alternative concrete mixtures. It is observed that the best resistance obtained in gray concretes is that corresponding to the mixture containing CDW with 59.27 MPa followed by the mixture containing fibers with 53.46 MPa, even these two samples show less variability since a standard deviation is observed lower than those presented by the other two mixtures.

These results coincide with the reported by [16], who attribute an improvement in the concretes compressive strength due to use the greater an amount of RA in replacement of conventional aggregates combined with coal ash or artificial pozzolans, due that RA improve the pozzolanic reaction of the ash, leads to a greater pore structure and interfacial transition zone (ITZ) refinement in the matrices of the material.

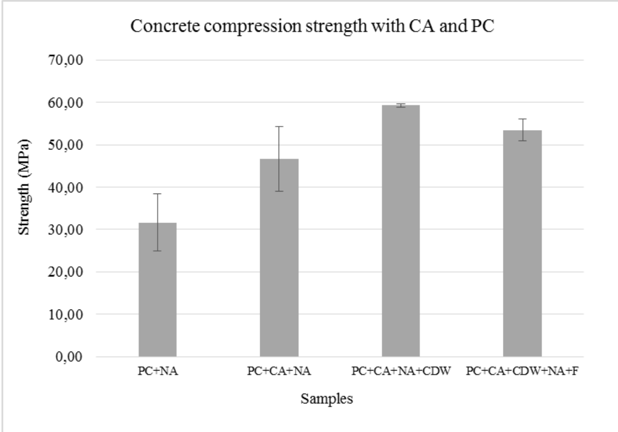

Figure 8. Concrete compression strength with CA and PC, evaluated at 28 days age.

According to [17], in concretes with replacements up to 40% of RA, the development of mechanical resistance improved due to CH and C-S-H present in the recycled aggregates acted as nucleation sites, accelerating hydration reactions and stimulating the formation of new hydration products. The CH also acts as a sink for calcium and silicate ions, which allows further dissolution of tricalcium silicate (C_3S) (F.M. Lea 1988). All this has a direct impact on the densification of the microstructure.

The concrete that contains PC, CA, NA, CDW and fibers (F), presented the best properties of the evaluated concrete, its maximum resistance recorder a value of 50.2 MPa with a standard deviation of 2.4, its elastic modulus is 11095.169 MPa, and a deformation in the area elastic of 0.0011 mm / mm. These properties are taken into account for the analysis of finite elements.

5. Static analysis in finite elements of the chair model

This analysis simulates the critical loads that the chair may be subjected when is going to put it into service, therefore two possible scenarios are proposed, the first one concentrating the load on the outer edge of the cantilever of the part Figure 9 and the second in the entire back and seat area as shown in Figure 10.

For the simulation, the characteristics found in the tests carried out on the concrete are taken into account and the greater amount of waste and alternative materials within the sample is taken into account, so the results of the gray cylinder with ash replacements, CDW and Fibers was taken.

In the case of the loads on the edge of the chair (Figure 9, b and c) the load of 4 people seated on the lower edge was simulated, which corresponds to 2744 N (70 kg per person). By running the model, with the characteristics of the selected concrete it is found that the stresses are concentrated towards the center of the edge of the cantilever, the higher displacement found were 0.0405 mm.

Therefore, the selected concrete had a deformation of 0.0011 mm / mm within the elastic material area, indicating that the piece would not deform in presence of this load. Additinally, the safety factor indicates that it could withstand up to 13 times the simulated load to reach the material deformation limit (Figure 9, d).

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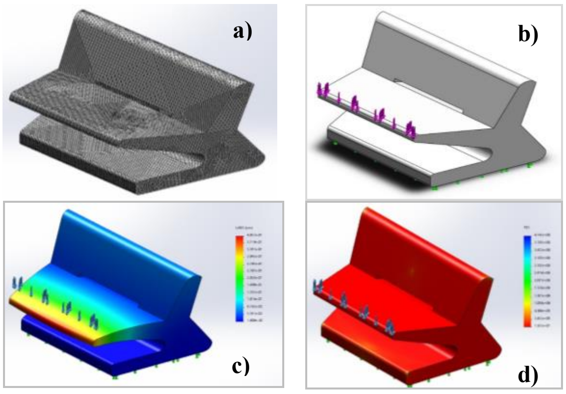

Figure 9. a) Solid mesh with distribution of nodes. b) Distribution of loads on the edge of the piece. c) Deformation in mm. d) Safety factor.

For the case in which 4 people corresponding to 2744 N located on the main seat, and that 3 people corresponding to 2058 N located on the backborder edge (Figure b and c), when running the model for this case, it was found that the efforts were concentrated on the edge of the cantilever and that there would be deformations of 0.14 mm. Thus, the selected concrete had a deformation of 0.0011 mm / mm within the elastic material area, indicating that the piece would not deform in presence of such load. Additionally, the safety factor indicated that it could support up to 16 times the simulated load to reach the deformation limit of the material (Figure 10, d).

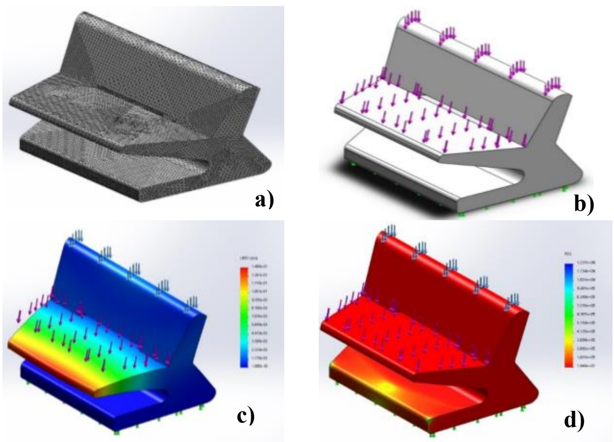

Figure 10. a) Solid mesh with distribution of nodes. b) Distribution of loads on the edge of the piece. c) Deformation in mm d) Safety factor.

6. Real-scale models developmen

In relation to the current stage in which the research project is, which is where the execution and implementation of urban furniture is carried out, a wooden referent was built in real scale according to the design selected (Figure 11, a) in order to get a mold (Figure 11, b). Then, the green concrete emptying was made (Figure 11, c) taking into account to CDW and CA dosages. After a day of hardening of the concrete, the mold is removed to obtain the piece (Figure 11, b).

Figure 11. a) Wooden models of chair, b) Mold c) concrete emptying and d) unclogged.

The above constitutes the final phase of the project since this depends on the quality of the product to be delivered. At the same time, the mold (Figure 11, b) is also a key aspect in the unit value variable.

7. Conclusions

Furniture design consists of solving creatively a problem that needs to be improved. In our case, the team proposed furniture that would not need additional reinforcements to its form. Proposing an alternative concrete which meet the appropriate strength and durable characteristics. This task required to articulate several disciplines focused to use geometrical and design tools that would allow an adequate distribution of loads and respond to the ergonomics of the furniture with comfortable and functional characteristics.

The design basis included factors such as materials, functionality and sustainability. The final result was a product that met the specific university identity, students` behaviour and the use of the available space and community needs.

Furniture elements` prefabrication, as a previous building process, guarantees two factors: standardization and industrialization. Standardization refer to, generating modular elements with ease, defined production parameters and standardized production methods. Industrialization refers to the process of manufacturing the element, using skilled human resources and applying technology using cutting-edge production techniques.

The main goal of those two factors are to guarantee a high quality product, increase productivity and improve process efficiency. The competitive advantage of prefabricated concrete elements under industrialized and standardized processes result in low overall cost, little maintenance and optimization of spaces and resources.

The green concrete assessed in this research states adequate characteristics for durable and strong prefabricated construction elements. As a result, offers a viable and sustainable alternative for using the permanently underused waste materials in the city.

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