57. Waste management and block production of recycled material *in situ* in a building of intermediate scale in the city of Buenos Aires, Argentina

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Abstract: This paper describes sustainable operations on recycling construction and demolition waste, applied to the construction of a multifamily housing. The stage of consultancy and training for making masonry blocks was based on the *Centro Experimental de la Produccion*, CEP from *Facultad de Arquitectura, Diseño y Urbanismo*, public local university, and approach for *in situ* material production. From a local building tradition rooted in masonry, the previuos CEP research selected and developed mixtures of concrete including remains of demolitions and other recycled materials such as expanded polystyrene, selected and processed to improve weight, thermal properties, carbon footprint reduction and overall structure lightening by avoiding materials transfer and virgin products use.

Key words: Materials, Sustainability, Housing, Recycling, Buenos Aires

1 Introduction, State of affairs, Selection Criteria

This work presents an update on the progress of a case study analysis of a medium scale building for multifamily housing, where principles were elaborated and disseminated by both, the Experimental Production Centre (CEP-FADU) and the Habitat and Energy Research Centre (CIHE-FADU) were implemented.

The focus is particularly on the design and optimization of the building envelope, by managing the waste site demolition for new material production, aimed to energy expenditure reduction, thermal capacity increase and shipments material to construction site decrease .From the experience of the CEP in the development of cementitious blocks with recycled aggregates, a three-layer block with an outer layer of cement mortar and water-resistant additive, insulating core cement concrete with sand as fine aggregate and rubble and EPS crushed as coarse aggregate, and cement grout to seal the surface and avoid shelling in handling was designed. Efforts were made in order to make the block of a similar weight and dimensions to those available in the local market, but with better finishes, including the possibility of colour, bevelled edges and especially, avoiding the need for plastering.

On the other hand, since it is a typical building of the city of Buenos Aires, without an exceptional budget or conditions, the concluding section of the paper highlights the replicability of this experience and its potential to become a widespread practice, with consequent benefits in terms of energy savings –during the construction and the lifespan of the building– and decrease waste of work.

While the field of study and research on bioenvironmental architecture and then sustainability in architecture has already an important tradition in Argentina– with working teams and academic centres founded already three decades ago– there are relatively few examples built to date. On the other hand, most of the examples made, and in general the study of this field ranges from cases of small isolated buildings that require a high level of energy autonomy, and building complexes or high-scale towers –usually with administrative or commercial uses– in severe need of reducing their high energy demand. However, the vast majority of buildings in cities such as Buenos Aires lie between these two extremes.

In these objectives fits one of the lines of research of the CIHE, oriented to criteria for the selection of materials in the framework of sustainability, whose first results allowed establishing general guidelines already applied in previous cases (Mühlmann et al, 2015) and that in the current expands to specific certifications for materials and products, such as the Cradle to Cradle - C2C (McDonough Braungart, 2012) linked to LEED v4 and the certification of German Sustainable Construction (DGNB GmbH, 2016).

C2C is synthesized on principles between which in the framework of this research are distinguished:

1. Materials Health: Select safe and healthy materials. Design products that are safe and healthy for humans and the environment from production to use and reuse. Safe ingredients perpetually cycled.

2. Materials Reutilization: Eliminate the concept of waste. Design to eliminate the concept of "waste" with international nutrient cycles to retain the full value of the nutrient. 100% recovery and upcycling.

The DGNB focuses on overall performance buildings or districts based on about 40 different criteria, including those according to this research which are:

1. Creating a plan to avoid, reduce and recycle waste.

2. Incorporating concepts of conversion and deconstruction of buildings and a recycling plan for components during design processes to protect resources and raw materials, and improve productivity.

3. Development of a deconstruction and disassembly plan to reduce the materials flow volume produced by the construction industry and redirect it to a permanent production cycle, avoiding waste and trying to reduce the level of harmfulness.
4. Application of specific guidelines:
    a. Homogeneity in the materials selection.
    b. Separability of materials.
    c. Use of recyclable free of contaminants construction materials.

2 Objectives

To present a built case that incorporates sustainability criteria in the selection of available materials in the local market.

To introduce innovative processes in the design and manufacture of new materials made with the inclusion of on-site recycled waste at the building work location, which among other features, provide thermal insulation capacity to the building envelope.

3 Methodology: case-study approach

3.1 Analysis of post-occupation and construction phase cases with sustainability criteria in urban architecture.

Local development of bio-environmental and sustainability architecture is not yet reflected in our markets of materials and construction products. In this context it is proposed to examine a built case in which both design and materialization in work decisions were intended to achieve the highest possible levels of sustainability, as it is argued that, even in a context that does not facilitate sustainability practices, it is possible to achieve significant improvements.

4 Case Study: Olaya Building

4.1Preliminary analysis and on-site recycled materials production

It's a five-storey building designed and built by the Kozak study, with completion in 2016, whose design was based on criteria of sustainability in urban architecture

(Fig. 1).The land counted as an asset with a two storey building which did not comply with current regulations and urban codes nor good security conditions.

Fig. 1 Exteriors and balconies. Source: own elaboration

The main innovation in this case was given by the on-site production of masonry from recycled materials from these demolitions. The project was carried out by Kozak Architects with a consultancy on Waste Management by Yajnes and Caruso Architects. The construction of the building began in August 2014 and it is scheduled for completion in September 2016. As a result of the application of the indicators mentioned above, the need to demolish the existing building for development of the new proposal arises. (Yajnes, Sutelman et al, 2014).The reuse of demolished materials is an issue of utmost importance nowadays.

4.2 Constructive proposal with Recycled Materials

Part of the demolition of approximately 28m3 (12.000kg) of rubble, measured in its demolition state, was saved for its recycling and transformation from residue to resource as aggregate in concrete to be used for the construction of non-structural blocks. As the result of CEP studies, two mixtures were selected for the manufacture of construction blocks for exterior double walls. They are three-layer blocks composed by: an outer layer of cement mortar with water-repellent additive and ferrite derivate colour, insulating core of concrete cement with sand as fine aggregate and rubble and crushed EPS as coarse aggregate, then grout cement is applied to seal the surface to avoid shelling in handling. It was sought a masonry that had weight and measures similar to those available in the construction market but featuring superior finishing's, including colour, shadow gaps and above all, avoiding the need to plaster and other cumbersome tasks of work both for economic investment and occupational hazards. The finishing is a coat of sealant or water lacquer for surface protection.

In the ongoing research on the use of rubble as coarse aggregate, the additions are measured in kg, so because of that it was studied a way to measure the volume of demolition to be reserved for the future manufacture of blocks during the construction work. For this purpose samples of rubble, including all existing variations in terms of size, shape and original materials (hollow and common brick, plasters and mixtures of seat), were removed and weighed to estimate the required volume. The sample measurements indicated 24,5kg of weight, a volume of 0,0424m3, and reached a specific weight of 578 kg/m3. Then the material was crushed to pass through the sieve of 12,5mm and keeping their weight, their volume went to 0,0297m3 with a specific weight of 826 kg/m3. In another stage the powdery material was separated, reaching a useful volume of 0.024 m3, a weight of 17, 5kg and a specific weight of 728 kg/m3, it was considered that it could be used 1 kg of powdery material in that proportion. The conclusion of this analysis determined the 28m3 required to meet the need of 12.000kg. Once the demolition was finished, the manufacturing of a batch of blocks with the two aforementioned mixtures was carried out to be tested for proficiency in certified laboratory.

4.3Three-layer block definition and insertion into the compound wall

The first layer, or outer face of the three-layer block is cement mortar with light gray colour obtained with the combination of gray cement and white and water-repellent additive MCI 1:3 1cm thick, the second layer or soul concrete aggregates thick EPS and HEPS crushed rubble 1:1:1:3.75 of 12 cm and the third layer or inner side of slurry cement mortar MC 1:3 to 0.5 cm. The wall then is completed with a chamber of thermal insulation, vapour barrier and inner revoked hollow masonry wall 08 suitable for guttering for the required facilities.

The exterior layers have been realized in mortars of 2.000 kg/m3 of density for being the traditional way in which those finishing's are resolved locally to obtain superficial hardness, the dosage of the soul was realized in accordance with tests of composition conducted in the research project TRP19, with which the resistance to compression of 2,5 Mpa needed in accordance with local norms was reached by thickness and constructive design in three-layer with 20 % of security reaching 3 Mpa as well as the minimal quantity of cement of 300 kg/m3 in the mixture.

4.4 Production process

Initial and advanced on-site training work for standard blocks (Fig. 2). The training was carried out in two stages, in the first instance took place a demonstration of the manufacturing process of three blocks to the members of the architecture practice and construction management as well as the main contractor. Recycled materials were processed at the CEP laboratory and taken to the site and the rest of virgin materials entered already separated and weighted. A mobile vibration table was moved. In the final training was used equipment already acquired by the architecture practice, such as the vibrating table and precision balance for standard units, or produced *in situ*, like the sieves for EPS and debris crushed for special units. In this case, one of the researchers trained an officer and an assistant together with the project manager for a week.

- Preparation of moulds for entrepreneurship: Two moulds of three blocks each were assembled to achieve greater productivity. The first one was built at the construction site during the pre-cut materials training, the second one was made by trained personnel.
- Preparation of interfaces: The intermediate pieces between the casting and moulds for purposes of protection and required finishing's were cut and folded together in the laboratory and linked *in situ*. They are composed of reused posters canvas, obtained from donations, and 0.5 virgin crystal PVC trays for the exposed face of the blocks.
- Processing of recycled materials: Rubble crushing and sifting; weighing of crushed rubble; Ground and sieved EPS, crushed EPS volume measurement
- Weighing of virgin materials (cement, lime, sand, additives, colorants, water).
- Pre wetting of rubble; mixed of EPS with water more additives.
- Dry mixing debris; mixed set of concrete
- Preparation of mortar for finishing's with their additives and colorants
- Casting of layers.
- Curing; Unmould; stowage; quality control and disposal of parts; controlled stowage.

- Cleaning of the place, moulds and tools.

Fig. 2 On-site training work: initial (left) and on manufacturing stage (right). Source: own elaboration

After the production of standard blocks for enclosure finished, the training and production of "parapet" blocks took place. These were used as a perforated enclosure of balconies and withdrawals. In this case, the blocks present 2 holes instead of the 3 ones of the original blocks, and the most defining, 5 of their 6 viewed faces have white and common cement mortar combined. For their production a single crystal PVC interface and an internal plate mould were used.

4.5Work building process

Usually, in construction works such as the present case study, EPS or EPOR packaging is available in two stages: during the construction from provision and placement done by the construction company of the different equipment devices installed in the building, which represents an estimate of 2000 lt. of already processed material, and during the stage of moving and occupation of the apartments (packaging of refrigerators, washing machines, etc.) which represent other 2000 lt. At the beginning of the construction, this volume of EPS is provided from earlier works. To complete the 40.000 lt. estimated for manufacturing blocks for exterior walls, it is proposed to establish a logistics of collection strategy with generators like appliances selling companies chains and hypermarkets, laboratories and waste collection cooperatives. It is also possible to include waste collection for recycling neighbouring points like the *Red de Puntos Verdes* Flores neighbourhood. In all these cases, the challenge is to minimize the special transfer movements given the volume of the pieces and the quantity of gaps that they present for its format.

Already a link to the neighbourhood community was achieved after the FADU Verde organization intervention with the Italian Hospital and Raffo Monteverde laboratory. Advantages were achieved in both cases: the proximity to the construction site (2 km) and the company logistic capacity respectively. The collected material was delivered to an industrial micro enterprising designer, trained at the FADU with the architects in charge of the technical consultancy on waste management, both in production processes and the development of prototype crusher sieve, perfected while attending Technology IV in the Chair Louzau. Advantage was taken from transfers between small businesses and building site for the exchange of EPS in waste and resource formats, favouring this way the linking chain between the university and building production system.

The blocks produced *in situ* were used for enclosure of fronts to the street and ground floor, completing the virtuous circle of raw material procurement, collection, preparation, training, moulding, stowage and put in use, within the same construction site, aiming to reduce economic and environmental costs.

4.6 Justification of crushed EPS incorporation in the mixture for blocks

Conventional mixtures, obtained from the addition of crushed rubble and coarse aggregate, generate specific weights that hardly fall of 1300 kg/m^3, which is unsuitable for the purposes of obtaining competitive products in weight and thermal insulation. From the SI TRP19 Project research, different results with EPS formulas that combine crushed and rubble were obtained. Within the range of available mixtures, for this project were preferable those which have a pasty binding, preferred by the contractor for its workability, with densities of 900-1000 kg/m3, called TRPN 1 and No. 10 with variations from 300 kg/m3 to 325 kg/m3 in the input of cement, sand and rubble and EPS coefficient between 3.75 and 3.25 times of EPS in litters on the cement expressed as kg. The dosage is 1: 1: 1: 3.25, corresponding to cement, sand and rubble respectively in kilos and EPS measured in litters. Every soul block 12 cm thick contains 2 kg of cement, sand and rubble and 7.5 litters of additivated EPS.

The superficial faces correspond to the cement mortar 1: 3 to 1 cm thickness in the outside and 0.5 cm in the inside. The walls will be double, over the *in situ* built blocks a water-resistant layer was placed, plus a thermal insulation of 3cm, and 12cm hollow brick and finishes. A wall built with a block 13 cm thick has a U value less than 29% that of a ceramic block according to own calculations based on tabulated values according to Local Regulations and testing performed by the INTI for La Pastoriza and approved by the DGFOC (GCBA, 2005). Regarding EPS, the recycling of this material developed a dynamic in recent times which makes modify the gaze on this input. The Government of Buenos Aires City (GCBA) incorporated it within the materials received in its Green Centres and there are companies or individuals that already grind and trade it, reaching a sale value similar to sand.

4.7 Block and mortar tests

Three blocks were tested at the National Institute of Industrial Technology (INTI) to Compressive Strength with average results of 3.10 Mpa, resulting suitable for non-bearing walls.
According to the opinion of experts on the behaviour of materials such as the architect John Martin Evans, the proper functioning of an enclosure is based on avoiding different contractions of blocks and mixtures. To achieve that goal different mixtures seat based on the proportions suggested by CIRSOC 501 standards were developed at the CEP laboratory, and replaced a proportion of conventional aggregates and sand by crushed EPS. Preliminary compression tests were performed in the laboratory of the University of Oviedo, School of Engineering under the supervision of Doctor Engineer Fernando L. Gayarre. Depending on these tests, the mixture of dosing 1:1/2: 3: was preselected whose components are, in that order: cement, hydraulic lime, sand and 6 mm crushed EPS with indicative consumption per m3 of 315, 157.5 and 945 kilos respectively and EPS 945 litters with the addition of 2 kg per m3 of plastic fibres. Regarding the use of fibres, glass and plastic ones were tested, with no significant differences on compressive strength, therefore, plastics fibres were chosen for their better handling.

5 Technical data of the materials

- Dimensions of the blocks: length 40 cm, height 17,5 cm, thickness 13.5 cm.
- Format of blocks for enclosing walls: prismatic with 3 holes for lightening and possibility of fills for reinforcements and linkages.
- Format blocks of parapets: prismatic with 2 perforations for lightening and possibility of fillings for reinforcements and linkages. All their faces have finishing's.
- Fire Tests related to the soul of lightweight concrete mixture: optical density of smoke level 1: materials that generate low amount of smoke 8 Level 1: Materials that generate low amount of smoke 8. Flame propagation, method hot plate RE 2 / A Materials with Very Low spread of flame 6.
- Mechanical resistance of the blocks: 3 Mpa. 3 tests in INTI Buenos Aires.
- Porosity: tests performed in the CEP where it was found the lower absorption of the mixture of concrete and cellular concrete in relation to traditional ceramic masonry.
- Square Meters built: 60 m2 of walls and 13 m2 of parapets.
- Training Time: 1 week.
- Time of manufacture: 1 month for two people: a construction official and an assistant.

6 Conclusions

The main innovation of the Olaya Building was the design and production of the blocks described in this paper. Girded by budget constraints and resources in general, that usually condition the intermediate scale constructions in our country, it was possible to materialize a building envelope which significantly reduces the ecological impact of the new building, with the following benefits:

- The use of recycled material:
  - Part of it, from the demolition done on-site.
  - Manufacturing has the support of studies and tests at INTI which verified fitness for a building of its kind in the city of Buenos Aires.
- The use of the system of concrete blocks from recycled aggregates, custom made.
- These blocks can be designed and manufactured tailored to the construction requirements in terms of dimensions and joints.
- The usual situations of cutting of parts are reduced and so their correlative emission of powdery material and waste generation.
- The difficulties caused by the use of standardized products designed by different technical and end-user design team are solved.
- The ecological impact of transporting the raw materials to the building site is decreased.

Among the difficulties encountered during the construction process, the main ones were related to the adaptation of the prototype developed at the CEP laboratory to the working site conditions, for example, to extend the moulds useful lifespan, and especially in optimizing production times. The original estimates regarding time, and therefore costs, taken for the blocks manufacture were too optimistic. For this reason, during the building work the decision to limit the blocks production to the strictly necessary to solve the entire housing front envelope, along with the ground floor walls was taken.

As a result a facade with excellent characteristics of acoustic-thermal insulation, whose construction meant a major environmental impact reduction, less waste production, less energy used in transfers of materials, recycled material utilization and, mainly, less energy demand for the building thermal conditioning during its lifetime was obtained.

Finally, in this case, the selection of materials was directly related to recycling and reuse of waste from the construction site itself or of previous works criteria, a process that evolved from the projective stages to the realization of it, pointing the development of technical and methodological guidelines that serve as a paradigm for future construction, based on a philosophy that promotes improvement in the quality of life of people and the preservation of our sources.

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