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DETERMINĂRI EXPERIMENTALE PRIVIND REUTILIZAREA BETOANELOR REZULTATE DIN DEMOLAREA CONSTRUCȚIILOR

Doctoral thesis – Summary
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CONTENT

1. INTRODUCTION

The construction industry is considered to be one of the major sources of economic growth on a global level. Eurostat estimates a growth of the production in the construction field for the European Union of 3.0% for the first two months of 2016 compared to the same period in 2015. For Romania the growth is even bigger, 4.25% for the first two months of 2016.

On the other side, this industry is one of the biggest polluter, from the process of extracting the raw materials to the demolition process of the existing constructions; creating a high quantity of CDW. Eurostat estimates that in 2014, the total generation of waste from economic activities and households in the EU-28 amounted to 2598 million tones, the biggest quantity starting with 2004 [1]. CDW represented 33,5% from the total.

The term CDW brings together two actions that are very different, and also the type and volume of waste produced by these two processes can differ greatly. Construction waste contains more topical materials compared to demolition waste, because new buildings are rarely demolished. In terms of quantity, demolition processes often produces around 30 times more waste material per square meter than construction processes. The volume of CDW produced in a country depends on many factors including education and population growth.

Construction waste materials are very different around the world, depending on the building structure, used materials and technological processes; United States has a large amount of family homes with the structure made from wood frame compared with European family houses, which have a structure mostly containing clay bricks [2].

Demolition waste are provided in general from old buildings which can contain materials no longer used in construction industry in our days, some of them are even considered dangerous; a good example is asbestos, which was used as cover for a long time. Demolition waste is often contaminated [3] with paints, fasteners, adhesives, wall covering materials, insulation, and dirt; which can make demolition materials difficult to recycle. The method used for demolition is an important aspect; methods which insure a selective demolition or a total deconstruction require more time and higher costs than a mechanical demolition. Concrete is one of the most present material, both in construction process and demolition process. It is the second most consumed material on Earth, after water. The consumption of concrete at aglobal level has increased according to [4]: from less than 2 up to 2.5 billion tones in 1950 to 21 up to 31 billion tones in 2006.

Intergovernmental Panel on Climate Change (IPCC) reported in 2005 [5] that the global warming has started and is a process due to human activities and henceforth, the concern about this issue has increased. Since 2005, the recycling topic was raised more often internationally as a solution to the global warning process and many studies were developed in this way. The present global policy concentrates on recovery, recycle and reuse (RRR) of various wastes including CDW.

The reuse, recycling and reducing of the waste are considered the only methods to recover the wastes generated; however, the implementations still have much room for improvement [6].

According to the revised **European Directive 2008/98/EC** [7], until 2020, the minimum percentage of recycled “non-hazardous” CDW, excluding soil and stones which do not contains dangerous substances, defined in category 170504 in the European Waste Catalogue should be minimum 70% by weight. This directive highlights the aspirations of EU regarding recycling while the average recycling rate of CDW for EU-27 in 2010 was only 47% [8].

In Romania, **Law no.211/2011** republished in 2014 [9] handles the waste problem in a technological, environmental and economical way.

The usual form taken by the CDW is as aggregates in road fillings. On a worldwide level the aggregate consumption is around 20000 million tones/year with an annual growth rate of 4.7% [10].

Based on the presented facts, the theoretical and experimental program from the present thesis has been developed.

The main objective of the current research is the study of recycled concrete aggregates (RCA), from different points of view: the technology used to prepare RCA, different properties of RCA, or the sustenability of this type of aggregates. On the other hand, it is studied the possibility to use the fines obtained from the concrete crushing as a binder.

2. CONSTRUCTION AND DEMOLITION WASTE (CDW) MANAGEMENT

The increase of the waste quantity, particularly CDW (construction and demolition waste), has lead to major problems regarding its storage, both locally and globally, especially considering the emphasis on urban environment nowadays.[11].

The **construction industry** produces varied waste on a global level, depending on the construction structural type, but also on the materials and technological processes used.

The environmental problems due to the unsuitable storage of CDW are a concern, because they affect both the cities and their surroundings, thus starting debates on adopting sustainable disposal measures for CDW. This has lead to stricter legal measures to make the ones that create waste responsible for their sustainable disposal, resulting in adopting a policy of minimizing and reciclyng the waste [12].

Waste from construction demolition is most of the times contaminated with materials from the woodwork, adhesives, finishes, thermo and hydroisolation, or other remains.

CDW can have varied compositions, depending on the percentages of the different natural materials used and their type. The composition is subject to the construction solutions implemented, but also by the time period when the construction was erected.

In the past 15 years, research regarding CDW has focused on three main topics: waste production, reduction and recycling. However, the subject is much greater: the reduction to zero of the waste needs a wider approach of the problem, considering the flourishing industry, new policies regarding the topic, fomal education starting at an early age, public awarenss and research topics to bring an attitude change and reduce wasteful consumption.

CDW management is treated differently depending of the country, being tightly coupled with the country legislation. However, we can generalize by stating that CDW management is done properly if the following actions are taken:

- Correct disposal of CDW, tracking the type and quatity, because this can provide information regarding the effectiveness of the equipment and the work team.
- Local investigation of the terms and disposal options for CDW, prioritizing the creation of systems for collecting, sorting and recycling CDW for construction companies.
- Pursuing the reduction, reuse and recycling of CDW, also called the the 3R policy.

The **Europen Commission** report **(DG ENV)** [13] concludes that defining CDW in the **European Directive 2008/98/CE** is not explicit enough to correctly identify CDW, in the most clear way possible.

Is is recommended that waste is categorized as CDW depending on their type and origin (construction or demolition activities), irrespective of who is performing the activity. The two problems caused by this categorization are:

1. Including waste produced by the construction industry through connected activities that take place during the work by personnel inside the site (e.g. food packages, food scraps), which are not included in the directive when defining CDW.
2. Excluding CDW produced by other industries, but which are included in the directive by their nature as CDW.

However, the quantities that derive from these two classfications are negligible compared to the total quantity of CDW produced and will be neglected henceforth.

An important factor in reporting the correct quantity of CDW is the inclusion or not of waste resulted from excavations. Many countries with high quantities of generated CDW have high percentages of waste from excavations.

Moreover, reporting too low quantities of CDW for some countries reflects the lack of control from the authorities. Therefore a minimum quantity of 0.94 tones/inhabitant was adopted for EU.countries [14]. This way, countries that declared lower quantities, were statistically considered with 0.94 tone/inhabitant, leading to a total quantity of CDW for the 27 EU countries (EU 27) of 459.6 million tones for 2004 and 461.37 million tones for 2005.

In the European Commision project entitled *'Resource Efficient Use of Mixed Waste'*, started at the beginning of 2015, was proposed the study of the actual CDW management for the EU countries, by evaluating the official statistics regarding the CDW quantities, identifying possible sources of inaccuracy and establishing the best management for the country. Also, recommendations are made to ensure the effective tracking of CDW and the statistics accuracy.

The most part of CDW are generally inert waste [15] and this is why it does not represent such a danger as the toxic waste and the municipal waste. CDW is usually mixed waste, their type depending mostly on the activity that generated then, be it construction or demolition.

Out of the total solid waste produced globally, 35% is generated by the construction and demolition activities. [16], most of them ending up as filling in other sites, in an uncontrolled and inadequate manner. In the past years, numerous studies focused on collecting data regarding the composition and the quantity of CDW generated in different geographical regions and different building construction systems.

Recycling consists of harnessing waste and transforming it into products or materials that satisfies the same function as the original or a new function. This concept has an important role in the efficient use of resources. Firstly, the efficiency of the recycling depends on the volume of the material that is recovered or recycled. This volume could include materials generated during the production process or at the end of a product's lifetime.

The recycling process is complex and consists of collecting waste, separating it, processing and reinserting it in the market under the same (or almost the same) for as the original one.

3. RECYCLING CONCRETE

Aggregates obtained from recycling concrete (RCA) from demolitions are one of the main topics in developed countries. Abusive exploatation of natural aggregates was restricted internationally due to the reduction of the quantity of natural resources in the context of protecting the natural environment [17].

The construction industry is responsible for a great quantity of waste produced by manking, but also for a great deal of the energy consumption [18]. RCA used in the construction industry can solve the aggregate deficit problem and can reduce the pollution of the environment.

The demand of aggregates can reach up to 83000 tones/year, taking into consideration the average volume of aggregates necessary for the support layer and road foundation (based on the road construction legislation in Portugal). RCA has an average density of 1950 kg/m^3 and therefore has a reduction factor of 44% [19]. The necessary aggregates quantity for producing concrete is estimated at 1640000 tones/year, based on the informations provided by the concrete stations in Portugal) [20]. This value corresponds to 35% of the cement used in the concrete stations (on a national level), having an average density of 1870-2400 kg/m^3 for aggregates and hardened concrete, respectively an average of 20% for RCA used in producing new concrete. However, these values have a high degree of uncertainty, as long as there is proof that RCA can be used in new concretes with acceptable properties in much higher quantities [21], [22].

Demolition techniques and CDW management are the main problems in developing a sustainable construction.

Another problem about waste management, especially in crowded areas, is the recycled concrete quantity produced by construction demolitions, twice the necessary of recycled concrete. Generally the demand for recycled concrete appears where the natural resources are poor in natural stone.

The two basic rules that need to be respected in demolition processes are:

- The existence of a waste management plan and the possibility to recycle.
- The demolition process needs to take place in safe conditions, based on a technical project meant to reduce the risk of accidents [23].

At the end of a construction's lifetime, there are 3 alternatives, depending on the budget and restrictions imposed by the protection of the environment [24].

- **Deconstruction** consists of removing non-structural elements and reconstructing it based on the old structure.
- **Reusing the entire structure** is done by dismantling and reusing the structural elements, this being often encountered in the case of steel constructions.
- **Demolition** can be partial, or more often, complete. To avoid producing waste and filling, reusing and recycling must be considered.

The predominant method in Europe is demolition by use of excavators, either by pulling down construction parts using the bucket, by dismembering using the hydraulic scissors or by percussion.

According to NP 55-88, the demolition process requires previous preparation, in order for it to be managed safely and with a waste quantity as low as possible.

Concrete can be recycled by grinding it and obtaining recycled concrete aggregates (RCA) or recycled finest (RCF).

After concrete is crushed, the aggregates are sorted and can be used either as support layer in the road industry, or for producing new concrete.

The concrete recycling installations work the same as the ones for recycling other mineral materials, being relatively easy and consisting of manually sorting it, grinding it, magnetically separating it from metal remains and finally, sieving it. The concrete recycling installations can be fixed, with multiple grinding and sieving processes, or mobile, having the advantage that the concrete does not need to be transported if it will be reused inside the same site.

Recycling concrete includes most of the times grinding it to different sizes with the help of the crusher. Lately, these devices were improved, thus allowing to produce a better quality of the recycled concrete and a higher quantity of material obtained.

4. RECYCLED CONCRETE AGGREGATES (RCA)

The use of recycled concrete aggregates in the construction industry began with the end of the Second World War, when the concrete from the demolition of the degraded roads was used as recycled concrete aggregate for the support layer of the new roads [25].

When we talk about recycled aggregates (RA), it is important to know their composition. There exists a classification for them [26] that establishes 3 main types:

- **Type I**: recycled masonry aggregates (RMA);
- **Type II**: recycled concrete aggregates (RCA);
- **Type III**: mied recycled aggregates (MRA).

The **Australian Standard CSIRO** [27], defines class 1A of RCA as consisting of good quality aggregates, with a maximum amount of masonry aggregates of 0.5%, that can be used in a large number of applications, subsequent to its characteristics being determined in a laboratory. This standard allows replacing natural aggregates up to 30% in the production of non-structural elements as curb-stone, but avoids using RCA in structural elements. Restrictions apply despite the fact that concrete with RCA reach strengths of 30-40 Mpa in non-aggressive environments.

The **Dutch Standard VBT 1995** allows the replacement of NAT up tot 20% with RCA or MRA in new concretes, without requiring extra laboratory trials for concretes whose compression strength is necessarily larger than 65 Mpa.

To obtain recycled aggregates of good quality, one must use performant mobile or fixed installations that have as final product coarse aggregates. A thorough sorting of these aggregates is required [28], using a sorting equipment, in order for them to be categorized according to their characteristics in aggregates for the road industry or for producing new concrete.

Compared to natural aggregates (NA) used for producing concrete, RCA has a lower density and a higher water absorbtion [29], due to the grinded cement stone. The content of the cement stone varies, being directly influenced by the strength of the cement stone from the demolished concrete, the size of the granules, the crushing type and the number of crushes it goes through during the process of production. [30]. Research until now has established the RCA contains 20% to 70% cement stone [31].

Another important aspect is that for RCA granules that contain NA and cement stone with similar characteristic, the influence of the cement stone characteristics on the properties of RCA is a linear graph [32].

Lately, research has focused on the study of recycled concrete aggregates, due to its superior properties compared to those of the recycled masonry.

Aggregates obtained from recycled concrete usually contain particules of natural aggregates coated partially or entirely by a layer of cement stone. The presence of the cement stone influences the quality of RCA.

Numerous authors studied the influence of the grinded cement stone, attached to the natural aggregates, on the physical properties of RCA (density, water absorbtion) and on the characteristics of the fresh and hardened concrete (workability, respectively mechanical and durability properties) made with RCA [33], [34], [35].

Moreover, until now no practical method of completely separating the natural aggregates from the cement stone was distinguished, therefore the quantity of cement stone from RCA varies [36].

The RCA used in a structural concrete must have the same properties as NA, which leads to a classification based on the following properties:

- Physical;
- Mechanical;
- Chemical;
- Geometrical.

All these properties are defined as values and interpretation, but also as determination methods according to standards specific to each country.

5. EXPERIMENTAL RESARCH ON RCA CONCRETE

The aim of the experimental work presented in this chapter is to develope normal mass concrete used for structural elements, with the natural aggregates replaced in different percent with RCA (50% and 100%), or with different fractions replaced. The maximum grain size used was 16mm (Table 5.1).

Fraction	**F1**	**F2**	**F3**	**F4**	**F5**	**F6**	**F7**
Grain size, [mm]	0-0,25	0,25-0,5	0,5-1	1-2	2-4	4-8	8-16

Table 5.1 Fractions notation

There were performed laboratory determinations involving the physical-mechanical properties on:

- Agreggate:
  - NAT (natural river agreggate);
  - RCA (recycled concrete agreggate).
- Concrete strength classes: C16/20 şi C20/25.

Concrete recipes were divided on 3 groups, depending on the concrete strength class and the use of the superplasticizing additive as is presented:

- **G1**: C16/20 strength class + superplasticizing additive;
- **G2**: C16/20 strength class (without superplasticizing additive);
- **G3**: C20/25 strength class + superplasticizing additive.

For G1 and G3 groups was proposed a slump test S3 fresh concrete class.

All the three groups G1, G2 and G3 have a reference recipe (M_Gx) and 8 other recipes made with RCA.

The most important aspects, followed in this experimental study, are presented below:

1. The influence of replacing natural river aggregate with 50% and 100% RCA, in normal mass concrete, with a C16/20 and C20/25 strength class can be observed for G1 and G3 groups; M, R1 and R8 recipes:

2. The influence of replacing a single fraction of natural river aggregate (NAT) with RCA , in normal mass concrete, with a C16/20 and C20/25 strength class can be observed for G1 and G3 groups; M, R1 and R8 recipes;
3. Characteristics for RCA concrete prepared without superplasticizing additive can be observed for G2 group;
4. The influence of superplasticizing additive on RCA concrete recipes can be observed by comparing G2 and G1 groups, witht and without adding additive;
5. Different properties of normal mass concrete, made with RCA especially for strength class growth, from C16/20 to C20/25.

There were used the following materials:

- Cement: CEM I 42,5R supplied by Holcim România;
- Aggregate :
    - RCA (0-16mm)- obtained from concrete recycling;
    - NAT(0-16mm)- natural river aggregate;
- Superplasticizing additive: SikaPlast 421 (suplied by SIKA) recommended for concrete prepared with low quality aggregate;
- Water: supplied by Timișoara water network.

The additive was proposed by the producer, taking into account that the experimental program suppose replacement of the natural river aggregate with recycled aggregate, with properties different than those of the natural aggregates.

The RCA used for the experimental program, resulted from the demolition of an industrial building, with a reinforced concrete structure, located in the city of Timisoara. The year of construction was around 1980, resulted a 35 years old concrete. In order to have a better control on the results, the used RCA was obtained from a single type of elements, reinforced concrete beams.

In another order of ideas, the thesis proposed cement mortar recipes to be developed, with a part of the cement replaced with reciced concrete finest. The aim of this study is to use the unhydrated grains of cement from the hardened concrete.

6. THE SUSTAINABILITY OF RCA

Sustainability term has many definitions, but the most frequent one is that „sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs".[37].

For the evaluation of buildings sustainability, there are many certificate programs at an international level, wich enclose them in performance levels.

The "Specific Model" takes into account three dimensions: environmental factor, social factor and the economical factor. It starts from the equation wich says that the sustainability index is obtained from those three parameters added, with the ideal result value "1".

$$SI = S_{env} + S_{eco} + S_{soc} \tag{6.1}$$

$$S_{env} = \sum_{i=1}^{n} \alpha i \times \frac{P_i^{Renv}}{P_i^{env}}\ ;\ S_{eco} = \sum_{i=1}^{n} \beta i \times \frac{P_i^{Reco}}{P_i^{eco}}\ \ ;\ \ S_{soc} = \sum_{i=1}^{n} \gamma i \times \frac{P_i^{Rsoc}}{P_i^{soc}} \tag{6.2}$$

Where:

SI- Sustainability Index
S_{env}, S_{eco}, S_{soc}- enviroment, economic and social sustainability index
αi- multiplication factor for enviroment dimension
βi- multiplication factor for economic dimension
γi- multiplication factor for social dimension
$P_i^{env}, P_i^{eco}, P_i^{soc}$ – calculated values for each parameter
$P_i^{Renv}, P_i^{Reco}, P_i^{Rsoc}$ – reference values for each parameter

Starting from 6.1, this has been improved resulting the following equation:

$$SI = \left(0{,}2 \cdot \frac{E^R}{E} + 0{,}2 \cdot \frac{L_S}{L_S^R}\right) + \left(0{,}2 \cdot \frac{C^R}{C} + 0.1 \cdot \frac{M^R}{M}\right) + \left(0{,}05 \cdot \frac{N^R}{N} + 0{,}05 \cdot \frac{W}{W^R} + 0{,}05 \cdot \frac{D^R}{D} + 0{,}15 \cdot \frac{R}{R^R}\right) \tag{6.3}$$

Where:

E- energy [mJ/m^3];
L_s- land saving [%/m^2];
C- cost [euro/m^3];
M- manpower [h/m^3];

W- waste [%/m^3];
D- dust [%/m^3];
N- noise [dB];
R- resistance [N/mm^2]

For the calculation of the environmental, social and economic factors, it has been followed the primary demolition as well as the shredding of the concrete beams, wich insured the material for the experimental program.

7. CONCLUSIONS AND PERSONAL CONTRIBUTIONS

From the comparison of NAT and RCA, resulted that the bulk density it is superior for NAT, for both loose and compact bulk density, suggesting that for RCA the sum between the spaces volume inside the bulk and the porosity of the grains is higher compared to the NAT.

RCA grains have a more angular shape than NAT for the most of the grain sizes, with a higher water absorbtion than the NAT.

The crushing strength (F7 8-16 mm), registers a decrease of 16% of the RCA compared with the NAT aggregate.

The RCA aggregates characteristics are influenced by the characteristics of the concrete from which were obtained, and by the technologies used for producing them.

The replacement of cement with 15%, 30% si 45% of recycled aggregate RCF or natural aggregates NAT (size <0,063 mm and <1 mm), resulted after 28 days in compositions with a reduced compression strength by 14% for a 15% replacement and 49% for a 45% cement replacement. There aren't significant increases in strength in the case of using RCF compared to the recipes where natural sand aggregate (NAT) was used.

The recipes studied showed high values of mechanical strength, both at the age of 7 days and 28 days, similar to conventional mortar; by using the power plant fly ash with RCF was achieved mechanical resistance of 10 N/mm^2 f_t and 70 N/mm^2 for f_c after 28 days.

The research of the carbonation depth in the concrete case achieved by RCA aggregate, both in normal conditions of carbon dioxide (0,03% CO_2), as well as accelerated carbonation conditions (50% CO_2), had led to the following conclusions:

- The value of the carbonation depth $(\bar{x})$ experimentally and theoretically determined is about 7 times higher in case of a concentration of 50% CO_2, which means that by increasing the concentration of CO_2 can simulate carbonated concrete to a longer period of time .
- The use of RCA with the same parameters of composition, without using additional superplasticizer additive, the carbonated depth increases at the same time with replacement of fine fraction. In this case even the compressive strength are lower, between 1 and 18% compared to the control recipe.

- The experimental measurements at a rate of 50% CO_2, in conjunction with the results reported in literature, aproximates a period of exposure to 0,03% CO_2 for 5 years in case of 100% RCA recipes, and 9,5 years in case of those with 50% replaced aggregate.

Personal contributions

Throught the proposed theme and developed during the PhD thesis, where highlited the following important personal contributions:

1. Proposing and implementing a wide experimental program that covers:
   - Demolition of existing buildings;
   - Realization of repair mortars and concrete of C16/20 and C20/25 class through the use of recycled aggregates.

   In the future research there is a plan to use the favorable recipes, to achieve and trying reinforced concrete.
2. Experimental determination through the use of modern investigation techniques of hardened concrete and aggregates properties, such as:
   - aggregates: physical and optical properties (SEM, BET, and microscopy analysis) mechanical properties (crushing resistance), chemical properties (XRD);
   - fresh concrete: mixing condition, consistency class, density
   - hardened concrete: f_c compressive strength and f_t flexural tensile strength, modulus of elasticity, resistance to freeze-thaw cycles, the average carbonation depth in normal conditions, as well as for accelerated carbonation.
3. To implement an extensive uses of recycled aggregates it was calculated the sutainability of experimental recipes by setting the sutainability index.
4. The theoretical contribution of the author refers to:
   - Estabilish an appropriate coefficient on accelerated carbonation of concrete;
   - Propose of own coefficients, used to calculate the sustainability index;
   - Interpreting the results of experimental measurements by comparison with theoretical estimates of literature and author proposals.

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