Circular Economy Strategy in the Construction Sector: The Use of Recycle Aggregates in the Sardinian Island

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Abstract. The recycling of concrete debris to obtain coarse recycled aggregates for structural concrete production represents a model of circular economy in the construction sector. It reduces landfill waste and raw material exploitation. In this applied research, the recycled aggregate, obtained from construction and demolition waste, was used in partial replacement of coarse natural aggregate in structural concrete. The analysis concerns two case studies: production process, and failure mechanism of precast reinforced concrete foundation made with coarse recycled concrete aggregate; method to estimate the demand of recycled aggregates in urban planning in three towns (Calasetta, Carloforte and Portoscuso) in southern Sardinia Island, for new construction, building refurbishment, cycle track, and pedestrian path.

In this context, the circular economy model is the best practice to achieve the sustainable development of the construction sector. The applied research offers an important contribution to the management plan of construction and demolition waste in Sardinia Island.

Keywords: Circular economy · Urban planning · recycled aggregate · Sustainability

1 Introduction

Concrete constructions largely contribute to the exploitation of non-renewable natural resources. For this reason, concrete debris could be recycled to produce recycled concrete aggregates, promoting a circular economy strategy. The use of recycled aggregates represents a valid alternative to natural ones for concrete production, promoting natural resources preservation and reducing landfill disposal.

Maximizing the quantity of recycled materials is an effective approach towards sustainable constructions (Kovler and Roussel 2011; Meyer 2009; Rao et al. 2007, Pepe et al. 2014, Pani et al. 2020). In Italy, following the European Commission guidelines, the Ministry of the Environment and the Protection of the Territory and the Sea has published

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the National Action Plan on Green Public Procurement (PANGPP), DM 11/10/17 2017. It defines, for all public contracts, the Minimum Environmental Criteria (CAM). They are the environmental requirements defined for the various phases of the purchase process aimed at identifying the best design solutions, products, and services from an environmental point of view throughout the entire life cycle. Applied researches show that there is no technical and scientific limit to the use of recycled concrete aggregate, in structural and non-structural concretes. Some general conclusions can be drawn about the use of coarse recycled aggregate in structural concrete (Ajdukiewicz and Kliszczewicz 2002; Etxeberria et al. 2007; Rahal 2007; González-Fonteboa and Martínez-Abella 2008; Pani et al. 2019, Pepe et al. 2014).

Available experimental data concerning concrete made with Recycled Concrete Aggregate (RCA) are variable (Pacheco et al. 2019, Francesconi et al. 2016, Koenders et al. 2014) and some authors (González-Fonteboa and Martínez-Abella 2008; Kou and Poon 2015; Rahal, 2007; Stochino et al. 2017; Tabsh and Abdelfatah 2009, Pani et al. 2020) found that recycled concrete having medium compressive strength can be produced, regardless of the parent concrete quality. Reinforced concrete columns made with RCA have been studied in the last years (see Xu et al. 2017, Xu et al. 2018, Xu et al. 2019) showing the applications of these materials to full scale structural elements.

In this paper, the use of coarse RCA in precast recycled concrete elements has been analyzed. In the precast concrete industry, the coarse recycled aggregate by crushing and screening of processing waste can be obtained, reducing landfilling costs and raw materials.

An important experimental campaign was carried out with a precast company of reinforced concrete elements (beams, plinths, and hollow core slabs). The research focused the attention on the production of prefabricated plinths, made with recycled concrete, in which the coarse aggregates, were obtained from the crushing of processing waste.

Moreover, this paper analyzed a method to estimate the demand for recycled aggregates in urban planning on the southwest coast of Sardinia.

The analysis conducted aims to define a methodological approach to support decision-making processes in the development of strategies to connect coastal areas, concerning the use of recycled aggregates in local planning. Furthermore, a method is presented to quantify the demand for recycled aggregates in compliance with local planning. The proposed method is implemented in three towns (Calasetta, Carloforte, and Portoscuso) in southern Sardinia Island.

2 Precast Plinth Using Coarse Recycled Concrete Aggregates

Precast reinforced concrete plinths made with natural fine aggregates and coarse recycled aggregates in partial replacement of natural ones were produced and tested. Two recycled concrete mixes with 30% and 50% substitution percentage, by weight, of coarse recycled aggregates were used.

For comparison, a reinforced ordinary concrete plinth, made with natural aggregates, was produced.

The test focus was to determine the mechanism and force of the collapse in precast reinforced recycled concrete plinths. The force on the structure is applied on the top of a precast reinforced concrete column connected to the plinth (Fig. 1). The connection between plinth and column were realized with ordinary concrete (Fig. 2).



Fig. 1. Plinth column element

The precast elements were made by prefabrication company Vibrocemento (Fig. 3). Tests were carried out in the Laboratory of Material Testing, Department of Civil Engineering Environmental and Architecture of the University of Cagliari.



Fig. 2. Connections between precast plinth-column



Fig. 3. Casting of the reinforced concrete plinth

2.1 Materials

Three different concrete mixtures were made: RC0% made with fine and coarse natural aggregates, RC30% made with fine natural aggregates and natural and recycled coarse aggregates (70% by weight of natural aggregates and 30% by weight of recycled aggregates), RC50% with fine natural aggregates and natural and recycled coarse aggregates (50% by weight of natural aggregates and 50% by weight of recycled aggregates). Precast columns were made with RC0%. The concrete mixes are shown in Table 1.

Table 1. Mix design of concrete (1 m^3)

Concrete		RC0%	RC30%	RC50%
Cement CEM 525 RI (kg)		350	356	352
Water (kg)		160	186	215
Fine natural aggregates (kg)	0–2 mm	120	130	120
	0–6 mm	600	595	600
Coarse natural aggregates (kg)	4–10 mm	520	365	255
	8–16 mm	600	415	300
Coarse recycled aggregates (kg)	4–16 mm	0	340	560

The results of natural and recycled aggregate characterization are reported in Table 2, in compliance with the UNI EN 933–1 and UNI EN 12620 standards. Figure 4 shows the aggregate particle size distribution used in the concrete mixes RC0%, RC30% and RC50%.

For each concrete mix, 6 cubic specimens (150 mm) and 1 prismatic specimen (side 160 mm, height 330 mm) were made. In Table 3 the results of compressive strength, tensile strength, and elastic modulus are reported in appliance with UNI EN 12390–3: UNI EN 12390-3 2019, UNI EN 12390-6: UNI EN 12390-6 2010, and UNI EN 12390–13: UNI EN 12390-13 2013. In plinths and columns reinforcing steel bars B450C were used.

Table 2. Parameters to characterize recycled and natural aggregates

Aggregate particle size (mm)	Water absorption (%)	Density (kg/m^3)	Fine content
0–2 (natural aggregate)	0.80	2562	f3
0–6 (natural aggregate)	1.31	2600	f3
4–10 (natural aggregate)	1.54	2673	f1.5
8–16 (natural aggregate)	1.06	2673	f1.5
4–16 (recycled aggregate)	4.48	2498	f4

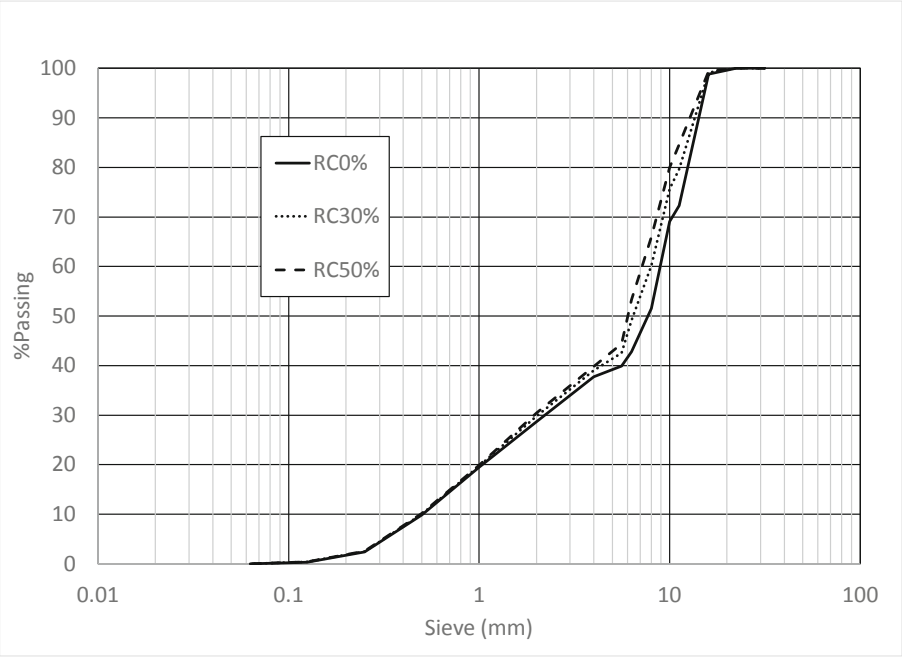

Fig. 4. Aggregate particle size distribution of concrete mixes RC0%, RC30% and RC50%

2.2 Testing Procedure

The test on each specimen was carried out by applying a horizontal load to the top of the reinforced concrete column connected to the plinth (Fig. 5). The horizontal load increases until the precast plinth-column system collapses, with a constant strain rate loading of 0.10 mm/sec.

The loading system can apply a horizontal force up to 500 kN, with maximum displacement at the top of the column up to 200 mm.

In all three specimens, a single crack at the base of the plinth was formed, when the collapse in the plinth-column system occurred, as shown in Fig. 6. In Table 4 the collapse force of the column and plinth systems is shown.

Table 3. Mechanical properties of concrete

Concrete mix design	$R_{c,28d}$ (MPa)	$R_{c,28d\ average}$ (MPa)	f_{ct}, (MPa)	$f_{ct,average}$ (MPa)	E_c (MPa)
RC0%	37.5	37.87	3.55	3.44	28640
	38.2		3.41		
	37.9		3.35		
RC30%	37.1	38.10	3.53	3.48	28814
	39.1		3.49		
	38.1		3.43		
RC50%	37.8	34.97	3.30	3.13	24678
	33.7		2.96		
	33.4		3.13		



Fig. 5. Testing setup

The results show that the presence of coarse recycled aggregate in partial replacement to natural ones does not cause a reduction in the mechanical performance of the prefabricated plinth.




Fig. 6. Crack at the base of the plinths

Table 4. Collapse force of plinth-column systems

Specimen	Collapse force (kN)
Plinth RC0%-Column RC0%	98
Plinth RC30%-Column RC0%	102
Plinth RC50%-Column RC0%	100

3 Recycled Aggregates and Urban Planning

This case study concerns the use of recycled aggregates in the development and implementation of the coastal plans and municipal urban planning of three towns in southern Sardinia: Carloforte, Calasetta, Portoscuso. Nowadays, the municipal urban plan (PUC), the coastal plan (PUL), and the management plan of Nature 2000 Network (PdG) focus the attention on different aspects concerning the territory and the protection of the natural environment. An integrated approach to these planning strategies is essential to environmental, social, and economic sustainability. The analysis conducted aims to define a methodological approach to support decision-making processes in the development strategies on the use of recycled aggregates in coastal areas local planning. In this context, the strategic environmental assessment (SEA) represents an important methodological approach.

The methodological approach concerns two phases. The first phase regards the definition of a logical framework (LF), and analyses the relationships between the various coastal area plans. For each municipality, the following documents were considered: the Municipal Urban Plan, the coastal use plan, and the management plan of the Natura 2000 Network.

Based on future planned developments, in the second phase, the evaluation of recycled aggregates demand was estimated from the analysis of the LF, several actions to encourage the use of recycled aggregates also in coastal areas can be adopted: the expansion of the territory for new tourist complexes (Carloforte), the construction of pedestrian and cycle paths (Calasetta and Portoscuso) (Table 5).

Table 6 shows the applied methodology in this study. The Ministerial Decree of 17 January 2018 (Ministry of Infrastructure and Transport) defines the maximum percentage of recycled aggregates: 30% for concrete C30/37 and up to 80% for concrete with lower resistance. For the construction of road foundations, it is allowed to use 100% of RA.

Table 5. Elements underlying the assessment of the quantity of recycled aggregates in relation to new constructions and refurbishment

Elements for estimating the amount of AR for new buildings	Elements for estimating the quantities of AR for refurbishment
Each building reaches the maximum height allowed by the PUC Technical Implementation Standards	
The quantities of demolition waste are considered to be equal to the quantities of construction material (Morabito n.d.)	The quantity of concrete for maintenance work is considered equal to 50–100 kg/m^2 (Morabito, n.d.). The maintenance area is equal to 12% of the total existing surface of the buildings in zone A, B and C (Altamura, 2012)
In structural concrete, the percentage of recycled concrete aggregates (Compression resistance class C30 / 37) is a maximum of 30% (Technical Construction Standards D.M. 17.01.2018)	
Estimated quantity of AR: 0.7 m^3 for every m^3 of concrete	

The towns studied here, Calasetta, Carloforte, and Portoscuso, are three medium-sized towns located on the south-western coast of Sardinia (Fig. 7). All municipalities are characterized by the presence of one or more Natura 2000 sites.

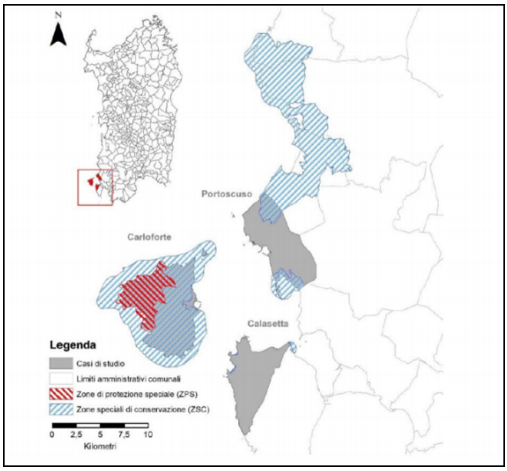

Fig. 7. Study area Source: elaborations on data available on the site of the Geoportal of the Sardinia Region

The planned actions in the three towns, according to the municipal plan, are as follows: the building of new tourist complexes in Carloforte; the construction of cycle tracks and pedestrian paths to connect the town center with the coastal areas in Calasetta; the construction of cycle tracks and pedestrian paths in Portoscuso. The analysis of planning systems indicates that recycled aggregates could use in different contexts, including coastal areas. The estimated quantities of recycled aggregates required for new constructions, refurbishments, cycle and pedestrian paths were 2, 0.1, and 0.5 t/m^2. In Table 6 are reported the estimated quantities of RA and C&DW that could be reused for new constructions, refurbishment, and road layers. According to the Ministerial Decree of 17 January 2018 NTC18, up to 30% by mass of replacement ratio of NA by RA can be used for concrete C30/37 strength class, this value can reach 80% when used for less resistant concrete, this value can reach 100%

Table 6. Estimated quantities of RA and recyclable C&DW

Town	Calasetta		Carloforte		Portoscuso	
RA	30%	80%	30%	80%	30%	80%
RA for new building (t)	8673	23127	15336	40897	18753	50008
RA for refurbishment (t)	152	404	342	911	486	1296
Town	Calasetta		Carloforte		Portoscuso	
RA	100%		100%		100%	
RA for road layers (t)	34198		167872		66989	
Town	Calasetta		Carloforte		Portoscuso	
RA total (t)	43022	57729	183550	209675	86228	118794
C&DW of concrete (t)	86044	115458	367100	419359	172456	236587

In this context, the evaluation suggested that up to 800000 t of concrete C&DW could be recycled.

4 Conclusions

The potential applications of including RCA in the production process of precast reinforced concrete elements is a good practice of circular economy, with several environmental and economic positive aspects. The tests conducted on the precast plinth including RCA, have shown that the presence of coarse recycled aggregate in partial replacement to natural ones does not cause a reduction in the mechanical performance of the prefabricated plinth.

The use of RCA will limit the exploitation of non-renewable natural resources, decrease the concrete debris disposed in landfills, by reusing them in the mix design. It will also reduce production and landfilling costs, due to the lower price of recycled aggregates if compared to natural ones and less amount of debris disposed.

The analysis conducted on the three towns, on the southwest coast of Sardinia Island, to explore the possibility of using RA in new construction projects (buildings and road layers for cycle and pedestrian paths) indicated that there are no impediments in using RA in coastal areas analyzing urban planning systems.

The final objective of this work is to strengthen the concept of sustainability in civil constructions which necessarily intends to provide an important contribution to the construction and demolition waste management plan for the Sardinia Island.

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References

1. Italian Minister for the environment and protection of land and sea: DM 11/10/17 - Minimum environmental criteria for design services and works for the new construction, renovation and maintenance of public buildings (2017)
2. Kovler, K., Roussel, N.: Properties of fresh and hardened concrete. Cem. Concr. Res. **41**, 775–792 (2011)
3. Meyer, C.: The greening of the concrete industry. Cement Concr. Compos. **31**, 601–605 (2009)
4. Rao, A., Jha, K.N., Misra, S.: Use of aggregates from recycled construction and demolition waste in concrete. Resour. Conserv. Recycl. **50**, 71–81 (2007)
5. Pacheco, J., de Brito, J., Chastre, C., Evangelista, L.: Experimental investigation on the variability of the main mechanical properties of concrete produced with coarse recycled concrete aggregates. Constr. Build. Mater. **201**, 110–120 (2019)
6. Francesconi, L., Pani, L., Stochino, F.: Punching shear strength of reinforced recycled concrete slabs. Constr. Build. Mater. **127**, 248–263 (2016)
7. Koenders, E.A., Pepe, M., Martinelli, E.: Compressive strength and hydration processes of concrete with recycled aggregates. Cem. Concr. Res. **56**, 203–212 (2014)
8. Kou, S.C., Poon, C.S.: Effect of the quality of parent concrete on the properties of high performance recycled aggregate concrete. Constr. Build. Mater. **77**, 501–508 (2015)
9. Ajdukiewicz, A., Kliszczewicz, A.: Influence of recycled aggregates on mechanical properties of HS/HPC. Cement Concr. Compos. **24**, 269–279 (2002)
10. Etxeberria, M., Marı, A.R., Vazquez, E.: Recycled aggregate concrete as structural material. Mater. Struct. **40**, 529–541 (2007)
11. Rahal, K.N.: Mechanical properties of concrete with recycled coarse aggregate. Build. Environ. **42**(1), 407–415 (2007)
12. González-Fonteboa, B., Martínez-Abella, F.: Concretes with aggregates from demolition waste and silica fume. Materials and mechanical properties. Build. Environ. **43**(4), 429–437 (2008)
13. Pani, L., Francesconi, L., Rombi, J., Naitza, S., Balletto, G., Mei, G.: Recycled Aggregates, mechanical properties and environmental sustainability. Planning Nat. Ecosyst. Serv. INPUT Acad. **2019**, 431–442 (2019)

14. Pani, L., Francesconi, L., Rombi, J., Mistretta, F., Sassu, M., Stochino, F.: Effect of parent concrete on the performance of recycled aggregate concrete. Sustainability **12**(22), 1–17 (2020)
15. Pepe, M., Toledo Filho, R.D., Koenders, E.A., Martinelli, E.: Alternative processing procedures for recycled aggregates in structural concrete. Constr. Build. Mater. **69**, 124–132 (2014)
16. Stochino, F., Pani, L., Francesconi, L., Mistretta, F.: Cracking of reinforced recycled concrete slabs. Int. J. Struct. Glass Adv. Mater. Res. **1**(1), 3–9 (2017)
17. Tabsh, S.W., Abdelfatah, A.S.: Influence of recycled concrete aggregates on strength properties of concrete. Constr. Build. Mater. **23**, 1163–1167 (2009)
18. UNI EN 12620: ggregates for concrete (2008)
19. UNI 933–1: Tests for geometrical properties of aggregates. Part 1: Determination of particle size distribution - Sieving method (2012)
20. Italian Minister Ministry of Infrastructure and Transport: DM 17/01/18 – Technical standards for construction (2018)
21. UNI EN 12390–3: Testing hardened concrete. Part 3: Compressive strength of test specimens (2019)
22. UNI EN 12390–6: Tests on hardened concrete - Part 6: Splitting tensile strength of the specimens (2010)
23. UNI EN 12390–13: Test on hardened concrete - Part 13: Determination of the secant modulus of elasticity in compression (2013)
24. Xu, J.J., Chen, Z.P., Zhao, X.Y., Demartino, C., Ozbakkaloglu, T., Xue, J.Y.: Seismic performance of circular recycled aggregate concrete-filled steel tubular columns: FEM modelling and sensitivity analysis. Thin Walled Struct. **141**, 509–525 (2019)
25. Xu, J.J., Chen, Z.P., Ozbakkaloglu, T., Zhao, X.-Y., Demartino, C.: A critical assessment of the compressive behavior of reinforced recycled aggregate concrete columns. Eng. Struct. **161**, 161–175 (2018)
26. Xu, J.J., Chen, Z.P., Xiao, Y., Demartino, C., Wang, J.H.: Recycled aggregate concrete in FRP-confined columns: a review of experimental results. Compos. Struct. **174**, 277–291 (2017)
27. Pani, L., Rombi, J., Francesconi, L., Mereu, A.: Circular economy model of recycled aggregates for the construction sector of Sardinia Islan. Environ. Eng. Manag. J. **19**(10), 1847–1855 (2020)