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THE CITY CHALLENGES AND EXTERNAL AGENTS. METHODS, TOOLS AND BEST PRACTICES

Vol.14 n.1 April 2021

print ISSN 1970-9889 e-ISSN 1970-9870
University of Naples Federico II

TeMA

Journal of
Land Use, Mobility and Environment

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1 (2021)

Published by
Laboratory of Land Use Mobility and Environment
DICEA - Department of Civil, Architectural and Environmental Engineering
University of Naples "Federico II"

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Editor-in-chief: Rocco Papa
print ISSN 1970-9889 | on line ISSN 1970-9870
Licence: Cancelleria del Tribunale di Napoli, n° 6 of 29/01/2008

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Land Use, Mobility and Environment

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1 (2021)

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TeMA
Journal of
Land Use, Mobility and Environment

TeMA 1 (2021) 51-68
print ISSN 1970-9889, e-ISSN 1970-9870
DOI: 10.6092/1970-9870/7354
Received 13th November 2020, Accepted 29th March 2021, Available online 30th April 2021

Recycled aggregates in constructions. A case of circular economy in Sardinia (Italy)

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Abstract

The paper is the result of an ongoing research, considering the use of raw and recycled materials in the construction sector. In particular, the idea is considering such use within a Circular Economy framework, analysing its potentials in the case of the closed market of Sardinia Island (Italy), identifying potential clusters and their 'optimal' shape. In the paper, we highlight a theoretical framework for circular economy, adapting a classical model of industrial location to the construction sector. We build a georeferenced database of activities related to the extraction, processing and disposal of materials related to construction, as a result of the MEISAR Project - https://meisar.org/en/. Such a result is presented in a tool named MEISAR_Map; we then propose a method, based on spatial analytical techniques, namely point pattern analysis, for delimiting spatial clusters. The closed market of Sardinia is analyzed and, in particular, the case study of the new football stadium in Cagliari, which involves the demolition of the existing stadium and the use of "secondary" raw materials for the construction of the new Cagliari stadium.

Keywords
MEISAR; Circular economy; Green economy; Recycled aggregates; Sustainable planning.

How to cite item in APA format
Balletto, G., Borruso, B., Mei, G., & Milesi, A. (2021). Recycled aggregates in constructions. A case of circular economy in Sardinia (Italy). *Tema. Journal of Land Use, Mobility and Environment*, *14* (1), 51-68. http://dx.doi.org/10.6092/1970-9870/7354

1. Introduction

The circular economy has become a new comprehensive and radical approach compared to the classic production model, opposite to that based on the over-exploitation of resources, instead focused on self-regeneration, in which the materials of biological origin are destined to be reintegrated into the biosphere, and the integrated ones must be used to be regenerating the biosphere (Ellen McArthur Foundation, 2019). The circular approach means re-evaluating and modifying the production cycles (Irache, 2020).

In particular, the circular economy is in contrast to the linear, traditional and classical economy, that does not consider neither the origin of resources nor the destination of waste (Migliore et al., 2020; see also Pirlone & Candia, 2016).

The principles of the circular economy also find application in the construction sector (not bio-based) characterized by high consumption of natural raw materials to a high production of waste (the so-called CDW - Construction and Demolition Waste; Hossain et al., 2020).

Furthermore, these principles are also applied to two main territorial scales: 1) The concept of urban mining sees the city as a mine of materials that can be reused; 2) the products and materials of individual buildings can be recycled at the end of their life cycle.

There are currently various strategies for the application of principles of the circular economy in construction, synthesizable: End-of-life Approach (selective demolition end of life management of demolition waste) and design approach (design for disassembling in the design of the new). In fact, the construction industry - globally - is responsible for 40% of CO_2 emissions and produces a third of all waste, ranking among the most polluting industrial sectors in the world. In Europe, approximately 30% of the 2.5 billion tons of waste produced is attributable to the construction sector (Migliore et al., 2020; Ruiz et al., 2020). In this framework, the circular economy of construction through a renewed balance between the 3Rs - Reuse, Recycling and Recovery - aims to promote the sustainability of the construction and demolition processes of buildings[1].

Through the application of the principles of circular economy, it is therefore possible to approach in a new way also for the relaunch of the construction sector in accordance with Agenda 2030, and the recent National Recovery and Resilience Plan - Next Generation Italy).

In this sense, the cities represent the privileged place to implement new circular economy models based on the enhancement of materials and goods and on the extension of their life cycle. In particular, approximately 60 million tons of construction and demolition waste are produced in Italy every year, approximately 43% of the total waste (Ispra, 2019). These are easily recoverable waste due to their substantially homogeneous nature, and not very dangerous for the environment: since they are inert materials, they are also by definition those with the least contamination problems.

Although the private construction market has been in crisis for at least a decade, the public works market instead shows a gradual and constant growth (CRESME, 2020).

The construction and demolition activities are therefore mainly attributable to initiatives of the Public Administration, such as Municipalities, Metropolitan Cities and the Regions. The potential markets, both for the natural aggregates (NA) and the recycled aggregates (RA) are closely linked to the actions of the Municipalities, the metropolitan city and the Region. In this framework, an important test will be given by the demolition of the Sant'Elia Stadium in Cagliari (Italy), intended to make room for the new stadium defined by the winning concept of the ideas competition (2019).

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[1] *Reuse* of waste means any operation by which products or components that are not waste are used again for the same purpose for which they were conceived; *Recycling* of waste is defined as any recovery operation by which waste materials are reprocessed into products, materials or substances whether for the original or other purposes; *Recovery* of waste means any operation the principal result of which is waste serving a useful purpose by replacing other materials which would otherwise have been used to fulfil a particular function, or waste being prepared to fulfil that function, in the plant or in the wider economy. From: Eurostat Glossary of Waste https://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Waste

On the occasion of the competition of ideas, the collaboration with DICAAR (Department of Environmental Civil Engineering and Architecture, University of Cagliari, Italy) was born for the times of sustainable territorial planning and among these also the management of CDWs, converged in the MEISAR Project research.
With the MEISAR project, the concrete of the old stadium was therefore characterized to evaluate the possibility of recovery after selective demolition. In particular, the characterization of the concrete of the Sant'Elia Stadium - beams and foundation blocks - with sampling - in accordance with the law - to evaluate the mechanical performance of the concrete, highlighted the good performance quality, so much so that it could be used as recycled aggregates (RA) for the production of structural cement (Pani et al., 2019).
The demolition will produce a high quantity of materials that, after being treated in the suitable plants, can be put back on the market as secondary raw materials (RA).
Through the MEISAR project, and in particular with the MEISAR Map, the geospatial representation of the CDW production sector was developed through a Weber theoretical model, described in paragraph 3.2.
With this study, we intend to investigate management and environmental issues to extend the knowledge theory in the construction sector. To this end, we intend to stimulate the "latent and emerging entrepreneurship" model (Caiazza et al., 2020) in an insular context such as Sardinia through the MEISAR Map. In particular, the aim of this paper is to identify the clusters of aggregates in geospatial terms to encourage a circular economy in the construction sector.
The rest of the paper is organized as follows. In paragraph 2, a literature review is performed, focusing on circular economy. In paragraph 3, Materials and Methods are presented and particularly: in paragraph 3.1 we focus on the materials, as the geographical database and the MEISAR_Map, containing an update of CDW recycling plants, CDW landfill, concrete production plants and quarries. In paragraph 3.2, the Weber Theory and its modifications are presented. Paragraph 3.3 tackles Point Pattern analysis and in paragraph 3.4, the methodology for the identification of the clusters is presented. In paragraph 4 we comment on the results obtained from the application of the methodology, in particular we identify the regional circular clusters of Sardinia and of the circular cluster for the construction of the new stadium in Cagliari Stadium. Paragraph 5 hosts Discussions and Conclusions.

2. Literature review

The results and perspectives of the report "Resource efficiency and the circular economy in Europe (EEA Report n. 26/2019) and Assessing air quality through citizen science" (EEA Report n. 19/2019) highlight how the transition to the circular economy is the only way to the reduction of the anthropogenic impact on ecosystems (Angrisano et al., 2019; Pilogallo et al., 2019; Shirgir et al., 2019; Bianconi et al., 2018). The development and increase of innovative initiatives and investments in the construction and demolition waste recycling infrastructures of the (European Commission, 2018) highlights the convergence of economic objectives with environmental ones. Finally, the detailed assessment of EU waste management plans (Deloitte, 2017) highlights how reuse is the prevailing solution in all national and regional waste management plans confirming that Construction and Demolition Waste - CDW - reuse policies are shared. In this sense, one of the pillars of the circular economy - the construction sector - is the recovery of materials, obtained through the replacement of natural raw materials with secondary raw materials (Eberhardt et al., 2020). The circular economy of building activity fits into this synthetic framework, with the recovery of materials, obtained through the replacement of natural raw materials with secondary raw materials (Eberhardt et al., 2020).
However, waste deriving from the building activity, due to their heterogeneity and in the absence of a prior selective demolition and appropriate management actions, is little reused, despite the objectives of the Community policies aiming, by 2020 to reach the threshold of 70% reuse of these products (Legambiente, 2015). However, it should be noted that the use of RA is influenced by the geographical context (Balletto et al., 2015; Balletto, 2017).

In particular, Sardinia is an example of a closed market for natural inert materials and recycled inert materials (Delvoie et al., 2019).
An interchange of such materials is in fact impossible - or at least quite difficult - given the difficulties in transport of such bulky materials from the island to the mainland and therefore moving materials to other Italian regions, as well as of sending waste from demolitions towards these same destinations. Building constructions and demolition need proximal locations of prime - and secondary - raw materials as well as for waste landfill (de Larrard & Colina, 2019; Balletto et al., 2018). Extraction of prime materials (resources), processing, waste disposal, processing of recycled (second) materials, re-inserting them into the production process must happen within the regional territory (Balletto et al., 2019). Another restriction regarding construction is given by the fact that concrete batching products must reach their destination from the processing plants within a range of 30 km (Renner, 1947).
Over such a distance the products are degraded and their quality is reduced (Pasini, 2013). In this geographical context, the MEISAR Project was developed within the University of Cagliari to support collaborative R&D activities for the development of new sustainable technologies, new products and Services. The MEISAR project aims to contribute to knowledge in the preparation and use of concrete with Recycled Aggregates (RA) deriving from the treatment of CDW and the related verification of economic and environmental sustainability, through experimental research carried out in collaboration with companies operating in the construction sector. It involves, in fact, a cluster of companies comprising both the recycling plants for construction and demolition waste and prefabricated concrete companies. In this sense, the MEISAR project aims to give a high added value to the Recycled Aggregates (RA) allowing their use as valuable raw materials for the concrete, including structural ones. In other words, the RAs are configured as a real alternative to the natural aggregates (NA) deriving from the extractive industry of natural materials (Pani et al., 2010a; Pani et al., 2010b; Pani et al., 2013a; Pani et al., 2013b). In fact, at present, the RAs have had a marginal reuse in particular referred to fillings or road substrates, while they are not used as an alternative to the NA for the production of concrete.
In fact, through the MEISAR project the economic and environmental applicability of the RAs was assessed, with reference to the case study of the Cagliari stadium, which represents a very interesting case on the possibility of creating a circular economy regime on the construction market in Sardinia.

3. Materials and Methods

The research is developed within a theoretical framework of circular economy of the RA, reviewing a classic model of industrial location adapted to the current situation. In particular, the authors adapted Weber's Theory (Weber, 1909) to a circular economy approach applied to concrete production (Balletto et al., 2019), to highlight possible clusters on Sardinia Island. This work involved several steps. The first, important step required the realization of a suitable, georeferenced database, useful for locating plants related to the construction materials' production chain in space, in order to have the spatial distribution of the potential markets. This work resulted in a mix of detailed desk research, integrated by direct contact and data taken from a set of selected companies participating in the MEISAR Project. A second step required the definition of a theoretical model, capable of putting the second raw materials in construction within a geographical location framework. This implied revisiting the traditional Weber's theory of industrial location within an updated situation, in which materials and waste become tightly integrated and interconnected, thus creating a dynamic situation in which places of raw material extraction, processing, waste management and re-processing often coincide.
After considering the original data (MEISAR_Map) and the theoretical framework (modified Weber's theory) a further, third step implied the identification of the clusters in the, nearly ideal from the theoretical and practical points of view, case of Sardinia - that, being an isolated context, results particularly interesting in examining a 'bulky' market as that of constructions. This step involved performing a point pattern analysis on the spatial distribution of plants in the territory, considering the areas with the higher concentration and therefore

providing hints for identifying potential 'circular economy markets' in the Island. A final, fourth step represents a planning proposal for the identification of the markets in the island.

3.1 Materials. The geographical database and the MEISAR_Map

The data collected were organized into a geographical database, in order to make them available for further elaborations. In particular, a dataset was created with different sources summarized for geocoding points were used as starting points then integrated and corrected using ad hoc refinements.

The research activity required both fieldwork and desk activity to obtain an original database. In particular, the recycling plants involved in the MEISAR project were asked to fill in a form containing their parameters and correctly geocoded. The different datasets then presented as layers required also different kinds of analysis from different sources. The landfills were derived from the 'Sardegna Ambiente' website, the Autonomous Region of Sardinia website dedicated to environmental issues. Data were updated and organized in forms, containing coordinate pairs in the Italian Gauss Boaga Rome 40 reference system.

The work carried out was then organized and shared in a project called "MEISAR_Map", based on a Google My Maps platform. In this sense, MEISAR_Map constitutes the geographical tool for the collection, archiving and visualization of the territorial data of the MEISAR project (Balletto et al., 2019).

The MEISAR_Map does not appear as a proper GIS - Geographical Information System, however the preparatory work implied a deep and intense work on building, organizing and elaborating geographical data from multiple sources, realized by means of the QGIS platform, an open-source cross-platform desktop geographic information system application that supports viewing, editing, and analysis of geospatial data.

With reference to the data realized and loaded onto the MEISAR_Map, we georeferenced the locations of the companies belonging to the MEISAR cluster, as well as all the players at regional level involved in the different processes of production, use and disposal of natural and recycled aggregates.

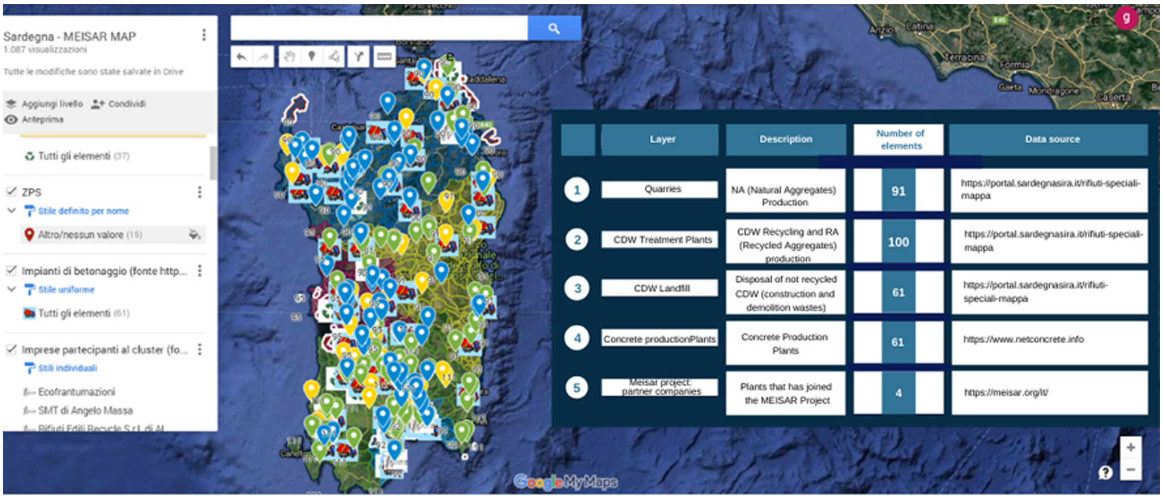


Fig.1 The MEISAR_MAP and a sample of the data realized. See http://bit.ly/MEISAR_MAP

In particular, the data loaded onto the MEISAR_Map include quarries, CDW treatment and CDW landfill, concrete production plants and partner companies of MEISAR Project (Fig.1). The MEISAR_Map is a support for territorial and geographic analysis useful for defining strengths and weaknesses on the management and reuse of CDW to stimulate policies and actions aimed at improving the sector of building.

3.2 Weber Theory in a circular Economy Framework

The classical model

Dealing with an opportunity of reinserting materials coming from construction and demolition waste, as RA, we realized it was important to insert this into a theoretical model, observing similarities with the standard

Weber formulation (1909). Weber argues that the location of industrial plants is strongly linked to the distance (between the source of production materials and the end market) and the production function of the industry. According to Weber, the optimal location of production plants depends on transport costs related to distance to and from places of origin of materials and energy, other than to and from the final market (s). The model was used particularly to explain the industrial location in the historical context of the Ruhr basin in the years of the Industrial Revolution in Germany. It however entered into a linear economic scheme, typical of the neoclassical theory: extraction of resources -> processing / production -> distribution into the final market. Within such a scheme, space entered as the origin of resources and destination for waste, without focusing on their impact. We hereby considered the possibilities for such a model of incorporating the basics of circular economy, particularly in terms of the basic change in the concept of resources. While Weber differentiated places of origins of materials, production plants and markets, with the possibility of production plants to be put in close proximity to materials extraction sites or markets, the consideration of a circular economy framework becomes interesting as the same production sites and markets become potential recycled materials sites.

In the basic Weber model, as in the 'Theory of the Location of Industries' (1929), some assumptions are made, among them, the fixed location of all input suppliers and markets, and that the manufacturing industry would choose the best location capable of minimizing the total sum of incoming and outgoing transport costs. In its most simplified formulation, the industry uses a single input localized in a given point of a homogeneous plain, and sells its output in a single market localized on the same plain. The technology presents constant returns of scale and does not allow input substitution.

Weber considers localized materials – having a fixed location in space – that can be divided in 'pure' – completely entering into the final product – and 'gross' – losing weight, and therefore creating waste, and entering only partially into the final product. Other materials are defined as ubiquitous – or non-localized – that are equally distributed and accessible in space.

Transport costs can be organized in assembly costs – transport costs of raw materials from the place of origin to the production site – and distribution costs – transport costs of products to the market. Transport costs are a constant multiplied by the ton-km - no terminal costs are present; ton-km costs are the same for inputs and outputs. The firm is 'price taker', holding a perfect knowledge of all the information necessary for accurately computing transport costs.

The target is the location bringing to minimizing the sum of the total transport costs. This happens, in the simplified Weber model, with only two points – materials and market – by minimizing the following formula:

$$T = t * w_r * d(R) + t * w_m * d(M)$$

where:

T = Total Transport Cost (in Ton-Km)

w_r = weight per unit input

t = transport cost in € per ton-km

w_m = weight per unit output

$d(R)$ = Distance RF (resource site – production site)

$d(M)$ = Distance FM (production site – market site)

The production plant F will be located in a point among the resource site R and the market site M.

Such location will depend on the weight of raw materials with respect to the final product. Weber define a Material Index MI such that:

MI = weight of localized materials / weight of final product

Pure Materials: MI = 1

Gross Materials: MI > 1

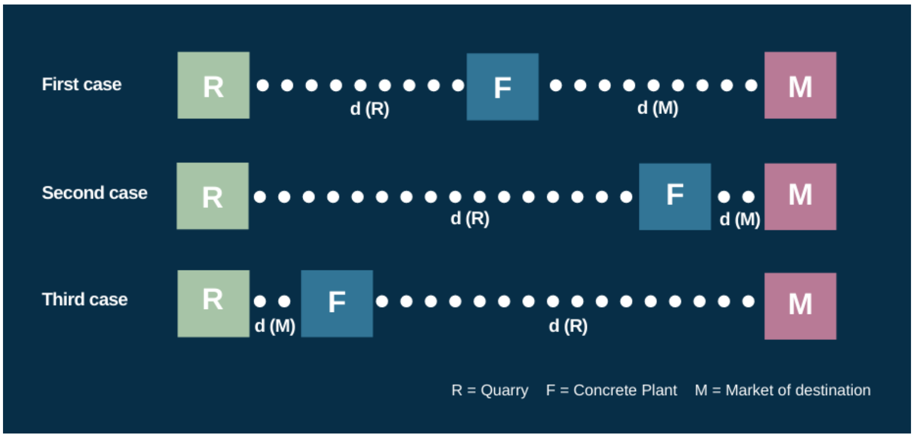


Fig.2 Location à la Weber in the simplified model, Source: Weber (1929). Elaboration by Balletto, Borruso and Mei (2019)

In the case in which materials are pure and are used completely in the final product, no waste will be generated, and therefore the location will happen in an intermediate point between R and M (1st case, Fig.2).
In the case of gross materials (MI>1), location will happen in proximity of the resource site R, to minimize waste transport cost (third case, Fig.2).
An extreme case will be that of the location in proximity of the market M (2nd case, Fig.2) in the case in which the final product is realized mainly by ubiquitous materials in proximity of the market itself (i.e., adding water, considered ubiquitous, in a soft-drink plant).

Weber Model in a circular framework

The Weber Model in a circular economy framework foresees a change of paradigm, as the classical sites of Resource extraction (R), Market (M) and production (F) now are flanked by the potential presence of a further site of Second, recycled resources extraction/creation (R2).
In the case of construction materials, R indicates the generic site(s) of extraction of resources, as quarries, source of AN as 'first' materials. M is the market – in one of the simulations hereby presented, the Cagliari Calcio Stadium. F is the site(s) of concrete production (batching plants).
Four scenarios are possible in the modified Weber model.
- Scenario 1 ('classic'). Production is localized in proximity to quarries, where extraction of natural aggregates take place. Batching plant is localized in proximity of resources, recycling of construction and demolition waste is not foreseen.
- Scenario 2, market place M is considered also as a second site of origin of materials (R2), together with quarries (R1). Location of batching plant F remains in proximity of prime materials but R2 becomes important for extracting second materials. In such cases, however, as these need processing, a transport of second prime materials from the place of extraction to the processing site, still located in R1, and then to the market M can be hypothesized.
- Scenarios 2 and 3 are extreme cases as based on hypotheses foresee the dominance of prime materials (NA) in the first case, and second prime materials (RA) in the second case.
- Scenario 4 (and others, future ones, hereby not presented) identifies a case à la Weber, where the batching plant could be located in a site F in an intermediate position where the cost function of prime materials (first and second: NA and RA) is minimized, not necessarily, therefore, foreseeing a location of patching plants in proximity of resource sites.

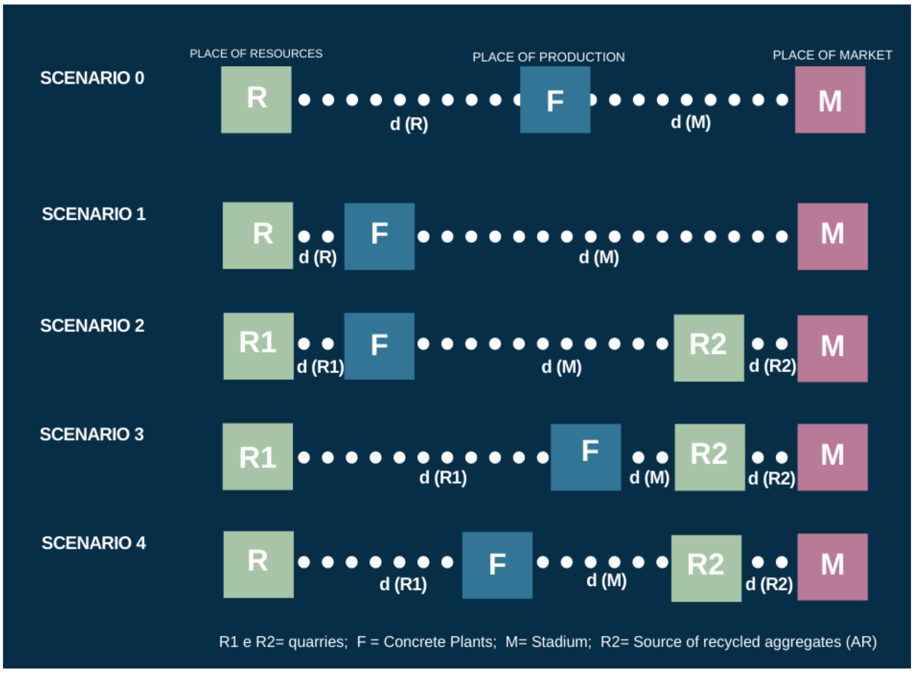


Fig.3 Scenarios of the modified circular Weber Model, Source: Weber (1929). Elaboration by Balletto, Borruso and Mei (2019)

3.3 Point Pattern Analysis. Density estimation

From a spatial point of view, the different locations related to the construction sector can be defined as a point pattern, as the different activities considered can be simplified as points in space, simplifying them according to their spatial coordinates.

Therefore, a point pattern analysis becomes important for understanding the spatial distribution of the phenomenon and provides some hints concerning the possible clustering of the different elements belonging to the distribution pattern. As observed, above, the starting point for the analysis has been the geographical database represented in the MEISAR Map.

The different activities (i.e., quarries, batching plants, waste disposal and treatment plants, etc.) were considered as 'events' in space considering their geographical position (Battino et al., 2012; Thurstain-Goodwin & Unwin, 2000; Borruso, 2006; 2008; Borruso & Porceddu, 2009; Danese, et al., 2009; Murgante & Danese, 2011; Gatrell, 1994; Levine, 2004).

The logic behind the function, is that of a general formula where a three-dimensional moving window is placed over every point - or some form of discretization of a point, that is a grid cell in a spatial tessellation of the region - of the study region and and samples all the events of the point pattern, assigning weights depending on the distance function and using weights stored in the point event database (Gatrell, 1994).

$$\lambda \ (s) = \sum_{i=1}^{n} \ \frac{1}{\tau^2} k\left(\frac{s-s_i}{\tau}\right) \qquad (1)$$

where $\lambda \ (s)$ is the density estimation of the point pattern measured at location *s*, while s_i represents the observed event. *k( )* is the kernel weighting function and the parameter τ is the radius of research of the function, or bandwidth, to be centered in locations, and searching for events is to be computed into the density function (Levine, 2004).

In a GIS environment, the density function is expressed by means of a grid of cells, whose values represent a probability or density function, with a smooth variation among neighbouring cells, therefore approximating a 3D distribution.

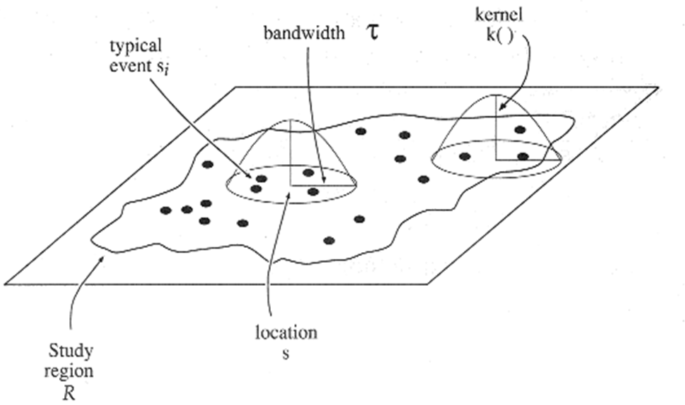


Fig.4 Point pattern analysis. Kernel Density Estimation, Source: Elaboration from Gatrell (1994)

3.4 Identification of the circular clusters of the aggregates in Sardinia

The above-described methods are relevant to propose a way for detecting clusters in a circular economy framework. Different steps were considered for obtaining an image of the closed study area of Sardinia, where clusters could be detected.

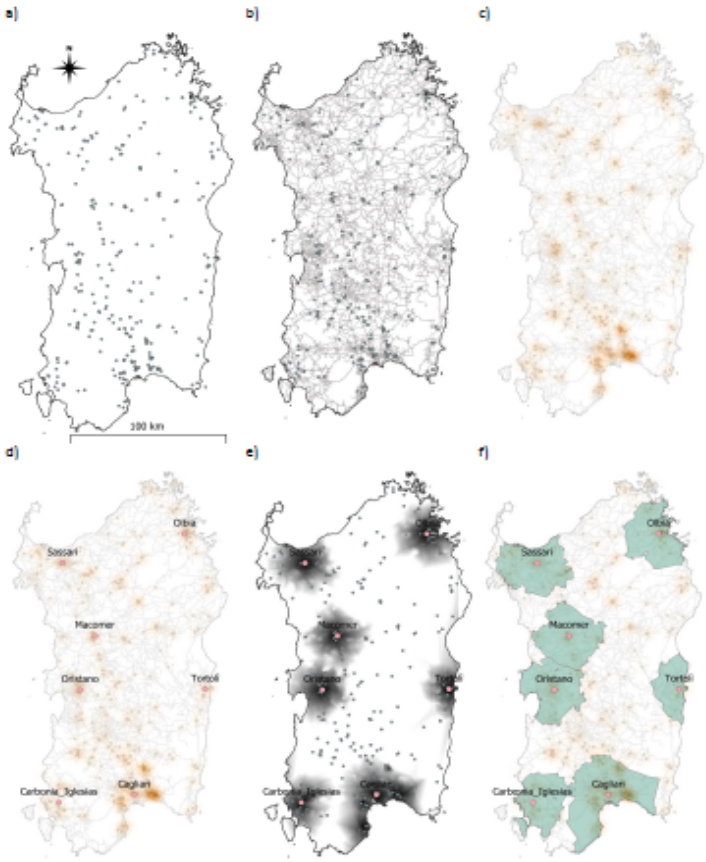


Fig.5 Forming the Circular Economy Clusters. Elaboration Borruso 2021, source: Dataset of MEISAR_Map. a) scatterplot of data from the MEISAR_Map; b) data plus street and road network; c) Kernel density estimation on MEISAR_Map dataset; d) highlights of the major clusters detected; e) 30km - catchment areas of the clusters; f) areas of the major Sardinian clusters detected.

The MEISAR_Map represents the starting point for observing the basic spatial distribution of the overall dataset, namely the spatial locations of quarries, batching plants, treatment plants and disposal sites (Fig.5a), also considered within the road network system (Fig.5b). Such a geographical dataset represents a scatterplot of the data, usable for a further point pattern analysis, as a Kernel Density Estimation, where the events are weighted according to their proximity and concentration (Fig.5c). The presence of peaks in the distribution helped in highlighting the geographical centre of the clusters, possible via the quantitative KDE analysis helped by a visual analysis (Fig.5d). The area of the proposed cluster was then elaborated from a network service area analysis using a 30km radius over the Sardinia Region road network (Fig.5e). For the Cagliari area, the clusters were merged considering a set of contiguous sub-clusters. Seven major circular economy clusters will be detected, as it will be presented in the Results paragraph.

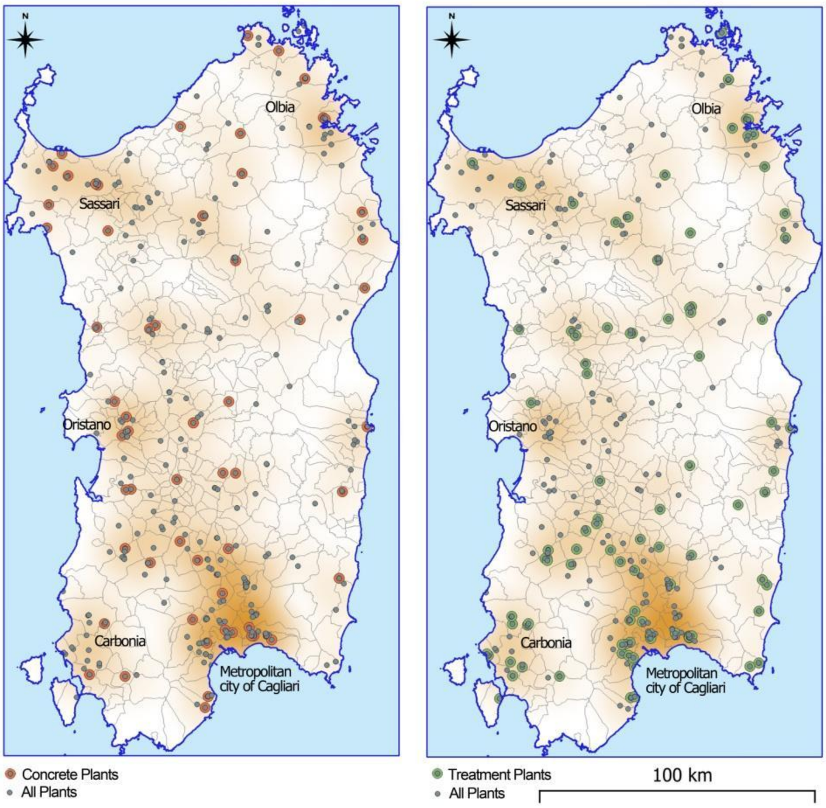
4. Results

The data from MEISAR_Map were elaborated in a GIS environment, where it was possible to build more complex elaborations such as 'Density maps'. In particular, Fig.6a shows the density of the concrete mixing plants, Fig.6b that of the CDW treatment plants, Fig.7a that of the CDW landfill and, finally, Fig.7b that of the quarries of aggregates. The distribution of the elements in the density maps shows that all the elements (quarries, CDW treatment, CDW landfill, concrete production plants and partner companies of MEISAR Project) analyzed show a greater density in the same geographical areas.

However, it is necessary to specify the main factors that influence the spatial pattern (Fig.6a, 6b, and 7a, 7b):

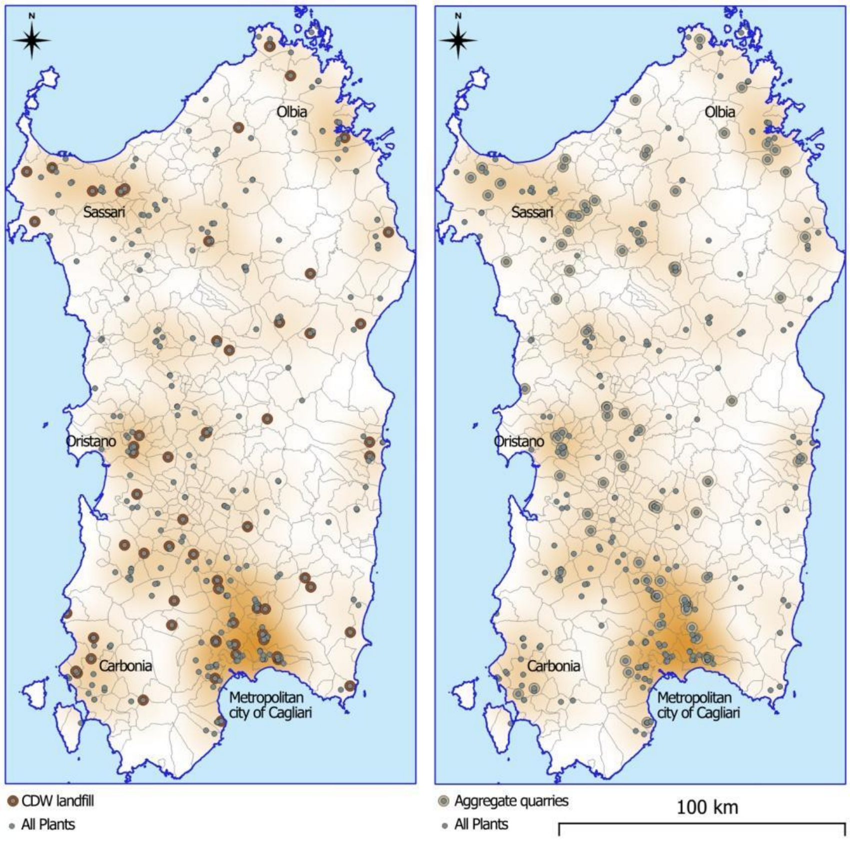
1. The transportability of ready-mixed concrete;
2. The transport costs of the CDW which defines the transportability radius of the waste from the place of production to the place of treatment;
3. Construction market.

In particular, there is a technical limit to the transportability of ready-mixed concrete which establishes the maximum distance between the production point and the point of use in 30 km, so that the optimal characteristics of the concrete are guaranteed. The 30 km limit was also defined for the maximum distance between the CDW production site and the treatment plants in Sardinia.



(a) (b)

Fig.6 (a) Location and density of concrete plants and (b) Location and density of CDW treatment plants



(a) (b)

Fig.7 (a) Location and density CDW landfill and (b) Location and density of quarries

This limit is economic, since the low value of the aggregate material does not allow economically compatible transport for longer distances. Finally, the low level of infrastructure of the road system in Sardinia, as well as the absence of rail freight transport, confirms this limitation. In particular, Sardinia ranks 20th in Italy for road freight transport (Istat 2017).

In order to visualize a first spatial organization of areas of major concentration of activities, a hot spot density map was performed over the point datasets to visualize clusters. Such maps provided a first visual impact of the areas hosting the major concentration of such construction-related facilities.

Through the visual analysis of the density maps, Fig.6-a, 6-b, 7-a, 7-b it is possible to identify the parts of the regional territory characterized by the circular economy process of the aggregates, allowing the use of RAs as a substitute of the NAs also for the production of concrete.

The areas of greater density in Fig.6 and 7 correspond to the main urban areas of the Sardinia Region, in particular, the metropolitan area of Cagliari and those of Sassari, Carbonia-Iglesias, Oristano, Macomer, Tortolì and Olbia.

Many areas of Sardinia are characterized by low population and little building activity, as well as by the excessive distance between urban centers - potential places of origin of the CDW market - and the places of production of RA and concrete. This spatial organization in the urban economy is defined as an industrial cluster: a group of companies, strictly interconnected within an economic process in this case of a circular type (Korhonen, J. et al 2018).

The C_clusters are territorial areas in which all the elements useful for the development of an RA market are concentrated. In fact, in the C_clusters there are recycling plants that transform the CDW into RA and concrete plants with NA production quarries which will satisfy the missing share of aggregates. Finally, the C_clusters are located - confirming the above - in correspondence of one or more urban areas closely connected with the main transport infrastructures. This is not possible in territories characterized by the absence of C_clusters, for which the natural fate of the CDW is the landfill or, in the worst cases, abandonment (Fig. 8 and Tab 1). In other words, the C_clusters constitute the most favorable territorial areas to activate circular economy processes much desired (Mei et al., 2019; Balletto et al., 2019; Pani et al., 2019) and consistent with the recent procurement code public in Italy (Law 11 September 2020, n. 120).

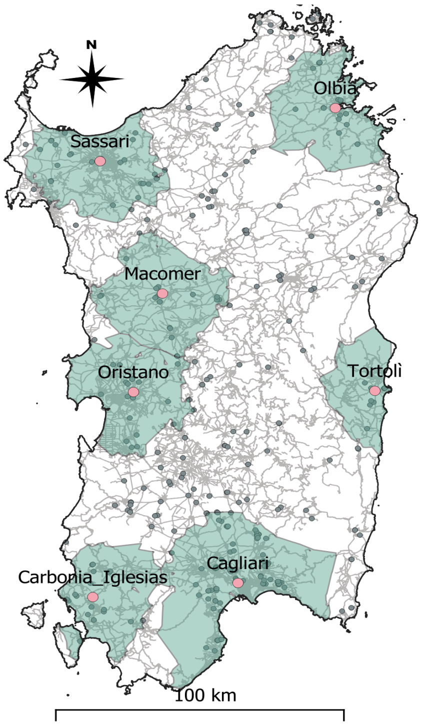


Fig.8 Sardinia Circular Cluster

Tab.1 Principal Dataset of Sardinia Circular Cluster, data elaborated from MEISAR_Map

	Area (km^2)	Quarries	CDW treatment plants	Concrete plants	Landfill	Total	% Sardinia	% Cluster
Cagliari	2102.29	22	23	34	16	95	27.07	42.79
Carbonia-Iglesias	1070.41	2	11	5	5	23	6.55	10.36
Oristano	1304.89	12	1	8	5	26	7.41	11.71
Macomer	1426.03	3	9	4	1	17	4.84	7.66
Sassari	1369.84	13	6	9	4	32	9.12	14.41
Olbia	1255.78	6	9	4	1	20	5.70	9.01
Tortolì	739.20	2	3	2	2	9	2.56	4.05
Total	9268.44	60	62	66	34	222	65.25	100.00

4.1 The case study of the Cagliari stadium within the island context of Sardinia

The state of obsolescence of the old stadium has reached the point of total non-usability, which has led Cagliari Calcio to start the authorization process for the construction of the new stadium (2018). The case is interesting as the new sports facility will be built in proximity to the existing one, and the demolition / construction process will take place in a condition of spatial and temporal proximity, with interesting implications in terms of CDW production, their treatment and reuse.

In this sense, with the help of the companies participating in the MEISAR project, concrete was produced with RA in different percentages of use (30%, 50% and 80%) to replace NA. In particular, the tests on recycled concrete (workability values at 14 and 28 days, compression,) gave the following encouraging results: recycled concrete produced with coarse recycled aggregates, even when the replacement percentages of natural aggregates reach 80 %, as demonstrated by the equivalent mechanical performance of ordinary concrete. In fact, the performance of recycled concrete is not related to the mechanical characteristics of the mother concrete (Pani et al., 2019). Following this positive evaluation, the authors, in order to reach the goal of using RA - coming from the demolition of the old stadium - have developed intra-disciplinary evaluations (environmental, geographical, chemical-mineralogical) which led to the quantification of about 9,000 cubic meters of CDW, which correspond to approximately 18,000 cubic meters of RA.

By doing so, approximately 50% of the concrete requirement for the construction of the new stadium will be met, which from the project results in approximately 35,000 cubic meters. The benefit will not only be environmental but also economic. In fact, the price of RA is lower than NA, which can be estimated at about half.

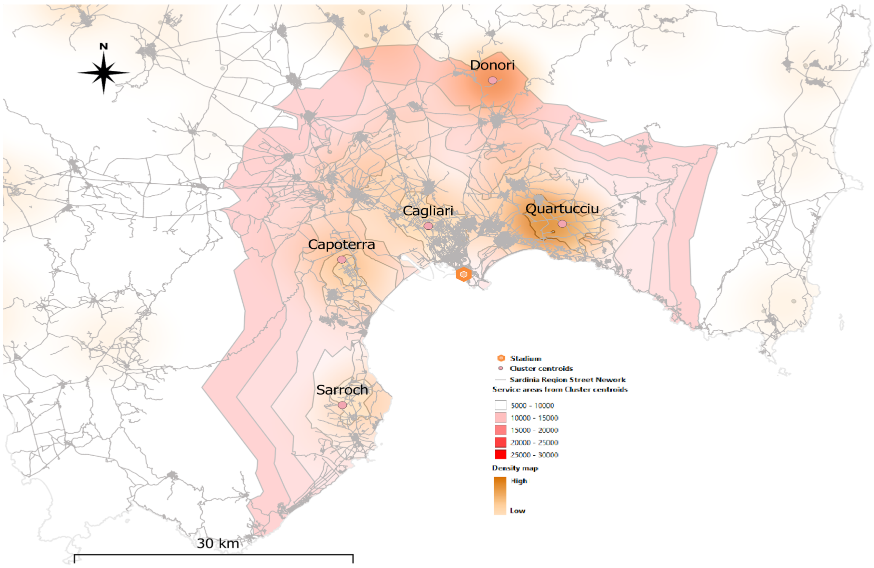


Fig.10 C_Clusters in the Cagliari Area. Data from MEISAR_Map; Sardinia Region (Street network); Elaborations by Giuseppe Borruso

Within the Cagliari C_cluster, aggregated flows will thus be generated from the place of origin (CDW source) and destination (installation), passing through the place of transformation (transforming CDW into RA for concrete). In particular - in the case study - new stadium - the place of origin and that of destination coincide, while the transformation sites are adjacent to the urban center of Cagliari and meet the requirement of a distance of 30 km (Fig.10).

Furthermore, the Cagliari Cluster originates from the merging of the 5 sub-circular clusters (SC_clusters): Sarroch, Capoterra, Cagliari, Quartucciu and Donori. The five SC_cluster meet both the design requirements and the principles of circular economy. The choice of the SC_cluster will then be guided by the market laws, by the production capacities (quantitative and qualitative) of RA and by the public procurement requirements for the construction of the new Cagliari stadium.

5. Discussion and conclusions

The construction sector, particularly in some geographical circumstances, can be considered as an ideal case study for proposing its transformation from a linear to a circular economy process. The general case study referring to Sardinia appeared particularly interesting for CDWs.

This is due to two main reasons. On the one hand, insularity makes the Region a closed system from the point of view of raw materials, primary and secondary (aggregates in particular). On the other hand, the main activity deriving from public works makes the use of recycled aggregates interesting from a design point of view.

In such a macro-context, the microanalysis of the case study - new stage - appeared interesting, also because they are closely related to each other.

In this sense, it is an interesting case in that a triple situation coexists. First of all, the former stadium is destined for demolition and reconstruction; secondly, a research project (MEISAR) on materials is already underway, involving local universities, public bodies and private companies engaged in construction innovation. Thirdly, a project was set up for the construction of the new stadium, after a competition was won by a consortium (Sportium), whose purpose is, among others, to work and build in the direction of sustainability, which includes the application of BIM modeling to minimize and optimize resources and production, in line with a circular economy framework. In particular, therefore, with this paper we evaluate a case of application of the principles of Circular Economy referring to the construction of the important public building of the new Cagliari Calcio stadium. This construction involves the total demolition of the current stadium, recovering the material deriving from the demolition to use it for the production of concrete for the new stadium.

The complex territorial assessment that led to the development of the MEISAR Map and the density maps has therefore made it possible to identify the circular clusters (C_clusters) of the Sardinia Region, characterized by a range of about 30 km, the result of the compromise between market value of natural and recycled aggregates and related shipping costs (Neto et al., 2017).

Furthermore, the metropolitan city, in fact, has an active and more developed building market than the rest of Sardinia. The metropolitan role played by Cagliari as the regional capital in attracting people for higher-order services and opportunities - public offices, residential spaces and commercial activities, higher education facilities favors the construction market and with them also the processes of circular economy. Transport infrastructures also favor circular economy processes. In the specific case, the five Sub-circular clusters identified are able to guarantee the supply of recycled aggregates for the concrete necessary for the construction of the stadium according to the criteria of the circular economy.

The case of the stadium has highlighted how the tools that promote knowledge of the characteristics of recycling aggregates such as MEISAR_Map constitute important applications for the diffusion of their use in the circular economic transition, made even more necessary by the health emergency, which highlighted the urgent need for a new ecologically sustainable Anthropocene (Mundula et al., 2019; Murgante et al., 2020).

In this sense, the circular economy, at the various levels of implementation, poses various operational challenges on the production process from a spatial point of view, as well as of course of architectural composition and realization (Della Torre et al., 2020; Bottero et al., 2017).

In particular, the demolition and reconstruction of the Cagliari stadium for the way it was designed will activate a circular economy process, which will develop between the five sub-circular clusters based on the market offer with the same technical characteristics of the recycled aggregates. Finally, the use and implementation of MEISAR_Map has contributed to the practical evaluation of the processes that can be potentially activated in the ambit of the circular economy referred to CDW, opening up a little explored theoretical discussion field for closed markets such as Sardinia (Balletto et al., 2019).

In this sense, research will continue to identify the main actions both with specific prescriptions in the urban plans and through bonuses in the form of tax breaks, similarly to what is implemented for actions on energy saving (Obe et al., 2019).

In summary, it intends to contribute both to the theoretical discussion and to the research applied to application case studies according to the objectives of the 2030 Agenda and the much-desired ecological transition.

The research is also ongoing to tackle other, more operational aspects of the circular economy applied to the construction sector. In particular, in a first stage we tackled the theoretical and methodological aspects of the industrial location model. At present, and as a future research, we are working on the possibility of quantification of the RA needed in the construction sector, in case of demolition and construction – i.e., with reference to the demolition of the old Cagliari stadium and the realization of the new one –, and also in terms of the carbon footprint impacts. That would allow us to examine the potential not only in terms of materials actually put again into the economic production process, but also in terms of the impacts related to carbon emissions in the different scenarios.

Authors Contribution

The paper derives from the joint reflections of authors. However, the following paragraphs can be so attributed: Paragraph 1 has been realized by Milesi A. and Mei G., while Paragraph 2 is meant to be attributed to Balletto G. and Milesi A.; Paragraph 3 has been realized by Borruso G. and Paragraph 4 has been realized by Balletto G and Milesi A. Paragraph 5 Was realized by Balletto G and Borruso G.

Acknowledge

This research was funded by the project "Materials for Sustainable Building and Infrastructure - Recycled Aggregates (MEISAR)", financed by the Autonomous Region of Sardinia (POR Sardegna FESR 2014/2020 - ASSE PRIORITARIO I - "RICERCA SCIENTIFICA, SVILUPPO TECNOLOGICO E INNOVAZIONE" Azione 1.1.4 Sostegno alle attività collaborative di R&S per lo sviluppo di nuove tecnologie sostenibili, di nuovi prodotti e servizi. REALIZZAZIONE DI AZIONI CLUSTER "TOP-DOWN") that wants to develop an eco-sustainable chain of concrete constructions by enhancing recycled aggregates.

Data Availability

Some or all data, models, or code that support the findings of this study are available from the corresponding author upon reasonable request. Some or all data, models, or code generated or used during the study are proprietary or confidential in nature and may only be provided with restrictions. Specific data concerning MEISAR – i.e., information concerning companies involved in the MEISAR project – are considered proprietary and confidential. They can be made available after contacting authors and evaluating the level of detail required. Datasets used are summarized and available through the MEISAR_MAP http://bit.ly/MEISAR_MAP. The origin of data organized there is public and elaborated by authors. The procedure and origin is described in the text. Images and maps were realized by authors from data originally collected, together with geographical data made available through Sardinia Region geodatabase.

Glossary

CDW (Construction and demolition waste): Wastes from construction and demolition activities. They represent one of the largest waste streams in the European Union (500 kg per capita in 2014);

RA (Recycled aggregate): the recycled aggregate is defined as a mineral aggregate resulting from the recovery of waste of inorganic material previously used in construction;

NA (Natural aggregate): Aggregate of natural origin used for the production of concrete. The natural aggregate comes from natural deposits, such as in the case of inert materials of alluvial origin, from rivers and is obtained by crushing the rocks;

All Plants: The mix of plants of natural and recycled aggregates in the circular economy (quarries, CDW treatment and CDW landfill, concrete production plants and partner companies of MEISAR project);

C_Cluster (Circular Cluster): The C_clusters are territorial areas in which all the elements useful for the development of an RA market are concentrated. In the C_clusters there are recycling plants that transform the CDW into RA and batching plants for the production of concrete together with NA production quarries which will satisfy the missing share of aggregates RA.

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