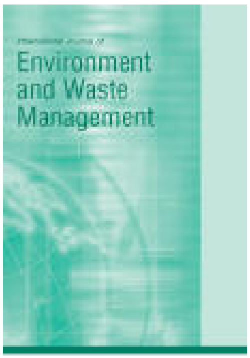


International Journal of Environment and Waste Management

ISSN online: 1478-9868 - ISSN print: 1478-9876
https://www.inderscience.com/ijewm

Mollusk shell waste: alternatives for reuse in construction

Ariane da Silva Cardoso, Emilia Rahnemay Kohlman Rabbani, Thayse Dayse Delmiro, Juliana Ferreira Bezerra Mocock, Sergio Peres Ramos da Silva, Gabriel Filippelli, José Vitor da Silva Macedo, Eliana C. Barreto Monteiro

DOI: 10.1504/IJEWM.2022.10035950

Article History:

Received:	08 June 2020
Last revised:	26 June 2020
Accepted:	12 July 2020
Published online:	22 March 2023

Mollusk shell waste: alternatives for reuse in construction

Ariane da Silva Cardoso,
Emilia Rahnemay Kohlman Rabbani*,
Thayse Dayse Delmiro,
Juliana Ferreira Bezerra Mocock,
Sergio Peres Ramos da Silva,
Gabriel Filippelli, José Vitor da Silva Macedo
and Eliana C. Barreto Monteiro

University of Pernambuco – UPE,
Polytechnic School of Pernambuco – POLI,
Recife, Brazil
Email: ariane_cardoso@hotmail.com
Email: emilia.rabbani@upe.br
Email: thaysedayse@hotmail.com
Email: julianamocock@hotmail.com
Email: sergperes@gmail.com
Email: gfilippe@iupui.edu
Email: jose.vitor_@hotmail.com
Email: eliana@poli.br
*Corresponding author

Abstract: Waste from the cultivation of bivalve mollusks has become an environmental issue in many parts of the world due to its irregular disposal. In Brazil, according to a diagnosis by the Secretariat for Sustainable Development and Environment, the Ilha de Deus fishing community, located in Recife, Pernambuco, produces about 408 tons of charru mussel shell waste annually. This waste is deposited directly into mangrove areas, producing serious environmental and social impacts. Seeking suitable ways to dispose of this waste, this study proposes possible uses for mollusk shells, identifying benefits, losses, and difficulties in the use of this waste through a systematic review of the literature. A chemical and thermogravimetric analysis of the mussel shell waste was carried out and several possible uses were proposed, mainly as a raw material for civil construction, taking into account local needs. The shells can be used as aggregate for mortar and concrete for various purposes and as filters for the treatment of effluents.

Keywords: bivalve mollusks; construction; recycled aggregates; solid waste; sustainable development.

Reference to this paper should be made as follows: da Silva Cardoso, A., Kohlman Rabbani, E.R., Dayse Delmiro, T., Bezerra Mocock, J.F., Ramos da Silva, S.P., Filippelli, G., da Silva Macedo, J.V. and Barreto Monteiro, E.C. (2023) 'Mollusk shell waste: alternatives for reuse in construction', *Int. J. Environment and Waste Management*, Vol. 31, No. 1, pp.61–80.

Biographical notes: Ariane da Silva Cardoso has received her Bachelor's in Civil Engineering, MSc in Civil Construction, and specialised in concrete structures and foundations and interior design student.

Emilia Rahnemay Kohlman Rabbani is an Associate Professor in the Civil Engineering Program at the University of Pernambuco (UPE), Recife, Brazil where she leads a multi-disciplinary research team on 'Safe and sustainable development' (https://desspoli.wixsite.com/dess) with more than 120 researchers and practitioners across Brazil, USA, Israel, and Portugal. She is a Civil and Environmental Engineer with experience in transportation safety, social and environmental sustainability applied to construction, solid waste management and sustainable education applied to extension projects and internationalisation efforts (https://emiliarabbani.wixsite.com/poli-upe).

Thayse Dayse Delmiro has received her Bachelor's and Master in Science degree in Civil Engineering from Universidade de Pernambuco.

Juliana Ferreira Bezerra Mocock has received her Bachelor's and Master's in Science degree in Civil Engineering from the University of Pernambuco.

Sergio Peres Ramos da Silva is an Associate Professor in the Mechanical Engineering Program at the University of Pernambuco (UPE)-since 1989, Recife, Brazil, where he founded and direct the Fuel and Energy Laboratory (2002). He earned his PhD in Mechanical Engineering (University of Florida – USA). He is a Mechanical Engineer and Industrial Chemistry, and his research interests are in waste to energy, biogas, biodiesel, pyrolysis, gasification, hydrogen use as fuel in IC engines, sustainable and green fuels. He has coordinated many R&D projects. He is a member of the Brazilian Biodiesel Network and of the PROTEGEER (Brazilian-Germany network on Climate Change Protection).

Gabriel Filippelli is a Chancellor's Professor of Earth Sciences and the Director of the Center for Urban Health at Indiana University-Purdue University Indianapolis (IUPUI). He is a biogeochemist with brand experience on paleoclimate, environmental health, and the impacts of climate change on human health. He hosts the North American hub of http://www.MapMyEnvironment.com, a global citizen science effort to provide up-to-date information on the human exposome.

José Vitor da Silva Macedo is a Civil Engineer with experience in the field of civil construction in vertical works, construction pathology and structural recovery. He has received his Bachelor's in Civil Engineering and Master's in Civil Construction.

Eliana C. Barreto Monteiro is a University Distinguished Professor in the Department of Civil Engineering at Pernambuco State University (UPE) and Catholic University of Pernambuco (UNICAP). She teaches in MBA courses in Civil Construction, Pathology, Repair System and Inspection of Reinforcement Concrete Structures all over Brazil. She supervises graduate studies and master's degrees. She provides consulting to construction companies in the area of concrete damage, inspection and rehabilitation of concrete structures. Her research interests include: reinforcement corrosion, durability and repair system. She has published over 300 peer-reviewed papers in journals and conferences, and she has given some invited key-note presentations.

1 Introduction

One of the greatest challenges mankind faces is the conscious and responsible interaction with the environment, which is suffering disastrous consequences due to reckless human activities. According to Postay (2015), among the most worrisome environmental issues are climate change, depletion of energy matrices and natural resources, and waste generation.

In Brazil, solid urban waste generation reached 79 million tons in 2018. More than 29.5 million tons of the waste collected was sent to improper locations, many of which lack the necessary systems and measures required to protect the environment against damage and degradation. Approximately 6.3 million tons of waste were not collected at all, being improperly disposed and causing negative social, economic, and environmental impacts (ABRELPE, 2019).

In addition to the great production of waste, abundant exploitation of natural resources also occurs, especially by civil construction. Environmental conditions are being modified as a result of inadequate human actions, compromising the quality of life for all living beings and for future generations.

The absence of stricter guidelines to establish sustainable levels of consumption and production causes conflicts between economic development and the environment. One of several methods that can minimise these effects is recycling. Civil construction, due to the large volume and diversity of materials used, provides a market with great potential to reuse waste, minimising the inconveniences that waste disposal or storage bring to the community. Also, the possibility of being able to replace natural resources with certain types of waste can be a path towards sustainable development.

In the fishing community of Ilha de Deus, an island located in Recife, Pernambuco, the main economic activity is mariculture, the cultivation of marine organisms in their natural habitats. Fishing (including shrimp and mollusk farming) is the main source of income for the island's 2,000 residents. However, the lack of proper collection and disposal of shell waste residue in the mangrove swamp (coastal ecosystem, serving as a transition between land and marine environments), has caused many environmental consequences, such as soil and water pollution and silting of the swampland surrounding the island. As environmental awareness has grown in recent years, more and more practices that seek to minimise impact to the environment are being observed.

This study proposes ways to dispose of the abundant waste generated by mollusk farming, known as *malacocultura*, and to reduce the consumption of natural resources, with a focus on sustainable development, through methods of using charru mollusk (*sururu*) shells collected from the Ilha de Deus fishing community in the construction sector, verifying their technical viability and identifying the benefits and challenges of using this residue. It's expected that the possible solutions identified from the analysis of the literature will promote discussions between the community, government, and entrepreneurs so that public policies can be created to remedy some of the consequences of inappropriate waste disposal which could then be expanded to other similar fishing communities in Brazil and around the world.

2 Theoretical framework

This section presents a review of the literature on *malacocultura* (mollusk farming), the construction sector and its environmental impacts in the context of sustainable development.

2.1 Malacocultura

Malacocultura is defined in English as mollusk farming. In Brazil, it consists of the farming of oysters, mussels, and scallops. The world production of mollusks is estimated to be 10.5 million tons per year. In South America, Brazilian production occupies second place with 210,000 t, surpassed only by Chile with 631,600 t. On the Brazilian coastline, the state of Santa Catarina is responsible for 90% of national mollusk production (Abrunhosa, 2011).

Figure 1 Charru mussels from the Ilha de Deus community in Recife, Pernambuco (see online version for colours)

Source: Non-governmental organisation *Saber Viver*

2.1.1 The Mytella charruana mollusk

Popularly known as charru mussel in English, or as *sururu* in Brazil, *Mytella charruana* (d'Orbigny, 1842) is a species of bivalve[1] mollusk. In the literature, charru mussels are classified as *Mytella falcata* in some studies and *Mytella charruana* in others. This is because these species are considered to be the same (Rios, 1985) and the *Mytella falcata* name is no longer accepted.

Mytella charruana is native to Latin America and has a large distribution, being found from the Atlantic coast of Venezuela to Argentina, as well as along the Pacific coast and in the Galapagos Islands (Narchi and Galvão-Bueno, 1983).

It is common in tropical regions and widely consumed in northeastern Brazil, often being the only source of protein in some poorer villages (Boffi, 1979 *apud* David, 2007). This species is characteristic of environments from loamy seas to shallow lakes. The mussels measure approximately 50 mm in length and 22 mm in width, with a yellow or brown anteroventral shell with a green dorsal part, as can be seen in Figure 1, showing the charru mussels collected from Ilha de Deus.

2.1.2 Physicochemical composition of mollusk shells

Silva et al. (2010) studied the physicochemical and microstructural characterisation of bivalve mollusk shells and found that calcium carbonate ($CaCO_3$) is its main constituent, composed of 93% aragonite and 7% calcite. The authors conclude that the high calcium content, as well as low levels of other metals, indicates potential uses for the shells, often considered waste.

Calcium is the main raw material of shells, but they also contain other elements, which vary in composition and content due to the temperature, pH, salinity, and concentration of chemical elements present in the habitat. Bezerra et al. (2011) determined the chemical composition of shells (Table 1) using X-ray fluorescence, showing the amount of each oxide found in the shells analysed. They suggested that the shells found along the Paraiba coast are of the species *Anamalocardia brasiliana* and *Tivela mactroides*, containing Aragonite crystal in their structures.

Table 1 Oxide content by X-ray fluorescence of bivalve mollusk shells of the species *A. brasiliana* and *Tivela mactroides*

Compound (oxide)	*Concentration (%)*
CaO	97.5372
Fe_2O_3	0.8697
SiO_2	0.8029
SrO	0.5300
SO_3	0.1462
Cr_2O_3	0.1140

Source: Bezerra et al. (2011)

Hamester and Becker (2010) also studied the chemical composition of different species of shellfish found in southern Brazil and obtained results similar to those of Bezerra et al. (2011).

However, Kurunczi (2001) points out that these values may vary according to the conditions of the water in which the mollusk develops, as they are filterers, making no distinction or selection of the filtered material. The author detected, through his studies, mercury (Hg) and lead (Pb) contents in mussel shells, due to contamination of the water where the mollusks grew.

2.1.3 Environmental impacts of malacocultura

The processing of shellfish for consumption in the form of food is done by heating it in a vessel and then stirring it in plastic boxes that serve as a sieve to facilitate the separation of the mollusk from its shell. During this process, the shells are disposed of, becoming waste (information provided in informal conversation with residents and producers of *sururu*, during a visit to the Ilha de Deus community, Recife, 2017).

In fishing communities, these shells are often discarded improperly, causing significant environmental impact, visual pollution, and hygiene problems due to the lack of sanitary control, as they are often thrown in the streets or into backyards (Santos, 2013; Bernardo et al., 2009). This inappropriate disposal of mollusk shells in the sea and in rivers, according to Petrielli (2008), causes the material to accumulate, leading to long-term siltation, which can cause a destructive ecological imbalance. When deposited in vacant lots, the shells promote the spread of disease by attracting animals and insects that feed on organic matter. Another problem is the pungent odor produced when organic matter decomposes (Chierighini et al., 2011). In addition, the entire marine reproduction cycle can be disturbed.

The problem of accumulation and improper disposal of shells from mariculture affects not only Brazil. Several studies with different recycling proposals have been performed in other countries. In Korea, research has been carried out since the 1980s on solutions for the disposal of oyster residues. According to researchers Yoon et al. (2010), about 300,000 tons of oyster shells are generated annually in that country. Studies prove that toxic gases, such as NH_3 and H_2S, are emitted during the process of microbial decomposition of the salts contained in the shells. Because of this potential impact on public health, the Korean government has funded a project to increase the recycling of this waste.

2.2 The construction industry and its environmental impacts

The construction industry is a significant part of the Brazilian economy, accounting for 6.2% of the country's gross domestic product (Federation of Industries of the Federal District, 2017). Construction is also responsible for the exploitation of natural resources and is characterised by extensive occupation and transformation of the landscape. This segment is responsible for causing significant environmental impact due to consumption and degradation of natural resources, as well as pollution (Sakr et al., 2010).

Construction waste sources are permanent, as there will always be construction, even after the end of the construction cycle, with renovations, demolitions, and new constructions (Loffi, 2014). According to United Nations data, construction consumes 40% of all energy, extracts 30% of all natural resources, generates 25% of all solid waste, consumes 25% of water, occupies 12% of the land, and accounts for 1/3 of the total emissions of Greenhouse gases (GHGs) (Benite, 2011).

Approximately 5% of world CO_2 emissions of anthropogenic origin come from cement production, according to Kihara and Visedo (2014). In Brazil, this value was 2.07% in 2012. According to the report of Annual Estimates of GHGs in Brazil, released in 2014, it corresponds to 25.3 million tons of CO_2.

GHG emissions from the cement manufacturing process occur in the production of clinker that is its main raw material. Clinker results from the calcination of limestone and dolomite, the main component of which is calcium carbonate and associations [$CaCO_3$ and $CaMg(CO_3)_2$, respectively]. Limestone heating promotes the thermal decomposition of calcium carbonate, resulting in lime (CaO) and carbon dioxide (CO_2), which is released into the atmosphere. GHG emissions originate not only from the burning of clinker, but also from the use of heating and drying fuels. Of the approximately 43 Mt of

CO_2 emitted in 2014 in Brazil, 60% are from the production of clinker and 40% from fuel combustion (Ferreira et al., 2018).

These are just a few aspects of the contribution of the construction industry to environmental degradation. There are countless challenges, but in essence, they consist of reducing and optimising material consumption, reducing waste generation, preserving the natural environment, and improving the quality of the built environment. Recycling can become an attractive form of waste and natural resource consumption management in the construction sector, as it transforms waste into input material, with innumerable environmental advantages.

3 Characterisation of the study site: Ilha de Deus and the environmental problem

The Ilha de Deus ZEIS (special zone of social interest), a fishing community located in Recife (latitude 8°05'13"S and longitude 34°54'06"W), in the state of Pernambuco, Brazil, was selected for this study. It suffers from inadequate disposal of bivalve mollusk shell residue, mostly charru mussels (*sururu*), left over after harvesting.

Ilha de Deus community is one of the oldest fishing communities in Recife, first settled in the 1950s. Considered a special zone of social interest (ZEIS) since 1995, it occupies a total area of 212 ha, with only 4.55 ha inhabited and 13.36 ha occupied by shrimp farming (Pernambuco, 2007; Pernambuco et al., 2014).

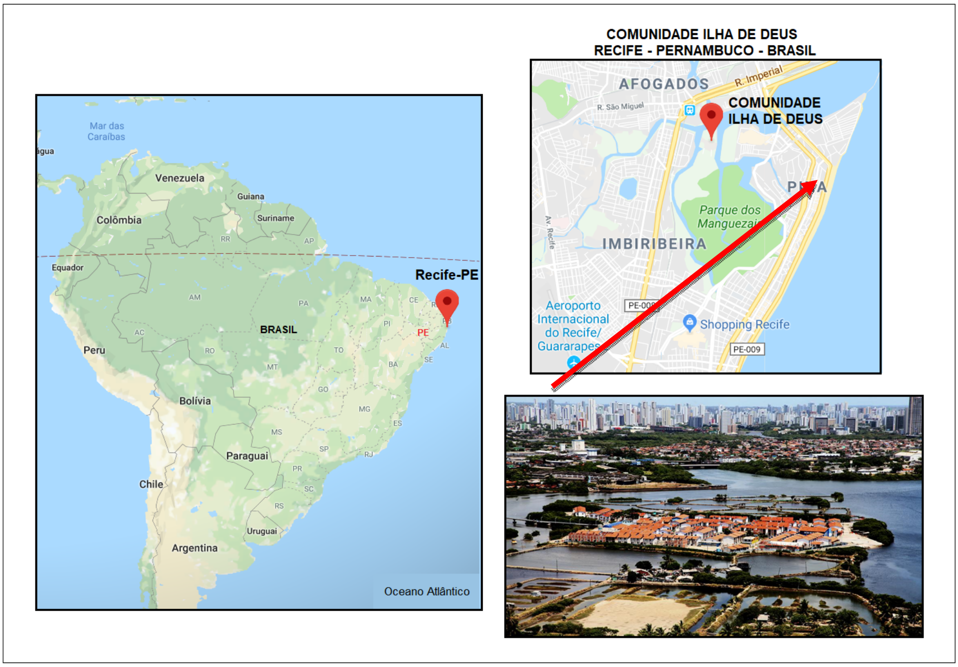
The island (Figure 2) is located in the Tejipió River Basin, between the Pina, Jordão, and Tejipió Rivers in the neighbourhoods of Pina and Imbiribeira, within a Special Zone of Environmental Protection (SZEP) known as Parque dos Manguezais, in the city of Recife.

During a visit to Ilha de Deus, in 2017, João Paulo Gomes, a social activist from the Secretariat of Social Development, Children, and Youth of Pernambuco, estimates that its population is made up of approximately 257 families (2,000 people), directly or indirectly linked to artisanal fishing work. Approximately 70% of these fishermen practice *malacocultura* and live mainly from harvesting *sururu* (charru mussel). The fishing areas are the Pina Basin, in the vicinity of Ilha de Deus, under the Pina bridges, and the Parque dos Manguezais, near the island of *São Simão* (Souza et al., 2010; Oceanário Institute of Pernambuco, 2010).

According to Hamester and Becker (2010), in Brazil of the total amount of shellfish produced, only 20% by weight is consumed in the form of food, with 80% consisting of shells. Petrielli (2008) adds that, after consumption of the mollusks, only 10% of the shells are reused or sold. The vast majority of them are discarded in vacant lots or thrown back into the sea, causing serious impacts to the environment.

In 2007, Ilha de Deus underwent a process of urban intervention entitled 'Integrated investments action plan for ZEIS Ilha de Deus', where urban requalification projects and social inclusion actions were carried out, promoted by the state government in partnership with the municipality and the federal government. From 2009 to 2014, the project evolved, replacing stilt houses with new masonry homes, along with other significant improvements to the community. However, there were no ideas regarding a suitable way to dispose of the large amount of waste generated by the community's principal economic activity: the *sururu* shells.

Figure 2 Ilha de Deus community in Recife, Pernambuco, Brazil (see online version for colours)



Source: Elaborated by the authors from Google images

Figure 3 *Sururu* shells deposited on the mangrove bank in Ilha de Deus (see online version for colours)

In most fishing communities, these shells are improperly discarded, causing significant environmental impact, sanitation problems, as well as visual pollution, as they are thrown in the streets, in backyards, and directly into the water (Santos, 2013; Bernardo et al., 2009). These problems can currently be observed in Ilha de Deus. Figures 3 and 4 show what was found during a community visit in October 2017.

Figure 4 *Sururu* shells deposited in vacant lots in Ilha de Deus (see online version for colours)

Source: Authors

The *sururu* shells have been deposited into the water and have accumulated along the mangrove banks in the community, potentially compromising fishing as well as the environment of other aquatic species that live nearby. The accumulation of shells at the bottom of the sea or mangrove can reduce the water depth, preventing the circulation of water and damaging the mariculture itself, which requires an uncontaminated environment to ensure production quality. Finding a suitable destination for this waste is necessary, to preserve both the environment and local fishing activity.

4 Applicability of mollusk waste

This section addresses studies on the reuse of shellfish residues and their application to civil construction and in other sectors.

4.1 Reuse of mollusk shells in construction

In Brazil, research related to residues from mariculture is still recent and scarce. Interest in the subject gained strength in the state of Santa Catarina, which is responsible for 98% of mollusks collected and consumed throughout the country (Rosa, 2015). The first tests using shellfish to replace the fine sand in pavement manufacturing took place 12 years ago, and today the Santa Catarina cement industry already considers shell processing as an official aggregate in the production of concrete blocks. With the evolution of the research, oyster and mussel residues have also been used, and, in addition to paving blocks, structural and non-structural concrete blocks have been manufactured, with a resistance up to 20% greater than that of conventional blocks (Santos, 2016).

Batista et al. (2008) produced blocks and pavement with a mixture of construction waste and mariculture residues. The blocks had resistance values compatible with class D – non-structural block, where the required resistance is 2.0 MPa. All samples of the concrete blocks had absorption values within the norm (10%), indicating that the blocks can be used in civil construction. Floors made with the incorporation of oyster and shellfish presented excellent results for this category, with water absorption rates well below the established standard, indicating that the properties of the conventional material can be improved upon.

In Florianópolis, Loffi (2014) analysed the incorporation of oyster shell powder into a mortar used in civil construction, and found that the effect of a 5% concentration on water absorption achieved the highest mechanical resistance result according to the analysed standards. The author also performed a chemical analysis of the oyster shell, showing the presence of 93% calcium carbonate, and an alkali-aggregate reaction (RAA) test, which proved to be favourable, finding no pathologies in the samples at all of the different concentrations tested.

When studying the reuse of shellfish as coarse aggregate in the production of non-structural concrete, Silva et al. (2016) observed a 48% reduction in resistance in samples with 100% shells. However, they did not discard their use for moderate stress situations, such as single-family dwellings. In addition, they considered the results to be acceptable for the use of concrete in the leveling of basements and subfloors, where it also resulted in a 25% savings in the cost of concrete, demonstrating not only environmental benefits, but also economic ones.

Rêgo et al. (2016) used shellfish powder collected in the city of Igarassu, Pernambuco as an aggregate in subfloor mortars and obtained very satisfactory results. The authors compared samples having a water/cement ratio of 0.7 without shells to samples where 50% and 100% of the aggregate was replaced by shells. In the samples with 100% shells, they observed an increase of 18.07% in compressive strength, a reduction of 2.98% in the modulus of elasticity, and an average increase of 5.4% in absorption.

Rios et al. (2016) studied the use of ground bivalve mussel shells to partially replace 5% and 10% of the cement for the production of mortars, finding results compatible with the reference mortar. The authors concluded that the shell powder does not present pozzolanic activity. However, it did not alter the consistency index of the mortars produced and did not influence the compressive strength of the mortars, but caused a 3.5% increase in the absorption by immersion in relation to the reference mortar. Another more recent work that studies this kind of substitution and find similar results can be find in Santos (2019).

Yang et al. (2005) investigated the properties of fresh and hardened concrete using oyster powder as fine aggregate and found that the workability is reduced as the oyster powder replacement rate increases. However, the gain in resistance was faster and there was no reduction in resistance when compared to the reference samples. In cases where sand is unavailable or difficult to obtain for concrete production, the authors considered its replacement by ground oyster shells to be a good alternative.

Yang et al. (2010) analysed the long-term performance of concrete with 10% and 20% of sand replaced by oyster shell powder and concluded that the resistance remained almost identical for the 10% replacement samples and slightly lower than conventional concrete for in the samples with 20% substitution. The authors observed that, in the long run, strength, modulus of elasticity, drying shrinkage, and permeability were significantly affected by the increased substitution of fine aggregate by oyster powder, while other properties, such as deformation and carbonation, as well as the results of chemical attack tests, were not substantially affected. More recently, Cardoso (2019) and Cardoso et al. (2018) studied the substitution of fine aggregate by charru shells at proportions of 10 and 20% and found similar results.

Hamester and Becker (2010) verified the possibility of using shellfish as an alternative source for the calcium carbonate obtained from the deposits, evaluating its physical, chemical, and thermal characteristics. The results showed that shellfish have an initial degradation temperature higher than commercial calcium carbonate and a similar mass loss, with 95% of the chemical composition of the shells being calcium carbonate. The authors further determined that commercial $CaCO_3$ and oyster and mussel shells do not have significant chemical differences, resulting in similar mechanical properties.

Another interesting application for shells is as filters, due to their absorbent property. The chemical composition of the shells with high levels of calcium carbonate indicates their potential use in the treatment of wastewater, especially in the adsorption of phosphorus. Park and Polprasert (2008) adapted a filter made of shells to a built wetland system and were able to remove significant amounts of phosphorus (P) and nitrogen (N) from wastewater under treatment.

Van Kaick et al. (2008), in a comparative study of the efficiency of an appropriate and sustainable sanitation technology in poor and rural areas built with alternative materials at a sewage treatment station, replaced gravel with oyster shells. The physicochemical parameters (biochemical oxygen demand – BOD and chemical oxygen demand – COD) were satisfactory, reducing the organic matter load below the established limits (60 mg O_2/L for BOD and 120 mgO_2/L for COD) for release of effluents into watercourses, as indicated by the Environmental Institute of Paraná.

4.2 Other alternatives to reuse of mollusk shells

The calcium carbonate obtained from mollusk shells, according to Chong et al. (2006), is an excellent alternative for use in polymeric materials such as polypropylene, having a low cost and being easy to obtain with low abrasiveness. Besides the possibility of using mollusk shells in related engineering areas, there are other possibilities for this source of calcium carbonate.

In South Korea, researchers reported on studies of oyster shells pyrolysed at a temperature of 750°C for one hour in an inert nitrogen atmosphere, which were converted into a product that could be used to remove phosphates from wastewater at an efficiency of 98%, making it a viable strategy for controlling eutrophication (Kwon et al., 2004).

In Spain, a factory was built in 2004 to recycle up to 80,000 t of mussel shells. It was able to produce calcium carbonate of 90% purity that can be used as raw material in the cement industry, as a soil broker, in the manufacture of paints, as an additive to paper and plastic, as well as in the pharmacological industry (Gremi de Recuperació de Catalunya, 2005).

Lee et al. (2007) demonstrated that mollusk shells restore the chemical and microbiological properties of soils, increasing productivity and making them a viable alternative to the use of fertilisers.

In 1989, a company was founded in the Galicia region of Spain to recycle sea shells with the intention of transforming them into ecological products. The company, known as Abonomar, uses shell residues to produce fertiliser pellets for use in agriculture that are composed of 20% shells. It also manufactures poultry feed based on 100% crushed shellfish, considered a calcium supplement capable of correcting the mineral deficiency of the birds and increasing the strength of the eggshells (Abonomar, 2017).

The calcium carbonate from shells was also presented as a possible complementary food supplement for humans (Kwon et al., 2004; Fujita et al., 1990).

Costa et al. (2012) studied the potential of the calcium carbonate for shells for soil acidity correction and concluded that the calcium carbonate present in the shells had superior performance compared to limestone in raising the pH values for the soil studied.

Paiva et al. (2014), concerned about the contamination of the Capibaribe River with textile dye from jeans washing at industrial laundries in Pernambuco, evaluated the adsorption of the anionic turquoise dye Indosol by *Crassostrea rhizophorae* oyster shells calcined at 1,000°C for three hours.

The results indicated that the optimum adsorption capacity was obtained when 0.5 g of adsorbent, 100 mesh granulometry, and 150 rpm were used for the oyster shells. The efficiency of the process was approximately 99%. The results showed that oyster residues are attractive in remediation of the dye under study because of both efficiency and low cost. Medeiros et al. (2014) performed similar studies with *Brachidontes solisianus* shellfish and proved that this shellfish is a good absorber, with an efficiency above 99% when prepared with 0.1 g adsorbent, 60 mesh granulometry, and a constant stirring of 300 rpm.

5 Methodology

A systematic review of the literature on shell recycling was carried out, using the preferred reporting items for systematic reviews and metaanalyses (PRISMA) method. This is a structured method of organising information contained in articles, journals, and other media, in order to optimise the reading, analysis, and processing of existing information on a given topic. In this way, it is possible to better understand the ways of using shell waste as well as to learn the results obtained so far. From this, it is possible to propose ways of reusing the shells from Ilha de Deus, presenting possible benefits, losses, and difficulties found.

The shells collected from the margins of the mangrove of Ilha de Deus were sorted manually to remove solid residues. They were then washed with running water so that impurities such as sand and small insects could be drained away. After washing, the shells were placed in an oven at 100°C ± 5°C to dry. Next, it was decided to pass the shells through a sieve again to remove excess impurities. After this screening, the shells were crushed with a blender until they reached a fineness corresponding to that of fine aggregate (<4.8 mm) with an appearance similar to sand grains (Figure 5). Finally, they were subjected to thermogravimetric analysis (TGA) and X-ray fluorescence spectrometry (XRF) test.

Figure 5 *Sururu* shells: before and after processing (see online version for colours)

Source: Personal archive

5.1 Thermogravimetric analysis

TGA analyses the change in mass of a substance as a function of temperature. The TGA of the *sururu* shells was performed at the Fuel Laboratory of the Polytechnic School of Pernambuco at the University of Pernambuco (POLICOM) on a Shimadzu brand DTG-60 thermogravimetric scale. The test was performed with a 35 mg sample and the maximum applied temperature was approximately 900°C. Differential thermal analysis (DTA) was also performed. The main objective of DTA is to detect the initial temperature of the thermal processes.

5.2 X-ray fluorescence spectrometry

The XRF test was performed to determine the chemical composition of the shell residue. A 10 g sample of powdered shells was sent to the Nucleus of Geochemical Studies – Stable Isotope Laboratory (NEG-LABISE) at UFPE, where the samples were oven-dried at 110°C. A portion of the dried sample was taken to a kiln at 1000°C for two hours to determine loss on ignition, as another portion was compressed into aluminum capsules with 30 tons of force, forming tablets. The tablets were analysed using an XRF Rigaku spectrometer, model ZSX Primus II, equipped with Rh tube and seven analyser crystals.

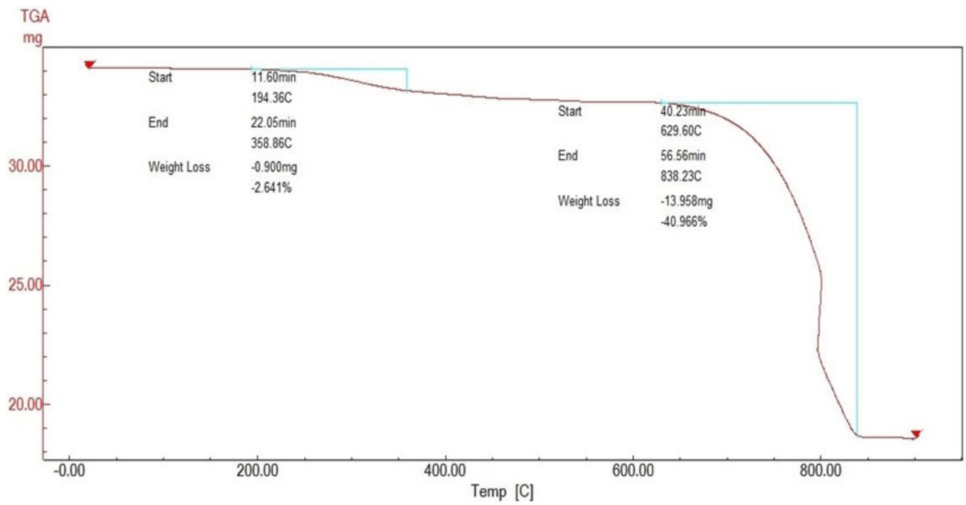
6 Results

6.1 Composition of shells from Ilha de Deus

Chemical analysis shows that the charru shell residue is made up of 97.86% calcium carbonate ($CaCO_3$), indicating its potential uses. In the TGA, illustrated in Figure 6, it can be seen that the shell residue preserves its characteristics as it heats up to approximately

630°C. The high loss on ignition value is related to the partial decomposition of calcite to form calcium oxide (CaO) and carbon dioxide (CO_2).

Figure 6 TGA of *sururu* from Ilha de Deus (see online version for colours)



TGA studies, along with those of other mollusks found in the literature, such as mussels, oysters, or cockles show that, in general, the calcination of shells at temperatures above 600°C results in shell powder residues with higher CaO content.

The chemical composition of the SSW, obtained using the XRF test, is shown in Table 2. The results of the semi-quantitative scan, are expressed in weight% and were recalculated to 100% after incorporating the loss value to fire.

Table 2 Results of the X-ray spectrometry test

Element	*Weight (%)*	*Element*	*Weight (%)*
CaO	49.52	P_2O_5	0.07
Na_2O	0.46	MgO	0.06
SO_3	0.44	BaO	0.05
SiO_2	0.43	K_2O	0.02
SrO	0.25	ZnO	0.02
Al_2O_3	0.24	LI*	48.34
Fe_2O_3	0.12	Total	100.00

Note: LI* – loss on ignition.

Source: Elaborated by the authors based on laboratory results

From these results, it can be seen that the *sururu* (charru mussel) shells have a chemical composition similar to that of limestone, as well as that of other bivalve mollusks, consisting mainly of calcium carbonate. When subjected to high temperatures, with the dissociation of carbonate, they change to being composed mainly of calcium oxide (CaO), with small fractions of other oxides. The results corroborate its use for the various applications shown in the next section.

6.2 Proposals for the use of sururu waste from Ilha de Deus

Based on the literature review and TGA, Table 3 presents possible applications for the *malacocultura* waste from Ilha de Deus, in civil construction and other areas, taking local needs into account.

Table 3 Proposals for the use of *sururu* (charru mussel) waste from Ilha de Deus

Application	*Advantages*	*Disadvantages*	*Potential market*
Replacement of aggregates in the manufacturing of pavement	Reduction, even partially, of the exploitation of natural resources	Possible interference in the mechanical properties of the concrete	Local construction companies Public projects Small projects in the community itself
Replacement of aggregates in the manufacturing of concrete blocks	Reduction, even partially, of the exploitation of natural resources	Possible interference in the mechanical properties of the concrete	Local construction companies Public projects Small projects in the community itself
Replacement of aggregates in mortars for different purposes. Examples: • leveling of basements and subfloors • bricklaying	Reduction, even partially, of the exploitation of natural resources For these purposes, it does not need high resistance values	Possible interference in the workability of the mortar in its fresh state	Local construction companies Public projects Small projects in the community itself
Filters for effluent treatment (residential and/or industrial)	Improvement of the basic sanitation and, consequently, quality of life of the inhabitants of the island and other communities in the city	-	Poor communities that suffer from the lack of sanitary sewage (both for Ilha de Deus itself and other ZEIS)
Soil pH balancer – liming[a]	Reduction, even partially, of the exploitation of natural resources Potential for correction of soil acidity (Costa et al., 2012).	-	Agrarian companies
Chickenfeed – alternative source of calcium in feed	High concentration of calcium in the *sururu* shells The use of organic sources of calcium is classified as renewable sources	Necessary tests/trial of zootechnical performance	Pernambuco has more than 1,600 poultry farms (AVIPE, 2017)
Handicrafts	Source of income for residents of the island Environmental/sustainable awareness of island residents	Need for manual skills	Tourists who frequent Ilha de Deus and other areas in Recife

Notes: [a]Limestone application (alkaline material) to neutralise the toxic effects of acidity-causing factors, as well as bringing nutrients to vegetables such as calcium and magnesium.

Specifically, for use in the manufacture of civil construction artifacts arises the concern regarding the durability of the cement composites produced with unconventional materials. For this reason, it is important to point out that the works presented refer to different species of mollusks, not using *sururu* exactly, highlighting the importance of research with other mollusks before any application.

7 Conclusions

The chorru mussel shells collected from Ilha de Deus in Recife, Pernambuco, are composed of approximately 97% calcium carbonate ($CaCO_3$), a material with great potential for reuse.

Among the potential uses for these residues, the most often cited was as a replacement for fine aggregate in the manufacturing of pavement, concrete blocks, or in mortars for various applications. The main advantage of using shell waste is the reduction, even partially, in the exploitation of natural resources. In some cases, the use of this material improves mechanical strength. Its principal disadvantage, however, is the possibility of affecting some of the concrete's mechanical properties, mainly those related to durability because there have still been no studies on the effects of shells on cement composites over the long term.

Another application worth mentioning is the use of shell residue as a filter for the treatment of effluent, as this has the potential to improve the quality of life of the residents of the island itself and other local communities, as these poor communities suffer from the lack of basic sanitation.

It can be seen that the waste generated from *malacocultura* can be utilised in a variety of areas, and that many studies can be developed to find a solution to the problem faced by the community of Ilha de Deus and other fishing communities around the world.

The recycling of all forms of shellfish residue can lead to significant environmental and social improvements, as the improper disposal of these shells currently causes serious environmental impacts, including air pollution and the generation of fungi and bacteria.

The reuse of *sururu* (charru mussel) shells not only favours the environment, but also the communities involved in this activity, through the generation of jobs and income.

Acknowledgements

This article is original and was developed as part of the Fall 2017 Diplomacy Lab project 'Climate partners Brazil: promoting sustainable development around the globe', developed through international cooperation between the University of Pernambuco (UPE), the American Consulate in Recife (through Paloma Gonzalez and Joana F. Cavalcanti), and Indiana University-Purdue University Indianapolis (IUPUI). The research work was also part of Ariane Cardoso's master's dissertation developed at UPE, available at Cardoso (2019), which received support from the Polytechnic School of Engineering (POLI) at University of Pernambuco.

References

Abonomar S.L. (2017) [online] http://www.abonomar.com/501/index.html (accessed 01 December 2017).

Abrunhosa, J.P. (2011) *Técnico em Aquicultura: Novas Oportunidades na Aquicultura*, Instituto Federal de Educação, Ciência e Tecnologia do Pará [online] http://redeetec.mec.gov.br/images/stories/pdf/eixo_rec_naturais/aquicultura/181012_piscicult.pdf (accessed 10 November 2017).

Associação Avicola de Pernambuco (AVIPE) [online] http://www.avipe.org.br/noticia_encontro2017-2.php (accessed 10 November 2017).

Associação Brasileira de Empresas de Limpeza Pública e Resíduos Especiais (ABRELPE) (2019) *Panorama dos Resíduos Sólidos no Brasil 2018/2019*, São Paulo [online] http://abrelpe.org.br/download-panorama-2018-2019/ (accessed 25 June 2020).

Batista, B.B. et al. (2008) 'Bloco verde: reaproveitamento de resíduos da construção civil e de conchas de ostras e mariscos', *Proceedings of Congresso Internacional de Tecnologias para o Meio Ambiente*, Biguaçu, Bento Gonçalves, pp.01–09.

Benite, A. (2011) *Emissões de Carbono e a Construção Civil*, Centro de Tecnologia de Edificação [online] http://www.cte.com.br/imprensa/2011-02-27-emissoes-de-carbono-e-a-construcao-civ/ (accessed 6 November 2017).

Bernardo, S.J., Maciel, M.I.S. and Silva, A.P.G. (2009) 'Avaliação dos aspectos higiênico-sanitários no processamento de moluscos na comunidade de pescadores artesanais da Ilha de Deus, Recife-PE', in *CBED 2009: Proceedings of the Congresso Brasileiro de Economia Doméstica*, Fortaleza, Brazil, pp.14–19.

Bezerra, U.T.A. et al. (2011) 'Production of filler aggregate from waste of bivalves mollusks shells', *Journal of Civil Engineering and Architecture*, Vol. 5, No. 4, pp.363–367, ISSN 1934-7359.

Cardoso, A.S. (2019) *Avaliação do Comportamento Físico e Mecânico de Compósitos Cimentíceos Produzidos com Conchas de Sururu*, Master's dissertation, Civil Engineering Graduate Program, University of Pernambuco, Pernambuco, Brazil [online] https://drive.google.com/file/d/0BwGBlk0fJbR3ZEFleElYQ3o3WWppa3FkZlRvNXJYYUxkVjRV/view (accessed 21 June 2020).

Cardoso, A.S., Kohlman Rabbani, E.R., Monteiro, E.C.B., Delmiro, T.D., Ribbas, A.F.C. and Silva, R.S. (2018) 'Utilização de resíduos de conchas de Sururu (Mytella falcata) como agregado miúdo reciclado na construção civil', in *Anais da Mostra de Extensão, Inovação e Pesquisa*, Vol. 5 [online] http:/ as.poli.br/revist /index.php/anais/article/view/1139 (accessed 21 June 2020).

Chierighini, D. et al (2001) 'Possibilidades do uso das conchas de moluscos', in *Proceedings of the International Workshop Advances in Cleaner Production*, Cleaner Production Initiatives and Challenges for a Sustainable World, São Paulo, Brazil, pp.01–05.

Chong, M.H. et al. (2006) 'Fire retardant plastic material from oyster shell powder and recycled polypropylene', *Journal of applied polymer Science*, Vol. 99, No. 4, pp.1583–1589.

Costa, A.R.S. et al. (2012) 'Viabilidade do uso de conchas de mariscos como corretivos de solos', in *Proceedings of the Congresso Brasileiro de Gestão Ambiental*, IBEAS, Goiânia, Brazil, pp.01–07.

David, J.A.d.O. (2007) *Estudo de Mytella Falcate*, Mollusca, Bivalvia, Como Indicadora de Efeitos Genotóxicos e Citotóxicos no Estuário de Santos, Tese, Doutorado em Ciências Biológicas, Universidade Estadual Paulista, Rio Claro, Brasil.

Federation of Industries of the Federal District (Federação das Indústrias do Distrito Federal) (2017) [online] https://www.sistemafibra.org.br/fibra/sala-de-imprensa/noticias/1315-construcao-civil-representa-6-2-do-pib-brasil.html (accessed 5 November 2017).

Ferreira, A.L. et al. (2018) *Emissões de GEE do Setor de Energia, Processos Industriais e Uso de Produtos* [online] http://energiaeambiente.org.br/wp-content/uploads/2018/01/Emissoes-dos-Setores-de-Energia-e-Processos-Industrias-Documento-de-Analise-2018.pdf (accessed 25 June 2020).

Fujita, T. et al. (1990) 'Increase of bone mineral density by calcium supplement with oyster shell electrolysate', *Bone and Mineral*, Vol. 11, No. 1, pp.85–91.

Google Maps, Ilha de Deus [online] https://www.google.de/maps/place/Ilha+de+Deus/@-8.0870074,-34.9028201,18z/data=!3m1!4b1!4m5!3m4!1s0x7ab1f26ad2c63a5:0x4636cd4b68b7cf34!8m2!3d-8.0869264!4d-34.9013802 (accessed 5 June 2020)

Gremi de Recuperació de Catalunya (Eds.) (2005) *Mejillones: De la Mesa a la Planta de Reciclado*, Recupera, Barcelona, No. 42, p.237 [online] http://www.gremirecuperacio.org/revista-ficha.asp?ficha=237 (accessed 7 October 2017).

Hamester, M.R.R. and Becker, D. (2010) 'Obtenção de carbonato de cálcio a partir de conchas de mariscos', in *CBECiMat 2010: Proceedings of the Congresso Brasileiro De Engenharia e Ciência Dos Materiais*, Campos do Jordão, Brasil, pp.262–269.

Kihara, Y. and Visedo, G. (2014) *A Indústria do Cimento e o Desenvolvimento do Brasil*, Associação Brasileira de Cimento Portland [online] http://www.abcp.org.br/conteudo/imprensa/a-industria-do-cimento-e-o-desenvolvimento-do-brasil (accessed 2 August 2017).

Kurunczi, S., Török, S. and Chevallier, P.A. (2001) 'Micro-XRF study of the element distribution on the growth front of mussel shell (Species of Unio Crassus Retzius)', *Mikrochimica Acta*, Vol. 137, No. 01, pp.41–48.

Kwon, H. et al. (2004) 'Recycling waste oyster shells for eutrophication control', *Resources, Conservation & Recycling*, Vol. 41, No. 1, pp.75–82.

Lee, W.E. et al. (2007) 'Green engineering – ceramic technology and sustainable development', *American Ceramic Society Bulletin*, Vol. 86, No. 2 pp.18–25.

Loffi, S.B. (2014) *Estudo sobre o Comportamento de Uma Argamassa Incorporada com Casca de Ostras*, Trabalho de Conclusão de Curso, Graduação em Engenharia Ambiental e Sanitária, Universidade do Sul de Santa Catarina, Palhoça, Brasil.

Medeiros, M.T.S., Assis Filho, R.B. and Motta Sobrinho, M.A. (2014) 'Absorção do corante indosol azul turqueza em conchas de marisco Brachidontes Solisianus calcinadas', *Revista Aidis,* Vol. 7 No. 3, pp.283–296. [online] http://revistas.unam.mx/index.php/aidis/article/view/46822/42207 (accessed 10 November 2017).

Narchi, W. and Galvão-Bueno, M.S. (1983) 'Anatomia funcional de Mytella charruana (D'Orbigny, 1846) Bivalvia: Mytilidae', *Boletim de Zoologia*, Vol. 6, No. 6, pp.113–145.

Oceanário Institute of Pernambuco (Instituto Oceanário de Pernambuco) (2010) Departamento de Pesca e Aquicultura da UFRPE, Diagnóstico Socioeconômico da Pesca Artesanal do Litoral de Pernambuco, Vol. I, II and III, Recife.

Paiva, T.M.N. et al. (2014) 'Estudo comparativo de absorção de corante têxtil utilizando carvão ativado e conchas de ostras Crassostrea Rhizophorae', in *COBEC 2014: Proceedings of the Congresso Brasileiro de Engenharia Química*, Florianópolis, Brasil, pp.8357–8366.

Park, W.H. and Polprasert, C. (2008) 'Roles of oyster shells in an integrated constructed wetland system designed for P removal', *Ecological Engineering*, Oxford, Vol. 3, No. 4, pp.50–56.

Pernambuco (3007) *Plano de Ação Integrada de Investimento para a ZEIS Ilha de Deus. SEPLAG/FADE*, Secretaria de Planejamento e Gestão do Estado de Pernambuco – SEPLAG,, Recife, Brazil, Vol. I, II, III and VI.

Pernambuco, Federação do Comércio de Bens, Serviços e Turismo do Estado de Pernambuco – Fecomércio-PE, Centro Pernambucano de Design – CPD and Ação Comunitária Caranguejo Uçá (2014) *Estudo da Iconografia da Comunidade Ilha de Deus*, Recife – PE, Brazil.

Petrielli, F.A.d.S. (2008) *Viabilidade Técnica e Econômica da Utilização Comercial das Conchas de Ostras Descartadas na Localidade do Ribeirão da Ilha, Florianópolis, Santa Catarina*, Dissertação de mestrado, Pós-graduação em Engenharia Ambiental, Universidade Federal de Santa Catarina, Florianópolis, Brasil.

Postay, R. (2015) *Correlação entre Compacidade, Energia Incorporada e Emissões de CO_2, Em Projetos de Habitação de Interesse Social*, Master's dissertation, Civil Engineering Graduate Program, University of Vale do Rio dos Sinos, São Leopoldo, Brazil.

Rêgo, M.A.M. et al. (2016) 'Avaliação do uso de concha de marisco como agregado miúdo na produção de argamassa para revestimento de piso', in *CBC 2016: Proceedings of the Congresso Brasileiro do Concreto*, IBRACON, Belo Horizonte, Brasil, pp.01–16.

Rios, E.C. (1985) *Seashells of Brazil*, 2nd ed., Editora Fundação Universidade do Rio Grande, Rio de Janeiro, Brasil.

Rios, S.F.D.M., Silva, A.P.G. and Moura, W.A (2016) 'Substituição do cimento por resíduos de conchas de moluscos bivalves em argamassas', in *ENTAC 2016: Proceedings of the XVI Encontro Nacional de Tecnologia do Ambiente Construído*, São Paulo, Brasil, pp.4279–4289.

Rosa, E. (2015) *Destaques no Cultivo, Florianópolis e Palhoça se Consolidaram Como Polos Gastronômicos no Brasil*, Ndonline, Florianópolis. [online] https://ndmais.com.br/noticias/santa-catarina-mantem-lideranca-nacional-na-producao-de-ostras-mariscos-e-vieiras-confirma-ibge/ (accessed 5 November 2017).

Sakr, D.A., Sherif, A. and El-Haggar, S.M. (2010) 'Environmental management systems' awareness: an investigation of top 50 contractors in Egypt', *Journal of Cleaner Production,* Vol. 18, No. 3, pp.210–218.

Santos, A. (2016) *Marisco vira Agregado Oficial de Blocos de Cimento* [online] http://www.cimentoitambe.com.br/marisco-vira-agregado-oficial-de-blocos-de-cimento (accessed 5 November 2017).

Santos, A.L.S.F. (2019) *Análise da Viabilidade Técnica da Substituição Parcial do Cimento na Argamassa de Revestimento pelo pó da Casca de Sururu Beneficiada*, Monograph, Civil Engineering Undergraduate Course, University of Pernambuco, Pernambuco, Brazil.

Santos, L.A.A. (2013) *Problemática e Perspectivas dos Resíduos Sólidos das Conchas de Mariscos Originados da Mariscagem nas Comunidades Tradicionais em Salinas da Margarida-BA*, Master's dissertation, Graduate Program in Geography, Instituto de Geociências, Federal University of Bahia, Bahia, Brazil.

Silva, A.I.M. et al. (2016) 'Reaproveitamento da concha de marisco como agregado graúdo na produção de concreto não estrutural', in *CBC 2016: Proceedings of the Congresso Brasileiro do Concreto*, IBRACON, Belo Horizonte, Brasil, pp.01–16.

Silva, D. et al. (2010) 'Caracterização físico-química e microestrutural de conchas de moluscos bivalves provenientes de cultivos da região litorânea da Ilha de Santa Catarina', *Química Nova*, Vol. 33, No. 5, pp.1053–1058.

Souza, A.C.F.F., Vieira, D.M. and Teixeira, S.F. (2010) 'Trabalhadores da maré: conhecimento tradicional dos pescadores de moluscos na área urbana do Recife-PE', in Alves, R.R.d.N., Souto, W.M.S. and Mourão, J.S. (Eds.): *Etnozoologia no Brasil: Importância, Status Atual e Perspectivas*, NUPEEA, Recife, pp.149–176.

Vain Kaick, T.S., Macedo, C.X. and Presznhuk, A. (2008) 'Jardim ecológico – tratamento de esgoto por zona de raízes: Análise e comparação da eficiência de uma tecnologia de saneamento apropriada e sustentável', in *SEMEA 2008: Proceedings of the VI Semana de Estudos da Engenharia Ambiental*, UEMS, Irati, Brasil, pp.01–12.

Yang, E., Kim, M., Park, H. and Yi, S. (2010) 'Effect of partial replacement of sand with dry oyster shell on the long-term performance of concrete', *Construction and Building Materials*, Vol. 24, No. 4, p.758-765.

Yang, E., Yi, S. and Leem, Y. (2005) 'Effect of oyster shell substituted for fine aggregate on concrete characteristics: Part I. Fundamental properties', *Cement and Concrete Research*, Vol. 35, No. 11, pp.2175–2182.

Yoon, G.L., Yoon, Y.W. and Chae, K.S. (2010) 'Shear strength and compressibility of oyster shell-sand mixtures', *Environmental Earth Sciences*, Vol. 60, No. 8, pp.1701–1709.

Notes

1 The term 'bivalve mollusk' is designated to the soft-bodied animal protected by an exoskeleton in the form of shells, which hinges together and are held together by the adductor muscles.