TECHNO-ECONOMIC FEASIBILITY ANALYSIS OF OYSTER SHELL VALORISATION FOR SOLID SURFACE COUNTERTOP

An Irish Perspective

Mohammed Zia Chowdhury, PhD, CChem

Ehiaze Ehimen, PhD

Atlantic Technological University, Sligo

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Case Studies: Oyster Shell of Donegal Aquaculture Services Ltd

In Ireland, two main types of oysters are farmed and eaten: European flat Oyster *(Ostrea edulis)* and Pacific Oysters *(Magallana gigas* or *Crassostrea gigas).*

The pilot case study partner for the project, Donegal Aquaculture Services Ltd (DAS), grades, packs, and ships *Crassostrea gigas* oysters from two big Oyster production farms which are situated in the inner Donegal Bay, located in the North-west region of the Republic of Ireland. Donegal is the second-largest oyster-producing county in Ireland after Waterford, with around 400-500 tons of oysters annually in the region.

DAS, along with other North-West regional oyster growers, generate 1000 to 3000 tons of discarded shell stock per year. This mollusc shell garbage was disposed of for €80-100 per ton. These enterprises, therefore, seek a responsible and ecological way to offset waste shells which are currently going to landfills. Current waste management legislation and initiatives need new prospects in sustainable shellfish farming. The discarded oyster shell can provide extra cash and create more jobs as a by-product resource. An ancillary shell by-product processing facility that might operate sequentially with existing major oyster-producing businesses has been researched by DAS.

A circular and bioeconomy-driven approach for oyster shell waste and other possible processing wastes to support their valorization activities was investigated by the EU NPA SYMBIOMA project and is presented in this report.

Chemical Composition of Mollusc Shell and Limestone

Calcium carbonate is the major chemical constituent (98 to 99 of dry wt%) of natural limestone and mollusc shells, namely Oyster, Scallop, Mussels, Abalone, Conch and Manila Clam (Figure 1).[1] **Virhe. Viitteen lähdettä ei löytynyt.**

Figure 1 limestone, raw Oyster, Manila Clam, Scallop, Mussels, Abalone, and Conch.[1](adapted with permission)

The chemical composition of different types of seashells may be the same, while the same species obtained from different places could have different chemical compositions due to various factors.[2] P. Lertwattanaruk *et al.* investigated the calcium carbonate component of short-necked clam, green mussel, oyster, and cockle shells and found 96.80%, 95.60%, 96.87%, and 97.13%, respectively. The chemical composition of some seashells is shown in Table 1

Table 1 Some Seashells' chemical properties.[3]

Chemical components	Oyster Shell	Queen Scallop Shell	Peruvian Scallop Shell	Cockle Shell	Coral Reef Sand	Clam Shell	Snail shell	Ordinary Portland cement	Mussel Shell
$CaCO_3$	95.99	50	53.70	51.5	50.46	67.70	61.95	62-67	94.6
Na_2O	0.98	0.2	0.50	0.46	-	-	0.25	0.5-2	0.5
MgO	0.64	0.1	0.18	0.18	3.1	-	0.18	1-3	0.27
SiO_2	0.69	0.2	0.10	1.37	0.42	0.39	10.20	17-25	2.58
SO_3	0.72	0.02	0.32	0.14	0.43	-	0.03	1-3	0.308
Al_2O_3	0.41	0.06	0.10	0.14	0.17	0.28	4.81	3-8	<0.01
Fe_2O_3	-	0.09	0.03	1.55	-	0.02	3.15	3-4	<0.05
K_2O	-	0.04	0.01	0.08	0.35	-	0.20	0.5-2	<0.06

Ji Whan Ahn *et al.* studied some mollusc shells and limestone under XRF.[1] The constitutional composition from that study is presented in Table 2.[1] Due to similarities in chemical composition, recycling mollusc shells to replace natural limestone is considered more beneficial due to its short lifecycle and carbon footprint.

Table 2 XRF analysis of the different mollusc shells with natural limestone.[1]

(Wt%) Composition	**CaO**	**Loss of Ignition**	**SiO_2**	**Al_2O_3**	**Fe_2O_3**	**MgO**	**K_2O**	**Na_2O**	**TiO_2**	**MnO**	**P_2O_5**
Limestone	55.54	43.79	0.11	0.03	0.09	0.20	0.03	<0.02	<0.01	0.1	0.01
Oyster	53.66	44.56	0.45	0.12	0.06	0.26	0.06	0.55	<0.01	0.01	0.16
Scallop	54.96	44.09	0.07	0.01	0.02	0.05	0.03	0.42	<0.01	<0.01	0.12
Mussels	52.83	46.17	0.07	0.01	<0.01	0.17	0.02	0.38	<0.01	<0.01	0.06
Abalone	53.04	46.23	0.15	0.04	0.01	<0.01	0.03	0.59	<0.01	<0.01	0.02
Conch	54.59	44.68	0.11	0.02	0.01	0.09	0.03	0.53	<0.01	<0.01	0.02
Manila clam	54.27	45.06	0.12	0.03	0.02	<0.01	0.03	0.65	<0.01	<0.01	0.06

General Overview of Oyster Shell

The oyster shell is a structured biogenic composite of mainly anhydrous calcium carbonate (>95 wt. %) in association with an organic matrix (up to 5 wt. %).[4] According to the phylogeny, edible aquaculture oyster and pearl oyster Orders (Figure 2) are distinctly different in shell composition and structural characteristics.

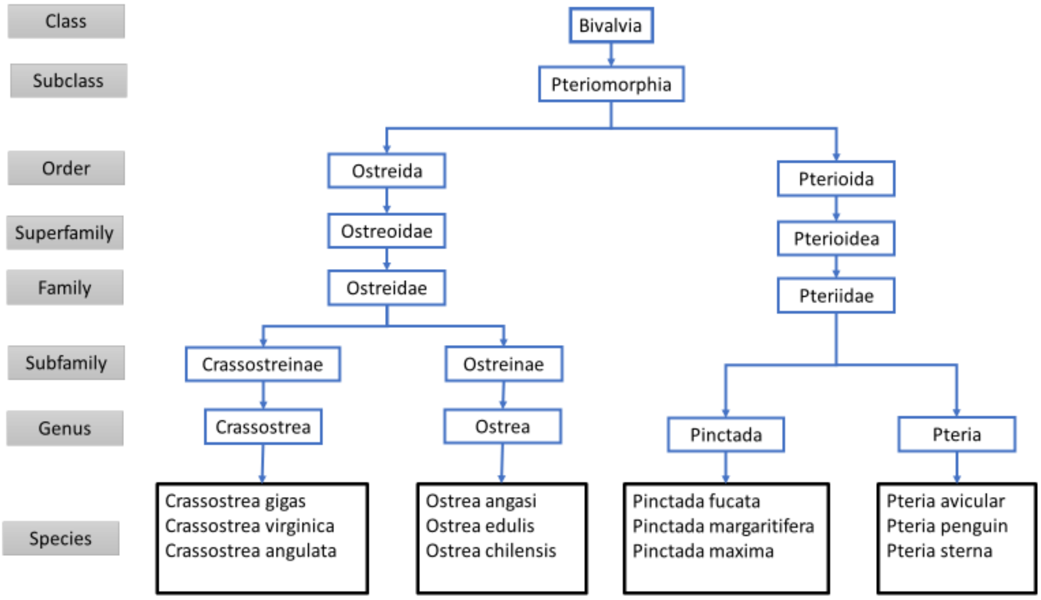

Figure 2 Phylogeny of Oyster and Scallop.

The content of humidity, density, pH, and ash of the Oyster shell, is represented in Table 3.

Table 3 Physical characterization of wet shells (Fraction <2.00mm).[5]

Bulk Density	*Unit*	*Location 1*	*Location 2*	*Location 3*
Real Density	g / cm^3	*2.5284*	*2.6374*	*2.4921*
pH (10%)	-	*8.97*	*8.83*	*8.99*
Ash	*%*	*54.67*	*55.15*	*55.11*
Humidity	*%*	*0.55*	*0.77*	*0.72*

DAS Oyster shell composition and its techno-economic feasibility

As supplied, the nutritional composition of DAS C. Gigas shell powder was analyzed for NPK and minerals by an external UKAS-accredited laboratory. The purpose of this analysis was to determine the supplied shell powder's suitability for the production of secondary products i.e. as a soil conditioner/fertilizer and animal feed supplement.

The analytical results are shown in Table 4. The pH level of this shell powder sample is within the range of the pH of other seashell compounds. Compared with the literature value of calcium content of pacific oysters (Table 5), the supplied DAS oyster shell's calcium is a little high, which may be due to normal variation of shell composition such as harvest habitation and dryness of the sample. The morphological changes of the oyster shell may occur during storage time also. It was found by Young Han LEE *et al.* that the storage time positively changes the oyster shell for fertilizer application.[6] The ammoniacal nitrogen content is a key indicator of the organic matter's suitability for fertilizer application. Compared with nitrate nitrogen, the ammonium nitrogen in the sample was observed to be high in the shell powder, which indicates it could be a good candidate for soil conditioner applications. The shell powder's suitability as a livestock feed is further determined not only content of nutrients but also by the level of heavy metal contamination. As other mineral content is within the range, the heavy metal content must be further determined for such an application.

Table 4 Compositional analysis of C. gigas shell powder.

Determinant on a DM basis unless otherwise indicated	**Units**	**Oyster composition**
pH 1:6 [Fresh]		**8.79**
Oven Dry Matter	%	**95.9**
Total Nitrogen	% w/w	**0.20**
Ammonium Nitrogen	mg/kg	**364**
Nitrate Nitrogen	mg/kg	**<10**
Total Phosphorus (P)	% w/w	**0.037**
Total Potassium (K)	% w/w	**0.037**
Total Magnesium (Mg)	% w/w	**0.165**
Total Sulphur (S)	% w/w	**0.178**
Total Copper (Cu)	mg/kg	**1.22**
Total Zinc (Zn)	mg/kg	**8.77**
Total Sodium (Na)	% w/w	**0.641**
Total Calcium (Ca)	mg/kg	**397728**

Table 5 Percentage of calcium and organic matter in some oyster shells.[5]

Species	Calcium %	Organic Matter %
O. lurida	38,6	1,68
C. virginica	33,7-37,8	2,16-2,34
C. gigas	34,6-36,2	1,33-1,71
M. arenária	38,6-38,8	2,22-2,44

In terms of profitability and environmental sustainability, recycling applications are considered from high volume to volume applications with low tech capacity of DAS. The balance between the cost of collection/decontamination/processing and the product's added value is considered by short- and medium-term low-tech economics and the current operational setting of the business.

Sustainable use of shell waste in low-tech, high-volume applications

Soil Amendment

Liming or soil amendment is the second biggest application for the shell market. While traditionally, quicklime is used for neutralizing acidic soil and increasing the acid-base buffering capacity of soils, sea shells could replace quicklime as an excellent alternative.[7] According to Haynes and Naidu, the technique of liming has several favourable benefits on the productivity of agricultural crop yields and can also have longer-term positive effects on soil quality and structure.[8] Furthermore, although the issue is still unsettled, it has been hypothesized that the application of a liming agent to agricultural soil can operate as a net carbon sink mechanism under certain conditions.[9]

Instead of mollusc's shell disposal, it could be milled as wet or dry powdered at elevated temperature and then calcinated at 800 °C to convert into calcium oxide (CaO). The Oyster-shell ultrafine powder not only reduces soil acidity but also adds calcium and magnesium content to the soil, thereby improving fertility.[2] It was demonstrated that soil conditioners prepared with oyster shell improves soil pH. The soil conditioner also increases water retention and porosity by 27% and 9.6%.[10] A study in Korea has established the link between the application of crushed Oyster shells in soil and its improved nutritional value in terms of phosphate availability and organic matter mass.[11] Acidic soil, which could benefit from the application of a liming agent, is found across much of Europe, especially in the north.[12] Galicia is currently a key region in Europe for using shell waste as a liming agent on a significant basis. This is due to the presence of a big shellfish processing factory as well as the proximity of agricultural land to huge shellfish aquaculture sites.

Livestock Feed Supplement

Calcium supplementation of the seashell is shown to be effective for livestock health, particularly bone health and the strength of eggshells of laying birds.[13] Oyster is becoming popular instead of traditional limestone as it is also comparatively cheap.[14] It is also suggested that invasive mussels such as zebra mussels could be used for the same poultry feed purpose instead of disposed of at landfills.[15]

According to Regulation (EC) No 1069/2009, Shells can be used for supplementation in the EU as long as they meet the free-from-flesh criteria, after which they are exempt from animal by-product classification. The identification of free-from-flesh standards is under the responsibility of each member state's relevant competent authority. Finally, the distance between each farm and the shell production facility must be addressed. Only farms in close vicinity to a large shell production facility are likely to be suitable for this form of shell valorization, both environmentally and economically.

Gardening and Landscaping

Gardeners and landscapers had already taken an interest in using shells as decorative topsoil or mulch on a smaller scale (Figure 3). Shells are offered mostly for ornamental purposes in these circumstances, but they may also have the ability to operate as a liming agent/pH buffer.

Figure 3 Shell Cottage Baile Chuilinn, Dublin (left), landscaping (right) (open access image)

Shell Aggregates

Shells have been exploited as a simple building material or included in aggregate and mortar mixtures in a variety of ways. Shell wastes have a number of features that make it a good candidate for construction aggregates. Shell waste is being included in aggregate mixtures as part of ongoing initiatives. Table 6 shows a comparison of the chemical composition of some calcinated seashells with Portland cement. It can be clearly seen that the CaO composition and other compounds are in good agreement compared to traditional cement qualities.

Table 6 Comparison of Chemical composition of some calcinated seashells with Portland cement

Chemical compositions (%)	**Materials**				
	Portland cement	**SCS**	**GMS**	**OS**	**CS**
SiO_2	20.3	0.84	0.73	1.01	0.98
Al_2O_3	5.18	0.14	0.13	0.14	0.17
Fe_2O_3	3.21	0.06	0.05	0.07	0.06
CaO	65.15	53.99	53.38	53.59	54.24
MgO	1.17	0.08	0.03	0.46	0.02
K_2O	0.29	0.03	0.02	0.02	0.03
Na_2O	0.04	0.39	0.44	0.23	0.37
SO_3	2.82	0.16	0.34	0.75	0.13
Cl	0.008	0.02	0.02	0.01	0.01
SO_4	3.76	0.06	0.11	0.43	0.07
Free CaO	1.25	–	–	–	–
$CaCO_3$	–	96.8	95.6	96.8	97.13

Crushed scallop shells have been utilized as a simple walkway aggregate on the Isle of Mull, Scotland, while whole oyster shells are used for modest wall structures in coastal villages linked with oyster aquaculture in China (pers. observ.). A trail of mussel shells as aggregate, insulating and acoustic filling material at a demonstration building in Galicia, Spain, is now become a tourist visiting spot. This can be seen on (https://www.lavozdegalicia.es/video/coruna/2017/04/03/cemento-hormigon-concha-mejillon/0031_2017045383189179001.htm?jwsource=em).

However, due to the fact that many construction materials are strictly regulated for performance and safety (as described in EU Regulation No. 305/2011), caution should be exercised when making such recommendations. At this time, shell incorporation in aggregates and mortars is largely primitive, and more research is needed to see shell aggregates as an established building material market.

Biofilter Medium

A substantial amount of study has been done on the use of mollusc shells as a biofiltration medium for wastewater treatment. However, much of that research does not directly employ shells but rather pre-treats them with calcination or pyrolysis to produce CaO. This modified product is then revealed to be an effective filter medium.[16] However, as previously indicated, high-energy shell conversion is not yet considered a viable or scalable solution to the problem of large-scale shell waste. The suitability of uncalcined/unpyrolyzed shells as biofilter mediums is a more feasible for potential large-scale valorization scope.

The European Water Framework Directive's aquatic environment quality standards necessitate a significant reduction in nutrient load from agricultural land. According to the SupremeTech research project, subterranean highways can be disconnected by deploying artificial wetlands and drainage filters to collect nutrients lost by agricultural drainage, lowering nutrient loads in the aquatic environment. The combined effect of water temperature, hydraulic residence time (HRT), and filter design is critical for optimal performance.

The horizontal constructed wetland performed best with an annual removal of total N (TN) amounting to 53 to 54% of the load, corresponding to a daily removal of 2.16 to 2.32 g N m^{-3} d^{-1}. During summer, when the hydraulic load was low and HRT was up to >96 h, N removal was about 100%.[17]

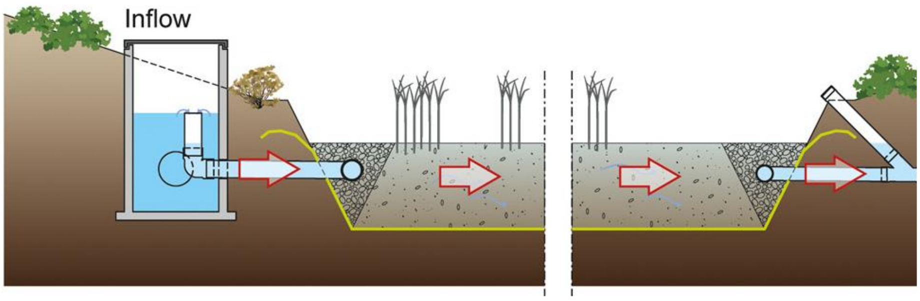

Figure 4 Principal sketch of subsurface flow constructed wetlands (SSF-CWs) with the horizontal flow.[17] The SSF-CW components include inlet wells, perforated distribution pipes, a coarse granular distribution layer in inlet and outlet zones, and woodchips–seashell biofilter matrix. (Adapted with permission).

Waste oyster shells were applied in a mangrove demonstration area of Fengtang Tidal River of China as an active filler for treating combined wastewater of the estuary with a treatment volume of 5 × 103 m3/day.[18] The mixed pollution system of freshwater from an inland river and tidal water from a tidal river from the sea or ocean is referred to as combined wastewater at estuaries. The quality and quantity of tidal river water at an estuary dramatically change under the influence of the tide and is vastly different from freshwater river pollution, making combined wastewater treatment at estuaries a complex task. The wastewater was first pushed into the bio-contact oxidation tank using a submersible sewage pump, which was then filled with waste oyster shells (Figure 5). Secondly, after a hydraulic retention time, the treated wastewater flowed into the clarifying tank, and the effluent water was discharged into the Fengtang Tidal River from the outflow. Finally, due to progressive sedimentation in the filler, these waste oyster shells had to be discharged back into the bio-contact oxidation tank once the majority of the empty space had been filled up after a long period of operation.

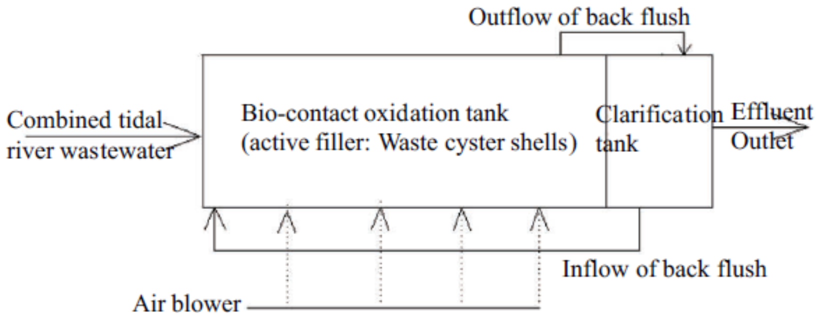

Figure 5 Tidal River wastewater treatment equipment and process

In this bio-contact oxidation process, the average removal efficiency of COD, BOD, NH3-N, TP, and TSS was 80.05%, 85.02%, 86.59%, 50.58%, and 85.32%, respectively.

Sustainable use of shell waste in low-tech low-volume applications

The following valorization outcome still needs to be process optimization, validation for industrial pre-scale trials, production cost, techno-economic and environmental feasibility for industrial-scale development and life cycle analysis.

Heavy Metal Adsorbents for Soil

Both aragonite-rich razor clamshells and calcite-rich oyster shells were used to test the usage of mollusc shells as a treatment for heavy metal contaminated wastewaters. Because calcite-rich shells are more common in geological $CaCO_3$, James P. Morris et al. argue that aragonite-rich shells could be useful in wastewater treatment facilities.[14]

A study by Osorio-Lopez et al. in 2014 at Galicia (Spain) shows that application of ground mussel shell increases heavy metals adsorption into it like Arsenic and decreases the release of it into the soil and hence reducing the risk of heavy metal pollution into soil and plant.[19] C. Torres-Quiroz *et al.* investigated the performance of oyster shells, zeolite and red mud in stabilizing two actual samples of sandy soil contaminated with toxic metals at the laboratory scale, with the pollution levels close to permissible limits.[20] Oyster shell powder can immobilize multiple metals in contaminated soils. The heavy metal ion immobilization efficiency follows the order of: Pb2+ > Cu2+ > Zn2+ > Cd2+ > Ni2+, where the proportions of immobilized Pb and Cu ions are up to 82% and 78%, respectively.[20]

Two fundamental phenomena explain the natural oyster shell (NOS) ability to remove pollutants: first, the ionic interaction between ions and the surface of the NOS; and second, the precipitation of insoluble salts on the NOS surface due to the presence of carbonate, calcium, and hydroxyl. As demonstrated by the varied adsorption behaviours between the prismatic and nacreous layers, the shell structure and microstructures can influence NOS' ability to absorb contaminants.[21]

Ponds and Aquaria

Shells have a relatively small market in ponds and aquaria as filtration and pH buffering mediums.[14] Due to the presence of algae/plants and respiring creatures and the corresponding variation in dissolved CO_2, the pH of ponds and aquaria varies according to day/night cycles. However, maintaining a constant pH flux is critical for healthy ponds and aquaria. Crushed shells are sold as simple pH buffering substrates to prevent severe acidification. They are sold for use in trickling and biological filtering systems for their ability to remove unwanted water pollutants, such as heavy metals, in addition to their pH buffering capabilities.

Artificial Stones

Artificial stones are typically made from waste materials, including quartz sand, stone sludge, and scrap glass.[22] The mechanical qualities of the oyster shell powder blended with unsaturated polyester resin are equivalent to natural stones and other commercial artificial stones, making it suitable for table tops and workbenches.[23]

This report will further focus on artificial stone production from Oyster shells, presenting an initial assessment of its feasibility for use in processing industries.

Techno-economic Analysis for Artificial Stone Production

The growth rate of the countertop market is 89 billion USD, with a growth rate of 2.8%.[24] The market share of solid surface countertops is shown in Figure 6.[24]

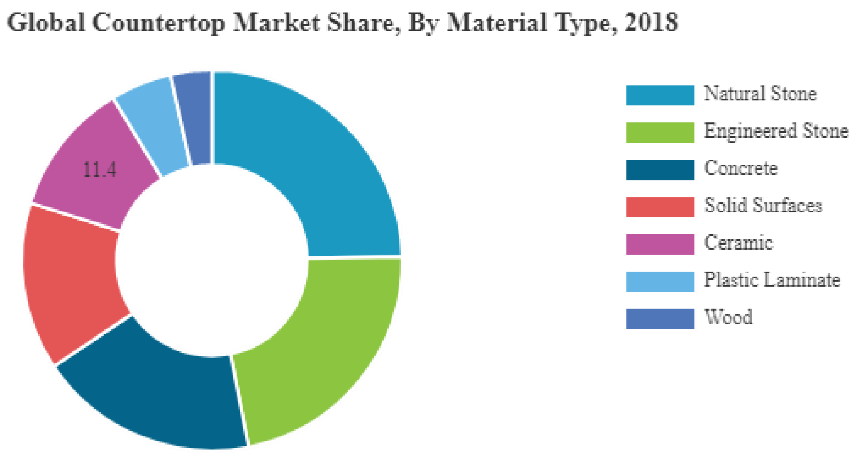

Figure 6 Global Countertop Market Share.[24]

The polyester solid-surface countertops demand is increasing globally due to its being less expensive than another similar performing artificial sloid stones, high chemical resistance performance, brilliant texture, colour and polish. Although it is known to be polyester, solid-surface material is more brittle than acrylic, but the damage is limited to transportation and fabrication, not by customer uses.

A summary of a cost evaluation is done for Donegal Aquaculture Services Ltd, keeping in mind that the company pilot plant premises would utilize the Oyster shell aquaculture industry's mortalities and processing waste. In the pilot processing facility, the techno-economic analysis was done for both Animal By-Product Regulated (ABPR) residual meat containing shell and the "free of meat". Donegal Aquaculture Services Ltd. Already have enough empty space in its existing oyster processing facility. So, cash injection would not be required for renting new premises or the associated cost of personnel and logistics with simple integration of new operational lines.

Figure 7 ***Existing production facility of Donegal Aquaculture Services Ltd.***

Thamyres H. Silva *et al.* have shown that oyster shell resin with unsaturated polyester resin concrete has excellent chemical resistance. But there is also a certain volume shrinkage property.[23] Although they highlighted that reinforced fibre could increase the concrete properties, in this proposed application, the focus of this techno-economic analysis will be just on exploring a few options where reinforced would be needed for light applications such as solid surface countertops. After the proof of concept is validated and reinforcement fibre is needed for the top-end application and better performance, the incorporation of reinforming fibre will be considered.

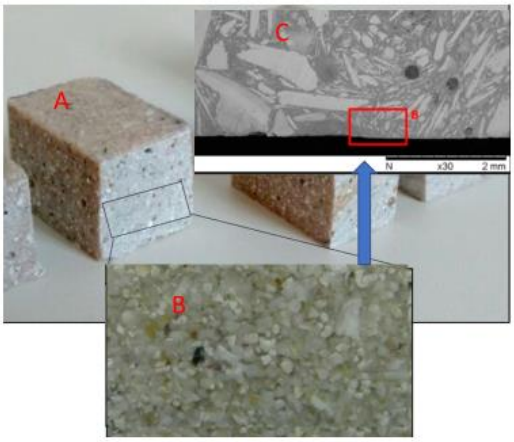

Figure 8 A: Artificial stone made by a Brazilian company by incorporating Oyster shell into unsaturated polyester resin.[23] B: Dispersion of cursed oyster shell into the resin matrix. C: SEM image of packing.

In a recent PhD work, Ana Guimarães calculated that packing the oyster shell of a mixture of coarse particle size of less than one centimetre, and the packing gap is around 62%.[25] So, instead of using 20% unsaturated polyester resin, in this proposed work, the resin will be increased to 25% for better interconnection of resin. Based on the performance, the resin would be tested for 30%. The proposed oyster shell valorization of countertop artificial stone application by moulding with unsaturated polyester resin for the DAS project is shown in Figure 9.

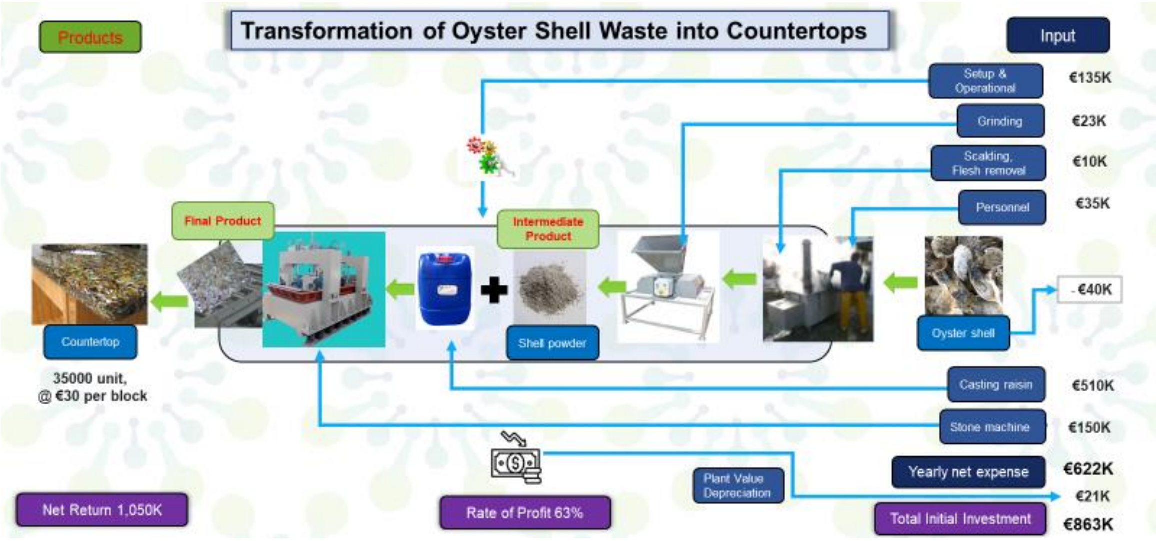

Figure 9 The Schematic view of the techno-economic analysis of oyster shell valorization for artificial countertop application. The input of materials, cost, process, output product, income, depreciation and profits are depicted in this scheme,

The details breakdown of the machinery aquation stage, plant setup, raw material cost, personnel cost and others are calculated in the following tables as accurately as possible with market values. As mentioned earlier, no investment or rental fee was added for the plant premise. Table 7 calculates the main machinery pieces, specification and origin source, freight cost, relevant tax, loan interest, and depreciation rate.

Table 7 Property, Plant and Equipment

Item	**Unit**	**Capacity**	**Power**	**Origin**	**Price ($)**	**Ref.**
Scalding Equipment	1			China	10,000	
Grinding Machine	1	10-25t/h	22kw	China	23,000	A1
Resin Solid Surface Production Line	1		250KW	China	150,000	A2
Freight	All				50,000	A3
Import tax					20,000	
Other minor tools					10,000	
Property, Plant and Installation	No extra cost. Plant space is available at the existing facility. Installation is free with one year warranty					
Total Cost					**263,000**	
Interest in the total cost	@ 4% interest	At ten years of repayment			56,530	
Total setup investment					**319,530**	
Yearly depreciation	For fifteen years period				21,302	
Maintenance	yearly average				5,000	
Yearly investment	Calculating fifteen years of lifetime				**26,302**	

One of the main pieces of machinery is hot water scalding equipment for flesh removal from oyster shells. The grinding machine would be capable of breaking down the oyster shell with a range of fine and coarse powder no longer than 1 cm for the largest size distributed particles. The resin moulding solid surface production line would come up with all necessary automated parts, which a maximum of two personnel could operate. There would be an option for the machinery coating and auto colour spray.

All the purchase costs are shown in USD to ease international price comparison. At the end of each table column, a reference was added for the price comparison of the market. The web link to the references will be found at the end of this document. All the pieces of machinery would come with one year warranty and a free installation offer. It is projected here that the lifetime of machinery will be fifteen years with regular maintenance costs added. By taking into account a bank loan offer, with 4% interest and a ten-year repayment period, and the lifetime of the machinery as fifteen years, the yearly investment in the plant would be around twenty-six thousand euros.

In Table 8, A price comparison of resin, curing agent, coating resin and pigment cost, source of origin for the best value of money, and relevant transportation and import tax is shown with reference.

Table 8 Raw Materials Cost

Item	**Unit Price ($)**	**Quantity**	**Origin**	**Price ($)**	**Ref.**
Polyester Artificial Stone Resin	18,500 1.75/kg	250,000 L	China	437,500	B1
Coating Resin for Artificial Stone Surface	$2.80/kg	7,000 L	China	18,374	B2
Resin Cold Curing Agent	$2.90/kg	2,500 L	China	7,250	B3
Pigment	$100	Ten pots, 5 kg each	UK	1,000	B4
Freight	$18,500	40 feet, Four containers	China	74,000	A3
Import tax				46,312	
Total Cost				**510,436**	

The moulding resin and its transportation cost are found to be the main expenses of the project. If the chemical could be sourced from Europe, it would be nice for reducing carbon footprint and better sustainability. But sourcing the bulk resin from Europe would cost at least two times more than from Asia, but it would still not guarantee that if it were sourced from a European supplier. Whenever an alternative cost-effective and local chemical supply source is found, the supplier can be switched back to local with ease at any time as none of the resin and couloirs are high speciality or sensitive to the product quality.

In Table 9, the labour, electricity and other relevant bills were calculated. It is estimated for the capacity of the machinery that with the input volume of feedstock from the north-west region and output production size, the plant would not be needed to be operational fully for more than six months of the year.

Table 9 Labour and bills

Item	Unit Price ($)	Quantity	Price ($)
labour	35,000/y	Two persons, Six months	35,000
Electricity and water			40,000
Sundry cost			10,000
Total Cost			**85,000**

To ensure a low carbon footprint of the transportation of oyster shell feedstock supply and to keep product selling volume low just for local needs, it is considered in the techno-economic analysis the oyster shell waste collection from only the North-west region. Six months of the operational period would be enough to process those limited volumes of one thousand tons of oyster shells in the proposed artificial stone-making processing line. The hot water scalding and grinding facility could be used by the existing workforce of the DAS when the main moulding line is not operational. As the grounded shell powder could either be stored or sold as an intermediate product if demand arises, the operation of the main stone-making processing facility for six months would be enough. One labour would be enough for full-time at a slow operating period. Otherwise, during busy periods two full-time operators could cover the tasks.

Table 10 estimates the total initial investment with both loan options and without a loan. In the estimation, the labour and raw material cost are also included.

Table 10 Total Initial Investment

Items	Value ($)
Property, Plant and Equipment	263,000
Maintenance	5,000
Raw Materials Cost	510,436
Labour and bills	85,000
Total without a bank loan	**863,436**
For bank loan interest	5,653
Total with a bank loan	**869,089**

Table 11 here is drawn to show how much total yearly expense would be if a ten-year bank loan payback option is considered. It can be seen that nearly 622 thousand euros be the expense in the pilot plant operation.

Table 11 Yearly Total Expenses

Description	**Amount ($)**
Investment (at ten years payback option)	26,302
Raw Material	510,436
Labour and bills	85,000
Grand Total in Euro	**621,738**

In Table 12, the total raw material input volume is calculated to consider both a regional supply of oyster shells and the company's own shell supply.

Table 12 Total Raw material Input Volume

Waste volume Production	tons	Volume (m^3)
Form DAS	315	
North-West regional	1000 to 3000	
Estimated raw shell input from the region	1000	1200
After adding a 25% volume of raisin		1200
Total volume	42378 cubic feet	

Taking the input volume of Table 12 is account, and if the minimum block size of produced solid surface is considered one square foot with a thickness of 1.2 inches. The final produced size and shape are flexible by using different moulding shapes. Considering the produced artificial stone sizes are one square foot, the total production unit would be thirty-five thousand.

Table 13 Annual Production Unit

Item	Total unit
if a solid surface countertop is 1 square foot with 1.2 inches thick	35315
Estimated damaged or faulty items	315
Total Production unit	35,000

Finally, in Table 14, the net yearly profit outcome is calculated based on all the above constraints and flexibility.

Table 14 Yearly Loss/Profit

Product	Unit price (€)	Total unit	Ref	Total price (€)
Minimum price in the market	50	35,000	C1, C2	1,750,000
If sold wholesale	30	35,000		1,050,000
Saved disposal cost	80/t	1000		80,000
Goods and feedstock transportation & storage costs at the processing site	40/t	1000		-40,000
Net profit from wholesale at minimum price				1090,000
Net expenses				641,674
Net profit from wholesale				**63%**

In the bottom row of Table 14, the very conservative profitably is shown by considering the minimum price expectation at a wholesale market. It could be found in the reference of C1 and C2 that the resin solid surface countertop prices in the market range from $50 to $125 per square foot. As it is likely to be sold the produced products in the local market, the actual selling price per unit would be around the lower end of the market price of fifty euros per unit. At this very conservative price output, the profit is projected to be 63%. If continuous product development is performed with local needs and tests, the profitability could easily suppose more than 100% of the yearly expense. The high return would encourage the company to explore more product ranges with comprehensive product features.

Summary of the Techno-economic Analysis

A summary of key partners, activity, resources, value proposition, product selling channel, customer segments, revenue streams and challenges are highlighted at crucial bullet points:

Key partners, activities and resources

Supply

- Oyster shell waste.
- Chemicals (unsaturated polyester raisin, coating and colouring agent, electricity, water, labour)

Processing

- Collection of waste and mortality of Oyster farm from Northwest region.
- Hot water washes to remove residual flesh from the oyster shell.
- Grinding of shell into >1 cm coarse powder.
- Casting of shell powder with raisin into the solid surface countertop.
- Dispose of flesh material and recycle the wash water.

- Supply the shell powder and countertop to the regional

Value propositions

Countertop

- The semi-translucent polyester resin and oyster shell-filled countertop could bring sustainability and elegant product to home furniture, kitchen and bathroom of various sizes and shapes.
- As the coated countertop will be nonporous, it will be fungal and bacterial growth protective with a quick and easy-to-clean countertop solution with a competitive price to the locals.

Oyster shell Powder

- The oyster shell powder could be directly sold in the market as an alternative to mineral calcium oxide source for the Northwest region's farmers and relevant industry.
- Supplement of this shell powder for livestock feed would provide a bone health benefit.
- The shell powder could also be sold as a soil amendment, biofiltration media, and buffering agent for the pond and aquaria sector.

Other social benefits

- Sustainable and high-value application of local environmental nuisance.
- Local value chains boost local prosperity.

Product selling channels and customer segments

Oyster shell Powder

- Oyster shell powder end-user industries are healthcare, feed, cosmetics, and watercourse management, and various industries that use the natural oyster shell for biofiltration.
- Liming or soil amendment is the second biggest application of the shell market.
- Construction industries can also use the shell powder for other aggregates than for countertop
- The fine chemical industries and the pharmaceutical industry have a demand for natural and calcinated oyster shell powder for medical uses and catalytical works, and material synthesis.

Countertop

- The countertop has a growing market in Kitchen, bathroom, decorative furniture and in laboratory benchtop furniture market.
- Due to look, colour variation possibilities and style, the good quality artificial stone will enter into green concrete market mineral stone applications also.

Revenue streams

Solid Surface Countertop

Annually, 3500 units of one square foot solid surface artificial countertop could be sold into the wholesale market at an attractive price of 30 euros per piece. The annual return would be at least a million euros.

Oyster shell powder

When market demand arises, the oyster shell powder could be sold in agriculture, animal feed market and environmental and at local industries in the region with a price of one to two euros per/kg based on selling size.

Saving on Disposal Cost

The proposed project would save an annual seashell disposal cost of 80,000 euros for the Oyster farms and processing SMEs in the Northwest region

Challenges

- High initial investment.
- Competition with similar replacement products in the market.
- Cost of research on high-quality product development.
- A thorough comparison of market product prices and production costs.
- A year-round supply of oyster shell processing waste.
- Maintaining the processing plant to guarantee a steady performance.

Conclusions

Any recycling process's economic viability is determined by two key parameters: the cost and logistics of collecting the shell on the one hand and the added value of the recycled product. In an ecologically friendly attitude, the formation of pollutants, emissions, or new waste must be reduced; however, this may be acceptable if the final product's increased value can cover the treatment cost in environmentally friendly settings. Natural waster shell is a desirable raw material for fundamental applications such as animal feeding that require low-cost and straightforward processing procedures on a big scale. The balance between the cost of collection/decontamination/processing and the added value of the product and its use determines the economics of recycling. This recycled product demand may alter as a result of customers' increased awareness of environmental issues. In this report, some sustainable use of low-tech high volume and low-tech low volume product valorization option of the oyster shell are highlighted with respect Irish scenario. A very prospective techno-economic analysis is estimated for a pilot plant taking account of the Irelands Northwest regions. Oyster cultivations shell waste problem faced by the industries, locals and the environmental regulatory authorities. Here the unsaturated polyester-supported oyster shell-based artificial solid surface countertop valorization scope is analyzed, and the outcome seems very promising. A summary of key partners, activity, resources, value proposition, product selling channel, customer segments, revenue streams and challenges are identified for the future direction of this promising route of oyster shell valorization scope.

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A2:Jinlu Manual Acrylic Resin Solid Surface Production Line,Acrylic Corian Artificial Marble Stone Solid Surface Production Line - Buy Polyester Resin Solid Surface Production Line Acrylic Solid Surface Making Machine Line Corian Sheet Machine,Corian Hanex Lg Staron Acrylic Mma Solid Surface Stone Manufacturing Machinery,Polyester Solid Surface Production Line Acrylic Solid Surface Making Machine For Corian Dining Table Corian Wall Panel Product on Alibaba.com

A3: https://www.freightos.com/freight-resources/container-shipping-cost-calculator-free-tool/

B1: Factory Direct Sales Standard Polyester Artificial Stone Resin Artificial Stone Resin - Buy Artificial Stone Resin,Standard Polyester Artificial Stone Resin,Factory Direct Sales Product on Alibaba.com

B2: Coating Resin Unsaturated Polyester Resin Price Used For Artificial Stone Surface - Buy Buy Resin For Artificial Marble Tile,Surface Coating Resin,Surface Coating Polyester Marble Resin Product Product on Alibaba.com

B3: Catalyst For Unsaturated Polyester Resin /curing Agent Mekp - Buy Mekp,Catalyst For Unsaturated Polyester Resin,Curing Agent Product on Alibaba.com

B4: Amber Transparent Polyester Pigment (ecfibreglasssupplies.co.uk)

C1: https://countertopguides.com/materials/resin-countertops.html

C2: https://www.dwell.com/guide/how-much-to-spend-on-kitchen-countertops-5b813888