ROADMAP

Reusing Oyster Shells in Construction Materials from Aquaculture Waste

Authors

Moreira, N.; Bellei, P.; Magalhães, F.; Mendes, M.P.; Vasco Silva, R.; Jenssen, M.; Pereira, M. F.; Dias, A.P.; Solstad, R.; Flores-Colen, I.

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PREFACE

The SHELLTER project is born from a strong belief in the practical application of sustainable development, not just as a requirement but as a collective responsibility that includes all sectors of society. Where the blue circular economy is concerned, the ocean and its resources play a vital role. As a result, it is crucial to explore inventive solutions to mitigate our environmental challenges.

Aquaculture, a key player in food production and the global economy generates substantial waste that is often discarded without proper handling. Oyster shells, which are abundant yet highly underutilized, emerge as a standout waste material. It is within this context that SHELLTER finds its inspiration and purpose.

The project aims to repurpose what is conventionally considered waste into a valuable resource for the construction industry. By recycling oyster shells, SHELLTER not only assists in waste reduction and marine ecosystem preservation but also explores new possibilities in material engineering. The belief is that future sustainable solutions will arise from the innovative reuse of Shellfish Industrial Waste.

May this project mark an important turning point in converting challenges into opportunities, and may SHELLTER become a benchmark for innovative constructive solutions for the blue circular economy and a more sustainable world.

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INTRODUCTION

The **Shellter** project, initiated in September 2022 at Instituto Superior Técnico in collaboration with Nofima, aims to reduce the environmental impact caused by aquaculture waste and invasive bivalve species by incorporating oyster shells into civil construction.

To understand the interdependencies and develop the best strategies to achieve the project's objectives, all stages of the process of transforming oyster shells from aquaculture into construction materials must be carefully mapped.

Roadmapping is a tool successfully applied in various fields and aims to provide a clear and structured view of the steps necessary to reach a specific goal, guiding teams and individuals from conception to successful implementation. It facilitates communication among all stakeholders, ensuring that everyone is aware of the project's progress and upcoming steps.

Thus, the main objective of this document is to develop the fundamental principles for a roadmap that will facilitate the understanding of the stages and challenges associated with applying oyster shells in construction materials.

SHELLTER PROJECT

The SHELLTER project aims to contribute to the circular blue economy by reducing pollution caused by aquaculture waste or invasive species in the environment through the use of oyster shells in composites, boosting the development of new solutions with local materials, increasing the chain value, and reducing the carbon footprint.

THE PROJECT COMPRISED THE FOLLOWING ACTIVITIES

Activities	Timeline
Activity 1: Survey, field research and waste data collection	September, 2022 – February, 2023
Activity 2: Technical feasibility of oyster shell particle size	February, 2023 – December, 2023
Activity 3: Assessment of environmental and economic impacts	August, 2023 – March, 2024
Activity 4: Development of a database and roadmap	January, 2024 – August, 2024
Activity 5: Communication and dissemination	September, 2022 - September, 2024

SOME PHOTOS DOCUMENTION OF THE PROJECT PATH

MEETINGS AND TECHNICAL VISITS IN PORTUGAL

MEETINGS AND TECHNICAL VISITS IN NORWAY

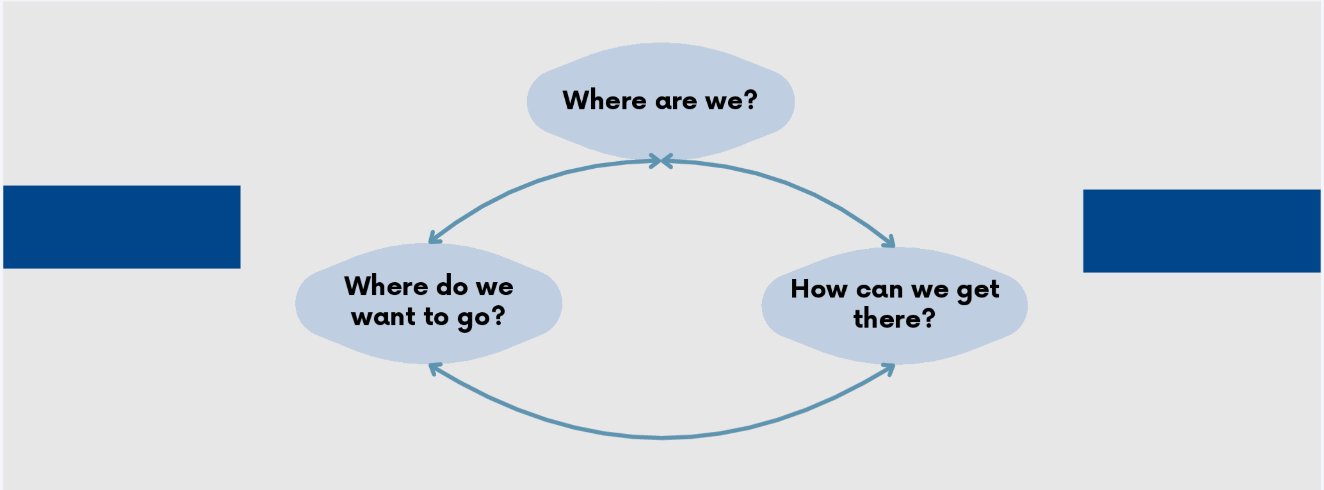
WORKSHOPS – MARÉS FEST AND AQUACULTURE SEMINAR

FINAL WORKSHOP SHELLTER PROJECT

WHAT IS A ROADMAP?

GENERAL DESCRIPTION

A roadmap provides a structured plan guiding teams and individuals from an idea to its final successful execution. It promotes effective communication, transparency, and outlines essential steps to achieve a defined objective.



Fundamental questions for the development of a roadmap, adapted (Phall and Muller, 2009).

SHELLTER ROADMAP BASELINE

FOLLOWING TOPICS TO BE ADDRESSED:

- **CONCEPTUAL FRAMEWORK**

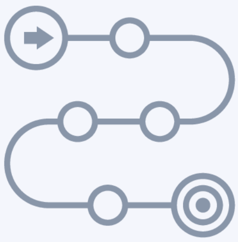
The discussion covers key aspects: issues, interconnectedness, influencing factors, stakeholders, expertise, and characteristics of systems, processes, and technologies.

- **STATE OF THE ART**

Where do we stand currently? This inquiry covers the state of technology, global most common practices, international differences, and identified challenges.

- **FUTURE SCENARIO**

Setting clear goals empowers project leaders to make strategic decisions, evaluate progress, and make timely adjustments for achieving desired outcomes.



- **DEVELOPMENT STRATEGY**

This section outlines the necessary knowledge, information, tools, concepts, and applications required to facilitate the development of respective systems, processes, and technologies over time.

- **RESEARCH CONTRIBUTION**

In the Research Contribution section, we elaborate on how the research conducted within the scope of the Shellter Project enhances the development strategy.

CONCEPTUAL FRAMEWORK

Circular Economy

The growth and development of urban spaces in recent decades have presented complex challenges in the treatment and disposal of waste on a global scale. This economic model, based on the recovery and recycling of resources, is characterized by "low pollution, low waste, and high efficiency," operating according to the principles of "reduce, reuse, and recycle" (Bouldin, 1966).

Blue Circular Economy

The Blue Circular Economy is an extension of the traditional approach and represents a sustainable strategy for resource management, with a specific focus on the sustainable use of marine resources. Given the diversity of the origins of these resources, this model has significant potential for implementing innovative solutions.

Oyster Shells as a Biomaterial

Among the various reusable products, oyster shells derived from the marine industry possess distinct characteristics that set them apart. Often disregarded as post-consumption waste, these shells exhibit unique traits like their irregular shape, and scaly texture, making them valuable across multiple economic sectors.

Calcium carbonate is the primary component of oyster shells. Despite being a widely used resource worldwide, historically most of these shells have been underutilized.

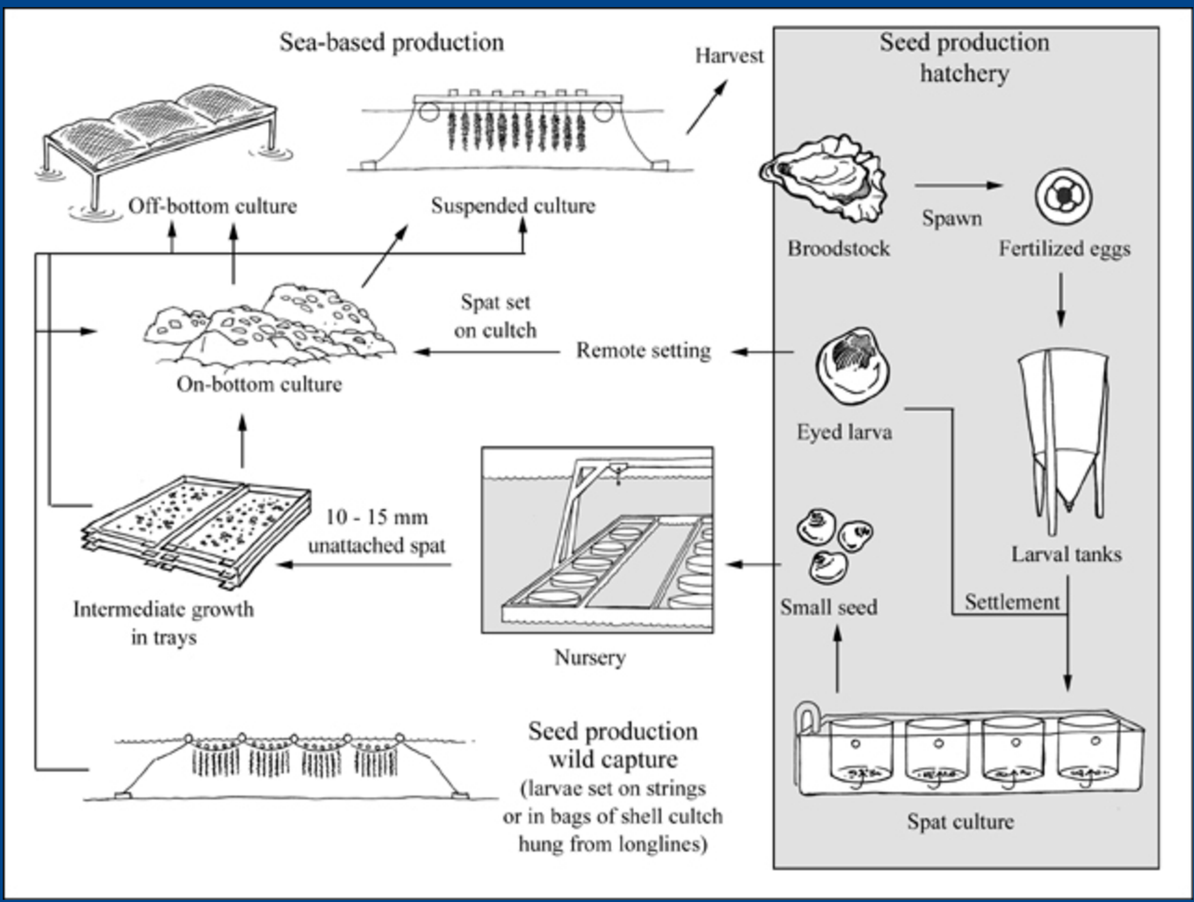
Pacific Cupped Oyster produced in the Algarve - Portugal

An evolution is unfolding as industries progressively recognize the value of reusing oyster shells. This growing interest highlights an increased awareness of the need for sustainable resource management. With ongoing research and technological advancements, the potential uses for these overlooked shells are expected to expand, driving innovation and supporting a more circular economy.

Oyster Shells Aquaculture Production Worldwide

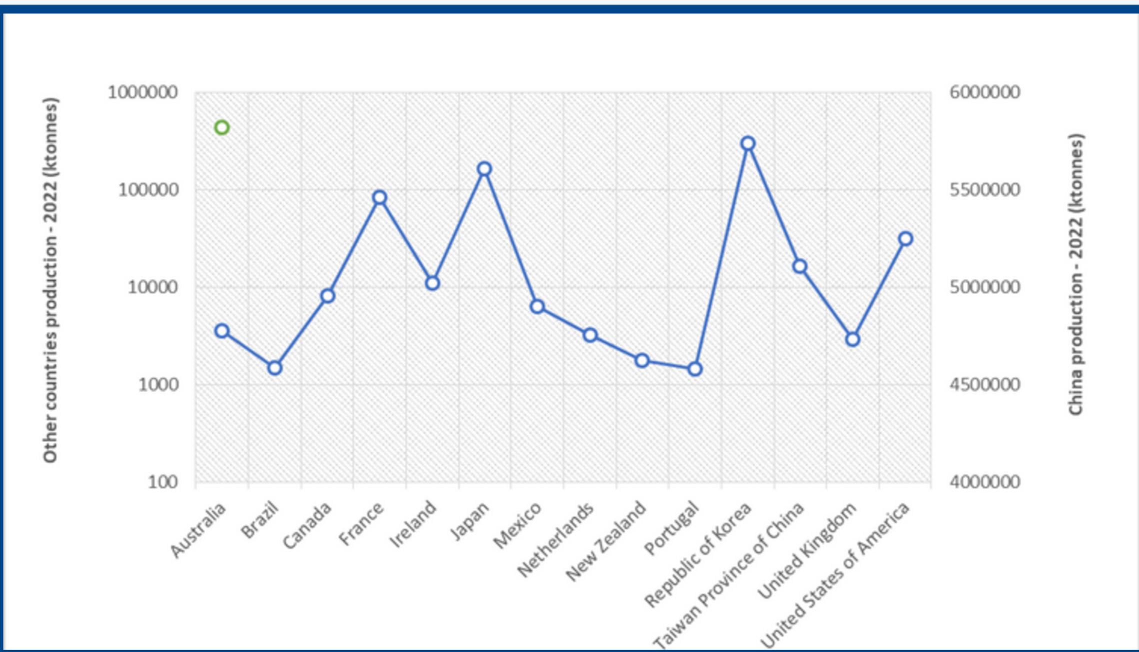
The ***Crassostrea gigas***, known as the Pacific oyster or Japanese oyster, is the most widely cultivated oyster species in aquaculture globally. Originally from Japan, this oyster has adapted to various coastal environments around the world, contributing to its widespread popularity. It is valued for its rapid growth rate and ability to tolerate a wide range of environmental conditions, such as different salinity levels and temperatures.

Crassostrea gigas is appreciated for its delicate flavour and firm texture, making it a popular choice in both local and international markets. Its production is significant in countries like China, Japan, France, and the United States, where it is farmed for both domestic consumption and export, solidifying its position as the leading species in oyster aquaculture.



Production cycle of Crassostrea gigas (© FAO 2024)

Oyster Shells Aquaculture Statistics Worldwide



Top 15 Global Producers in 2022 - © FAO 2024

The Case of Portugal

*Oyster production plays a vital role in Portugal's seafood industry, especially in areas like Ria Formosa, Ria de Aveiro, and Ria de Mira. Initially, the **Crassostrea angulata** (Portuguese oyster) dominated, but the **Crassostrea gigas** (Pacific oyster) is now more prevalent due to its rapid growth and disease resistance(Azeredo et al., 2018).*

The oyster farming sector in Portugal is recognized for its sustainable practices, as oysters aid in water filtration and ecosystem preservation. This industry not only provides employment opportunities and boosts the local economy but also holds a special place in Portuguese culinary traditions and heritage.

Oyster shell from Norway

Oyster shell from Portugal

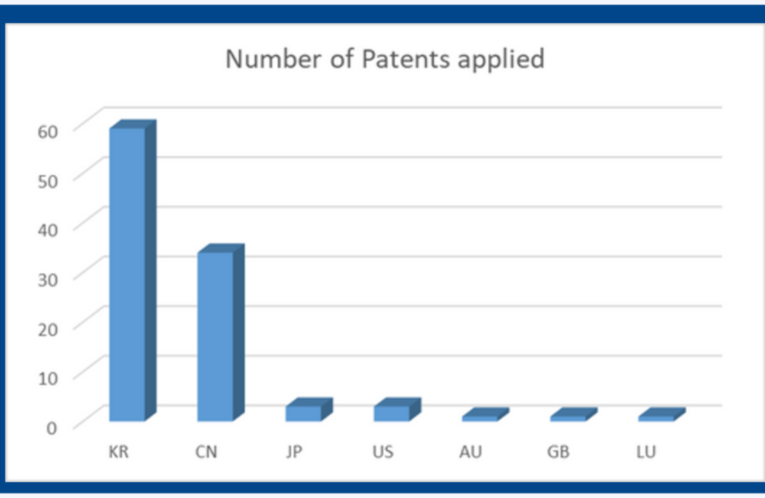
The Case of Norway

In Norway, despite the existence of ***Crassostrea gigas*** (Pacific oyster) and being classified as an invasive species (approximately 72.0 tonnes total in 2017(Mortensen et al., 2022), the cultivation of oysters through aquaculture processes remains relatively limited.

STATE OF THE ART

Research from the extensive global database of the European Patent Office (EPO), covering over 90 countries, shows that in the utilization of oyster shells in civil construction (CPC classification E and oyster shell cited as part of the title or the abstract of the patent), 81 patent results were discovered using the potential of this bioproduct in August 2024. One of the main uses identified was in the construction of artificial reefs and the incorporation of oyster shells into concrete.

Southeast Asian countries like China and Korea have shown significant progress in applying this material in the industry, with most of the patents being applied by them as shown in the graphic below. While this region has heavily invested in this material, other parts of the world are beginning to realize the potential of this natural resource.



Potential use of oyster shells in different domains

In the health and wellness sector, oyster shell powder is considered an excellent dietary supplement for preventing and treating skeletal bone mass loss due to its natural properties that are well-tolerated by the body (Nunes et al., 2006).

When it comes to water treatment, oyster shells are commonly used in various applications. Calcium carbonate derived from oyster shells can effectively eliminate hydrogen sulfide, recover boron from wastewater, and serve as a purifying agent in domestic wastewater treatment as an alternative to traditional methods using gravel (Asaoka et al., 2009; Tsai et al., 2011; Shih and Chang, 2015).

Studies have shown that oyster shell waste can also aid in treating soils contaminated with heavy metals and serve as a biosorbent material for removing pollutants like (SO_2), sulfur trioxide (SO_3), hydrogen sulfide (H_2S), and CO_2 (Moon et al., 2013; Jung et al., 2016).

Furthermore, oyster shells find utility in the aquaculture industry, either as a specially designed concrete reef or as a substrate for cultivating new oysters (Kong et al., 2022).

The application of oyster shells extends to the construction sector, particularly in concrete, a primary material in civil engineering. These shells can substitute cement or aggregates, offering economic and ecological benefits without the need for calcination. Oyster shell powder is also being explored as an asphalt additive to enhance technical performance (Zong et al., 2023).

Examples of oyster shells incorporated in civil construction elements

FUTURE SCENARIO

In the quest for a sustainable future, the creative utilization of oyster shells in the circular economy is attracting considerable interest. Industries and researchers are delving into the possibilities of these natural by-products, emphasizing the need for a comprehensive strategy to enhance their worthwhile reducing environmental harm.

This vision involves incorporating cutting-edge techniques, local planning, and community engagement to reuse oyster shells from refuse into beneficial, environmentally friendly materials that support sustainable progress and economic advancement.

BASED ON THESE PREMISES, THE ROADMAP OUTLINES FIVE EXPECTATIONS TO BE ACHIEVED IN THE UPCOMING YEARS:

Sustainable Approaches for Maximizing the Value of Oyster Shells

Despite the extensive research and development into utilizing oyster shells within the circular economy, sustainable approaches are still needed to enhance the resource's value and reduce waste and associated environmental impacts. To accomplish this objective, a multidisciplinary approach is crucial for analyzing and refining the process.

Regional Mapping and Geographic Information System (GIS) Development

Another crucial aspect is the regional mapping of the needs for shell utilization. Therefore, the development of a Geographic Information System (GIS) is essential to integrate the locations of the different stages at various levels, from local to regional. This will allow for the assessment of operational costs, such as the distances between stakeholders, CO_2 emissions, constraints, and operation optimization, as well as the identification of the best destinations for the product.

Economic Integration and Potential uses for Oyster Shells

By combining knowledge of the regional economies in the areas where oyster shells are produced, it will be possible to select an appropriate application for the material. The dissemination of information on the subject and the preparation of accessible materials for all audiences, from researchers to the general public, are imperative and should be encouraged.

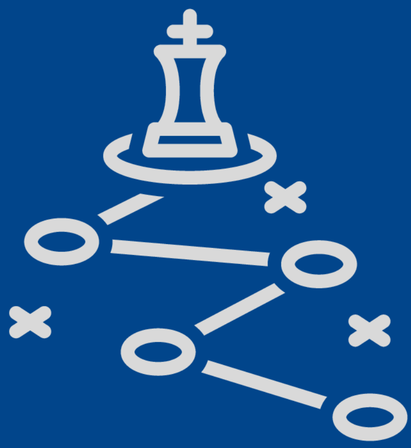
Technical Research and Methodology Development

The development of technical research to assess the chemical and mechanical properties of different shell species is important and should be promoted to enable their widespread adoption. Additionally, establishing a methodology to maximize the efficiency of oyster shell collection, cleaning, and processing, aiming to ensure their maximum utilization and minimal generation of waste and water usage, is essential in the coming years.

Community Engagement and Economic Benefit Distribution

Moreover, engagement with local communities and stakeholders is fundamental to raising awareness about the benefits of using oyster shells and ensuring the equitable distribution of economic benefits. This aims to integrate oyster shell-derived products into existing markets and supply chains, creating new economic opportunities and promoting the growth of sustainable industries.

DEVELOPMENT STRATEGY



Starting from the idea of applying a unified methodology as a development strategy to enhance the production and quality of future research related to the application of oyster shells in the construction sector, this approach was chosen to ensure consistency, efficiency, and scalability in the research and development process.

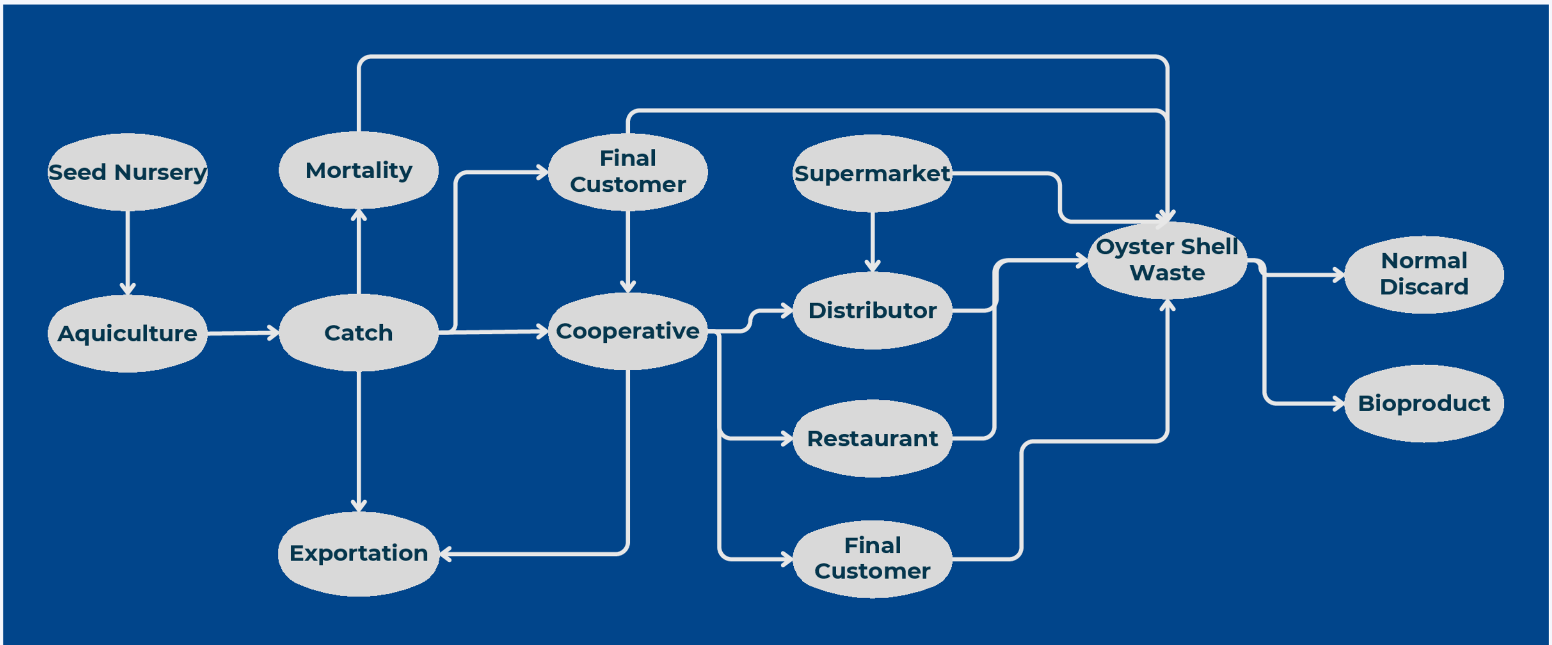
A unified methodology is crucial because it provides a standardized framework that can be applied across different projects and research initiatives, ensuring that all steps -from collection to commercialization- are conducted in a systematic and coordinated manner. This standardization minimizes variability in results, reduces the risk of errors, and allows for the effective comparison and integration of findings from different studies.

Based on these considerations, a **seven-step** roadmap has been developed: 1) Collection; 2) Transportation; 3) Sorting and Cleaning; 4) Identifying potential shell waste applications; 5) Processing; 6) Product development; and 7) Sharing outcomes and pursuing commercialization.

Step 1 - Collection

The first step consists of collecting oyster shells, which can occur post--consumption or before the oysters are commercialized. In the first case, it is necessary to establish partnerships with consumers and implement a collection process that can add value to this waste.

In the second case, the collected product would be the result of elevated oyster mortality during aquaculture, with an average of 10 to 30% of the production. The circuit below, developed by Magalhães et al. (2024), presents the circuit of the bivalves from production to possible waste destinations based on the Portuguese production chain.



Bivalves Circuit by Magalhães et al., (2024)

SURVEY IN OLHÃO AND CULATRA ISLAND, PORTUGAL, APRIL 2023

Step 2 - Transportation

After collecting the product, it must be transported to a facility that can operate as a sorting and cleaning area. At this facility, an initial sorting is performed, and other materials that may be mixed with the shells are removed.

Transporting oyster shells as aquaculture residue from Culatra Island to Lisbon.

Mechanical cleaning of the oyster

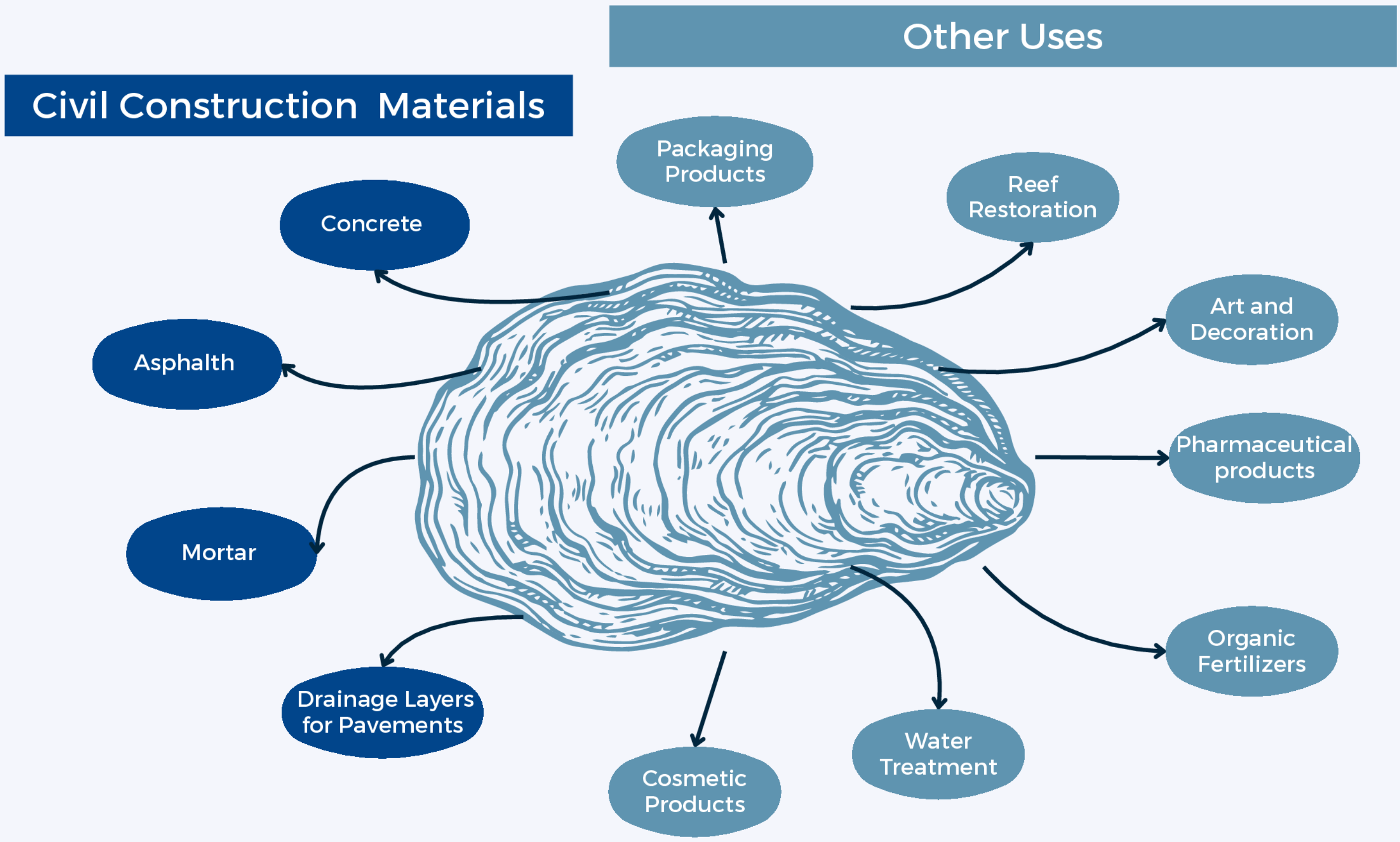
Step 3 - Sorting and Cleaning

Next, the material must be cleaned to remove organic residues or other impurities that may be associated with the product (Bellei et al., 2023b; Magalhães et al., 2024)

Step 4 - Identifying potential Shell waste applications

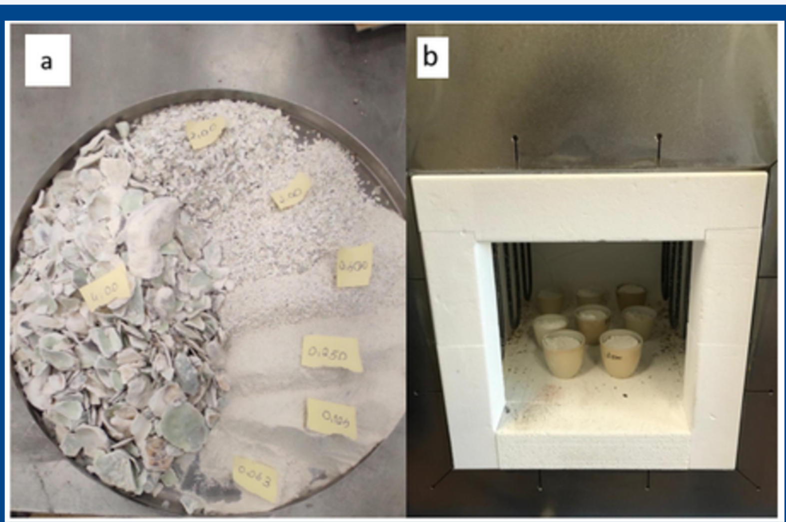
After the sorting and cleaning phase, it is important to understand the main applications of oyster shells in the construction sector. According to Bellei et al. (2023a), most studies focus on using oyster shells for concrete production, representing 79% of the cases analyzed. Only 21% of the articles address coating and bedding mortars (lime mortars), indicating the need for further research on the use of mortars with other binders and for other applications (Bellei et al., 2023b; 2024).

Oyster shell waste holds significant potential across various applications due to its high calcium content, primarily in the form of calcium carbonate.



Step 5 - Processing

The processing stage depends directly on the previous one, as the size and type of particles are defined by the future potential use of oyster shells. Depending on the research and planned application, the type of material after processing can have various particle sizes:
i) coarse aggregate (particles ≥ 4.00 mm); ii) fine aggregate (0.150 mm < particles < 4.00 mm); iii) powder; iv) calcined powder.



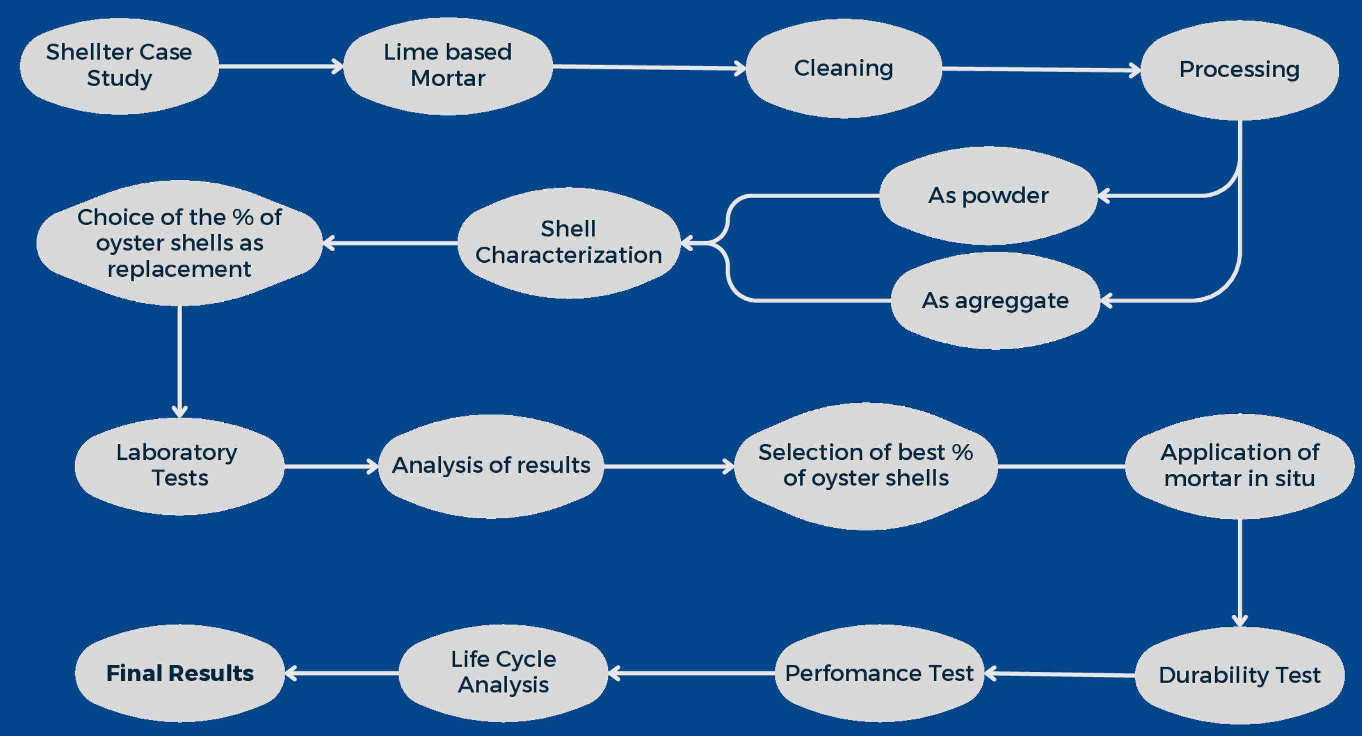
Example of varied granulometries of processed oyster shells (a) and calcined oyster shell powder (b).

Step 6 - Product development

The analysis of different mixtures is the most critical stage because it is directly related to product development. It is essential to determine the optimal proportion of oyster shells and the appropriate particle size (such as powder or aggregate) for each type of material to optimize application performance.

After defining the proportion of oyster shells in the composite, conducting laboratory tests is crucial to ensure the quality and reliability of the construction materials. These tests provide data on the mechanical behavior and long-term performance of the mixtures, allowing for the optimization of the proposed solution before widespread implementation.

As a case study based on Bellei, P. PhD thesis (ongoing), the Shellter project used the following flowchart for this stage of product development.



Product Development Flowchart - Shellter Case Study

Step 7 - Sharing outcomes and pursuing commercialization

Finally, commercialization and dissemination of results are essential to promote awareness, validate performance, drive market adoption, influence regulatory acceptance, and support education and outreach efforts.

Accelerating the transition to more sustainable and resilient construction practices that leverage the unique properties of oyster shells.

The final workshop of the Shellter project took place in May 2024, with the participation of AECycle, CIMA Ualg (Centre for Marine and Environmental Research, University of Algarve), Itecons, IGOT/Lab. Terra (Institute of Geography and Spatial Planning), AOF - Augusto de Oliveira Ferreira, Lda., CiTUA (Territory, Urbanism, and Architecture, IST) and the Norway Embassy in Lisbon. The workshop was supported by EEA Grants Portugal and hosted by DECivil Técnico.

Complementary Analysis

To complement the proposed unified methodology and the integration of oyster shells into civil construction materials, a SWOT analysis was conducted to assess strengths, weaknesses, opportunities, and threats.

The SWOT analysis serves to identify the internal strengths and weaknesses of the methodology, such as the benefits of a unified approach and potential logistical challenges. Additionally, it explores external opportunities and threats, including market expansion possibilities and regulatory barriers.

SWOT Analysis

Strengths

S

- Sustainability Innovation in the Blue Circular Economy;
- Versatility to be used in various sectors;
- Encouragement of scientific development in the area.

Weaknesses

W

- Limited availability geographically;
- Lack of planning collection schemes;
- Lack of incentive to separate post-consumer shells;
- The absence of a business model that sustains their feasibility in the market;
- Different agents are involved in the process, but often there is no interconnection between them.

Opportunity

O

- Encouraging sustainable consumption;
- Adding value to an otherwise considered waste product;
- Potential to drive innovation and promote sustainable development;
- Waste reduction may result in tax incentives or subsidies for sustainable projects.

Threat

T

- Competition with traditional materials;
- Uncertain economic viability;
- Apprehension towards adopting new products in the construction sector;
- Occurrence of unexpected events of high impact, such as unusual mortality rates.

RESEARCH CONTRIBUTION

PUBLISHED SHELLTER PROJECT RESEARCH CONTRIBUTIONS

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FINAL CONSIDERATIONS

The global waste management crisis requires actions to address the increasing production and improper disposal of waste. The circular economy presents a promising solution by promoting the continuous use, recycling, and restoration of materials. In this context, innovative approaches are essential to reduce the environmental impact.

The SHELLTER project exemplifies such innovation by transforming oyster shells from a waste product into valuable biomaterials for the construction industry. The project outlines key stages through a detailed roadmap, from shell collection and processing to their use in construction materials like concrete and mortar. This not only reduces waste but also supports the principles of the blue circular economy by creating economic opportunities and reducing environmental damage.

As the global community continues to explore solutions for waste reduction, this initiative is expected to inspire further studies and applications of marine waste, advancing efforts toward a more sustainable future in the construction sector and beyond.

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The agreement on the European Economic Area (EEA), Iceland, Liechtenstein, and Norway are partners in the internal market with the Member States of the European Union. As a way to promote a continuous and balanced strengthening of economic relations and trade, the parties to the EEA Agreement have established a Financial Mechanism year, known as EEA Grants. EEA Grants aim to reduce social and economic disparities in Europe and strengthen bilateral relations between these three countries and beneficiary countries.

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ANNEX

SHELLTER ROADMAP SUMMARY (IN ENGLISH)

The SHELLTER project aims to contribute to the blue economy by reducing pollution caused by aquaculture waste or invasive species in the environment through the use of oyster shells in composites. The activities developed within the scope of the project have enabled the creation of a roadmap which outlines the key stages, from conception to the implementation of oyster shells as a biomaterial in construction.

The first stage of the roadmap is the collection of oyster shells. In the case of the project, the shells were obtained directly from oyster producers due to their high mortality rate during cultivation. However, shells can also be collected after consumption, for example, from seafood restaurants or directly from consumers. This stage can be improved with the support of local governments by providing containers for shell collection, encouraging restaurants and consumers to separate shells from food waste, and raising awareness among fishers to create new opportunities from aquaculture-generated waste.

After collection, the shells are transported to processing sites (second stage). Efficient transportation logistics are crucial to minimize costs and environmental impact. Therefore, collection points close to shell processing sites are important to reduce carbon emissions. In the third stage, they undergo sorting to remove wastes and washing to eliminate organic matter and salts. The shells must meet quality requirements to be used as construction material, meaning they must be cleaned to meet at least the minimum standards.

The fourth stage identifies the potential for oyster shell application in the construction sector. The shells are prepared depending on the construction material being manufactured (e.g., concrete or mortar). Several variables need to be chosen, such as the type of conventional raw material being replaced, the percentage of replacement, particle size, and type of thermal treatment.

The processing stage (fifth stage) involves crushing the shells into coarse particles or fine powders, depending on the intended use. After crushing, the shells and the composites produced with this biomaterial are characterized. Laboratory tests are essential to assess the physical and mechanical properties, as well as the durability of the materials. Based on the performance of the mixtures, optimal compositions are defined, which must meet industry standards and performance criteria.

The sixth and final stage focuses on sharing the results and promoting the commercialization of shell-based products. The research findings on shells must be disseminated to engage stakeholders and encourage government incentives for practices that support more sustainable construction.

This roadmap aligns with the principles of the blue economy, impacting the following dimensions: sociocultural by influencing a practice with a longstanding local cultural identity; environmental by reducing environmental impact and enabling waste recovery, and economic by creating opportunities for shell reuse in the aquaculture industry, also promoting job creation. These impacts can affect more than one dimension because they are interconnected. The seven stages outlined in the SHELLTER project Roadmap aim to ensure consistency, efficiency, and scalability in the use of oyster shells in construction materials.

SUMÁRIO DO ROTEIRO DO SHELLTER (IN PORTUGUESE)

O projeto SHELLTER visa contribuir para a economia azul, reduzindo a poluição causada por resíduos da aquicultura ou espécies invasoras no meio ambiente, através da utilização de conchas de ostras em compósitos. As atividades desenvolvidas no âmbito do projeto permitiram criar um roadmap, que delineia as principais etapas, desde a concepção até à implementação das conchas como biomaterial na construção.

A primeira etapa do roteiro é a recolha das conchas de ostras. No caso do projeto, as conchas foram obtidas diretamente com os produtores de ostra, devido a elevada mortalidade do animal ocorrida durante o cultivo. Porém, as conchas também podem ser recolhidas após o consumo, por exemplo, em restaurantes de produtos do mar ou junto aos consumidores finais. Esta etapa pode ser melhorada com o apoio do governo local na disponibilização de contentores para recolha das conchas, pela adoção de práticas por parte de restaurantes e consumidores na separação das conchas dos restos alimentares, e pela sensibilização dos pescadores para criarem novas oportunidades a partir dos resíduos gerados pela aquacultura.

Após a recolha, as conchas são transportadas para os locais de processamento (segunda etapa). Uma logística de transporte eficiente é crucial para minimizar os custos e o impacte ambiental. Deste modo, pontos de recolha próximos aos locais de processamento das conchas são importantes para reduzir emissões de carbono. Na terceira etapa, as conchas passam por uma triagem para remover residuos que não serão aproveitados no processo, além de uma lavagem para eliminar matéria orgânica e sais. As conchas devem cumprir requisitos de qualidade para que possam ser utilizadas como material de construção. Logo, as conchas devem ser limpas até que atendam o mínimo desses requisitos.

A quarta etapa identifica o potencial de aplicação das conchas de ostra no setor da construção. As conchas são preparadas dependendo do tipo de material de construção a ser fabricado (por exemplo: betão e argamassa). Algumas variáveis devem ser escolhidas, como: tipo de matéria-prima convencional a ser substituída, percentagem de substituição, tamanho de partícula, e tipo de tratamento térmico.

A etapa de processamento (quinta etapa) envolve a trituração das conchas em partículas grossas ou pós finos, dependendo do uso pretendido. Após a trituração as conchas são caracterizadas assim como os compósitos produzidos com este biomaterial. Os testes laboratoriais são fundamentais para expressar os comportamentos físicos, mecânicos e a durabilidade dos materiais. A partir dos comportamentos apresentados pelas misturas definem-se as composições ótimas, as quais devem cumprir os padrões e critérios de desempenho da indústria.

A sexta e última etapa concentra-se em partilhar os resultados e promover a comercialização de produtos à base de conchas. Os resultados das pesquisas realizadas com conchas devem ser disseminados, para que haja o envolvimento das partes interessadas, e incentivo do governo para práticas que apoiam uma construção mais sustentável.

Este Roteiro alinha-se com os princípios da economia azul, afetando as dimensões: sociocultural, ao interferir numa prática com identidade cultural local estabelecida há muitos anos; ambiental, ao reduzir o impacte ambiental e possibilitar a recuperação de resíduos; e económica, ao criar oportunidades para aproveitamento das conchas na indústria da aquacultura, promovendo também a geração de empregos. Esses impactos podem afetar mais de uma dimensão, pois estas estão interligadas. As sete etapas indicadas no Roadmap do projeto SHELLTER buscam garantir consistência, eficiência e escalabilidade da utilização das conchas de ostra em materiais de construção.

SHELLTER VEIKART SAMMENDRAG (PÅ NORSK)

Prosjektet SHELLTER har som mål å bidra til blå økonomi ved å redusere forurensning forårsaket av avfall fra havbruk eller invasive arter i miljøet, gjennom bruk av østersskjell i kompositter. Aktivitetene utviklet innenfor rammene av prosjektet har gjort det mulig å lage et veikart som skisserer de viktigste stadiene, fra konsept til implementering av østersskjell som biomateriale i byggebransjen.

Den første fasen av veikartet er innsamling av østersskjell. I prosjektet ble skjellene hentet direkte fra østersprodusenter på grunn av høy dødelighet blant dyrene under oppdrett. Skjellene kan imidlertid også samles inn etter konsum, for eksempel fra sjømatrestauranter eller direkte fra forbrukerne. Denne fasen kan forbedres med støtte fra lokale myndigheter ved å tilby containere for innsamling av skjell, ved å oppmuntre restauranter og forbrukere til å skille skjell fra matavfall, samt ved å øke bevisstheten blant fiskere for å skape nye muligheter fra avfall generert av havbruk.

Etter innsamling blir skjellene transportert til prosesseringsanlegg (andre fase). Effektiv transportlogistikk er avgjørende for å minimere kostnader og miljøpåvirkning. Innsamlingspunkter nær prosesseringsanleggene er derfor viktige for å redusere karbonutslipp. I den tredje fasen sorteres skjellene for å fjerne avfall og vaskes for å eliminere organisk materiale og salter. Skjellene må oppfylle kvalitetskrav for å kunne brukes som byggemateriale, noe som betyr at de må rengjøres til de minst oppfyller minimumskravene.

Den fjerde fasen identifiserer potensialet for bruk av østersskjell i byggesektoren. Skjellene forberedes avhengig av hvilken type byggemateriale som skal produseres (f.eks. betong eller mørtel). Flere variabler må velges, som type konvensjonelt råmateriale som skal erstattes, erstatningsprosent, partikkelstørrelse og type termisk behandling.

Behandlingsfasen (femte fase) involverer knusing av skjellene til grove partikler eller fint pulver, avhengig av ønsket bruk. Etter knusing blir skjellene og komposittene produsert med dette biomaterialet karakterisert. Laboratorietester er essensielle for å vurdere de fysiske og mekaniske egenskapene, samt holdbarheten til materialene. Basert på blandingens ytelse defineres optimale sammensetninger som må oppfylle bransjens standarder og ytelseskriterier.

Den sjette og siste fasen fokuserer på å dele resultatene og fremme kommersialiseringen av skjellbaserte produkter. Forskningsresultatene om skjell må formidles for å engasjere interessenter og oppmuntre til statlige insentiver for praksiser som støtter mer bærekraftig bygging.

Dette veikartet er i tråd med prinsippene for blå økonomi, og påvirker følgende dimensjoner: sosiokulturell, ved å påvirke en praksis med en langvarig lokal kulturell identitet; miljømessig, ved å redusere miljøpåvirkningen og muliggjøre avfallsutnyttelse; og økonomisk, ved å skape muligheter for gjenbruk av skjell i havbruksnæringen, og også fremme jobbskaping. Disse virkningene kan påvirke mer enn én dimensjon, da de er sammenkoblet. De syv fasene som er skissert i SHELLTER-veikartet, har som mål å sikre konsistens, effektivitet og skalerbarhet i bruken av østersskjell i byggematerialer.

SHELLTER TEAM

MULTI-EXPERTISE: CIVIL ENGINEERING, MATERIALS, MARINE BIOTECHNOLOGY, ENVIRONMENT, GEOSCIENCES, CHEMICAL, ENGINEERING, ARCHITECTURE.

Inês Flores-Colen (PI), Runar Gjerp Solstad, Manuel F. C. Pereira, Ana Paula Soares Dias, Marte Jenssen, Rui Vasco Silva, Maria Paula Mendes, Poliana Bellei, Fernanda Caroline Magalhães, Nicollas Moreira, Julia Fontoura, and Giovanna Bartels.

Runar Gjerp Solstad

Responsible from Nofima Team

Ines Flores-Colen

PI of the project

Responsible from IST Team

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