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Contribution of Bio-Based Buildings Made with Seaweed and Seagrass in the Construction Industry. A Bibliographic review

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Contribution of Bio-Based Buildings Made with Seaweed and Seagrass in the Construction Industry. A Bibliographic review

Suzanne Segeur-Villanueva*

Universitat Politécnica de Valéncia, Escuela de Doctorado, Camino de Vera, s/n. 46022 – Valencia, España

Natalia Caicedo-Llano

Universidad Tecnológica Metropolitana, Facultad de Ciencias de la Construcción y Ordenamiento Territorial, Dieciocho 390, Santiago, Chile

Luis Manuel Palmero Iglesias

Universitat Politécnica de Valéncia, Departamento de Construcciones Arquitectónicas, Camino de Vera, s/n . 46022 – Valencia, España

Graziella Bernardo

University degli studi della Basilicata, Dipartimento per l´Innovazione Umanistica, Scientifica e Sociale, Campus Universitario Via Lanera, 20 75100 Matera, Potenza, Italy

*Corresponding author: **susevil1@doctor.upv.es**

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Abstract

Due to the construction industry, the climate crisis had deepest environmental impact. In addition to consuming scarce mineral-based materials, the building industry is responsible for up to 39% of global carbon dioxide emissions and the accumulation of solid waste in landfills, rivers, and seas. To cut carbon dioxide emissions and mitigate the effects of climate change on the construction industry, a new, more sustainable, and renewable production matrix must be considered. An approach is using seaweed and seagrass as bio-based materials matrix, from macroalgae or microalgae stranded on the shore or sustainable crops. Transforming algae into usable construction materials involves a process of harvesting, processing, and refining. This article has systematically reviewed the literature about advances and the potential of using marine species as construction materials matrix. To this end, this paper explores the existing literature on architectural projects and research on various species of seagrass and seaweed worldwide.

This review concludes that numerous case studies of dwellings around the world have demonstrated and validated the use of seaweed for applications such as coatings, thermal insulation, and construction additives. Among the most important construction related properties of seaweed are fire resistance, low thermal conductivity, and resistance to moisture and insect damage. For instance, prototypes incorporating Neptune grass (Posidonia oceanica) exhibited a thermal conductivity of 0.044 W/m·K comparable to that of expanded polystyrene, which typically ranges between 0.035 and 0.037 W/m·K.

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The availability of seaweed, considered the waste that pollutes an essential part of the world's coastline, is increasing every year. Nevertheless, not all types of seaweed can be used as construction materials. For this reason, there are some challenges in creating sustainable cultivation of seaweed species, like the need for efficient methods, harvesting, and its processing. In consequence, these costs must be incorporated into the selling price. However, these difficulties do not diminish the seaweed and seagrass's potential as a renewable substitute in the production matrix of the construction industry. These challenges must be overcome before the industrial use of marine species as building materials becomes a reality. Governments must provide financial support to get these initiatives off the ground, especially in the crucial pre-competitive phases. At the same time, the development of prefabrication systems is of vital importance. These systems will enable certification and compliance with building materials regulations and pave the way for a more sustainable future for the industry. It is also necessary to establish seaweed and seagrass cultivation methods that will make the initiative sustainable in the long term, incorporating the costs associated with cultivation, harvesting, and processing into the selling price.
Keywords: bio-based materials; seaweed; seagrass; macroalgae and construction.

Introduction

The construction industry exerts a substantial impact on the ecosystem throughout its life cycle, including solid waste accumulating in landfills, rivers, and marine ecosystems. Contributing significantly to environmental degradation and greenhouse gas emissions. (Liu et al. 2023), (Wang, 2023; Farghali et al., 2023; Yang et al., 2023). In Chile, for instance, it has been quantified that 35% of solid waste is a consequence of construction activities, and it is projected that by 2025, this will reach 7.4 million tons (MINVU, 2019).

In light of these challenges, it is increasingly necessary to transition from a production model reliant on mineral and petroleum derived materials toward one that prioritizes sustainable, low-impact alternatives. Among these, bio-based composites developed from living organisms such as algae have emerged as a promising avenue for reducing the environmental footprint of the construction sector.

This article seeks to examine the viability of marine biomass—specifically seaweed and seagrass species such as *Posidonia oceanica* and *Sargassum natans*—as sustainable thermal insulation materials in the built environment. The working hypothesis is as follows: *"Seaweed and seagrass species, such as Posidonia oceanica and Sargassum natans, provide thermal insulation properties comparable to those of synthetic materials, but with enhanced fire resistance."* To validate this hypothesis, the study presents a critical review of existing literature related to the application of marine species in construction, with a particular focus on architectural case studies and experimental research on the material properties of various algal and seagrass species.

Bio-based materials used in construction generally seek to replace cement and plastics, highlighting research into green cement, biodegradable plastics, plant-based thermal insulation, and wood-based composites. (Kuqo & Mai, 2022; Bousaria, 2021; Affan et al., 2023; Rocha et al., 2022; Azimatum & Nurmala, 2024; Dhanasingh et al., 2024; Deng et al, 2023; Ges et al., 2021; Lizundia et al., 2022)

The advancement of bio-based materials stands out for their potential to reduce greenhouse gases, use water in production, and avoid the accumulation of waste (Bjånesøy, et al., 2023; Chen et al., 2024; Delgado et al., 2023) for their thermal, mechanical, and acoustic resistance properties. Despite these benefits, the adoption of bio-based materials in construction remains marginal—representing less than 3% of the total material matrix—due to various barriers. These include a lack of awareness among industry stakeholders, limited regulatory support, high production costs, restricted material availability, technological incompatibility with conventional systems, and underinvestment in research and development (Hossain et al., 2020).

To overcome these limitations, further interdisciplinary research is required. Key areas of focus include the assessment of physical and mechanical performance, regulatory feasibility, material supply chains, cost analysis, and strategies for integrating bio-based materials into existing production systems. In this context, the present review aims to address these questions by exploring the potential of seaweed for applications such as surface coatings, thermal insulation, and construction additives.

The availability of algae as a renewable resource for construction has great potential because of its exceptional adaptability, brief growth time, and resource sustainability. (Waqas, et al., 2024) Climate change has caused some species, such as Japanese sargassum (*Sargassum muticum*) seaweed, to expand worldwide, in many cases generating the accumulation of it and pollution of coastal edges. (Affan et al., 2023) However, algae farms and carbon sequestration projects through seagrass meadow restoration make sustainable algae production globally available. (Zhang et al., 2022; González et al., 2021) The amount of biomass could be grown on less than a tenth of the land since algae grow ten times quicker than terrestrial plants. Algae farms do not compete with agricultural growth for land and do not need fresh water. (Tzachor, 2019) Data from the Food and Agriculture Organization (FAO) show that between 2000 and 2019, the world's algae production, both farmed and wild, rose by over three times, from 118.000 tons to 358.200 tons (FAO, 2021).

Seaweed and seagrass are two significant kinds of macrophytes within marine coastal ecosystems. Seaweed are primitive plants that lack roots and employ holdfasts to attach themselves to the seafloor. They are categorized into three primary forms of seaweed, also known as macroalgae, as in **fig.** 1: green (*chloropyceae*), brown (*phaephyceae*), and red algae (*rhodophyceae*). (Abdel – Kareem and ElSaied, 2022) While seagrass is a marine flowering plant, it has roots, stems, leaves, and flowers and forms seagrass meadows that are kilometers long. (Short et al. 2007)

Red Macroalgae Central Zone Chile | Green Macroalgae Central Zone Chile | Brown Macroalgae Central Zone Chile

Fig. 1

Seaweeds Central Zone Chile

Given its ecological importance, seagrass plays a crucial role in maintaining the health of coastal ecosystems, offering habitat for marine organisms, and aiding in carbon storage; seagrass meadows absorb more than twice as much carbon as terrestrial ecosystems. (Montero et al., 2023; Pereira et al., 2024). Although only 60 seaweed species are worldwide, its seagrass meadows stretch several kilometers of coastline. According to Short (2007), seagrass spread in four temperate bioregions worldwide; the Pacific is the largest and most diverse bioregion, home to 24 types of seagrasses.

Seaweed species are described as 50.000, considering freshwater and terrestrial species; over 7000 are red algae, 1500 are green algae, and 2000 are brown algae. (Guiry, 2024) In continental Chile, about 450 species of macroalgae out of 800 are described, including Rapa Nui, Juan Fernandez Archipelago, and Antarctica.

The growth of algae, like sargassum belt (Wang et al, 2019) and green macroalgae proliferation, "green tides," produce large volumes of algae stranded on the coast and the beaches, generate severe consequences for the local communities, as toxicity phenomena are produced by the emission of gases such as hydrogen sulfide (H_2S), and a significant environmental degradation. (Liu et al. 2033; Schreyers et al. 2021; Rodríguez et al., 2022; Bueno et al., 2023) During the year 2024, 4 tons of Lechuguilla (*Ulva Lactuca*) were reported stranded on the Chilean coast beaches of Coquimbo. To harvest them in a sustainable manner more specifically, hiring divers, had a cost for the local authorities of $9500 US per month (Diario Regional, 2024).

Methods

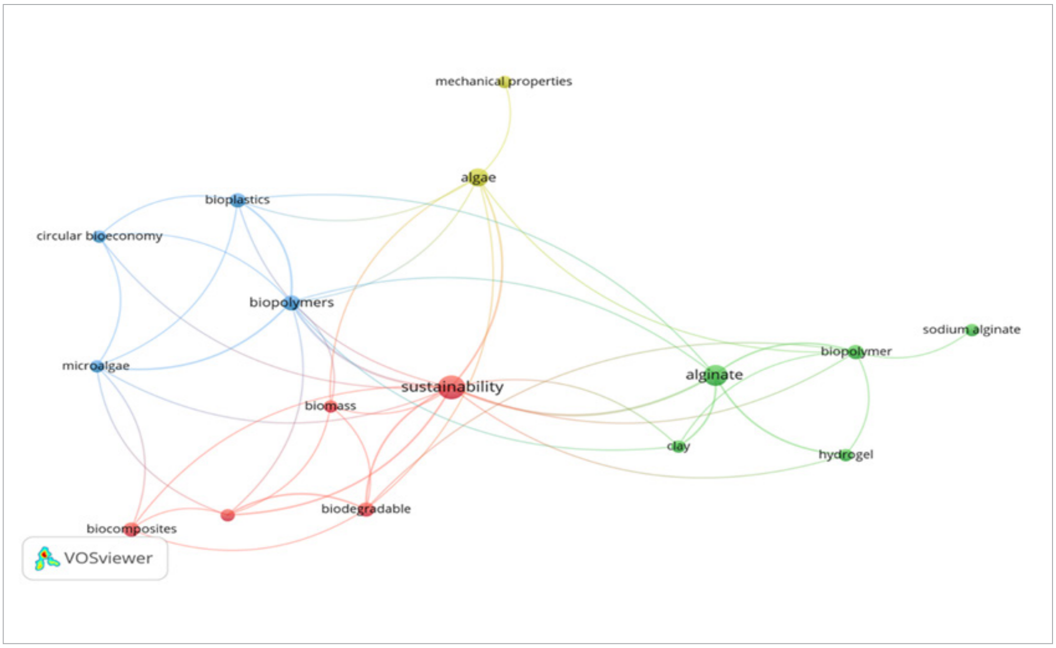
This study employed a systematic review methodology to examine the extensive body of existing literature thoroughly. The selection of target papers was conducted using data processing software, Fig. 2 (Vosviewer) with specific topic keywords related to the research area of seagrass insulation, seaweed insulation, seaweed as building insulation materials, and seaweed construction material from the databases of Web of Science, and Scopus, Google Scholar and Boolean operators was included for pivot tables analysis and final data processing. The criterion for selecting these papers included relevance to the research area, publication in peer-reviewed journals, and the publication date. To better understand the technical and constructive systems used, references before 2019 were included in the construction systems analysis and formulation of results. In the case of statistical analysis, we only consider publications done on peer-reviewed journals between 2019 and 2024.

During the bibliographic review, a substantial number of over 1500 papers were identified, the principal links were presented in Fig. 2 The initial articles that did not align with the construction area were eliminated, such as those focusing on food, fertilizers, coagulants, biofuels, and bioremediation. After this filtering process, 70 articles were deemed within the relevant years and related to the construction industry. The following data were analyzed from the selected papers: year, place of research, algae studied, and construction system used.

Based on the references studied, a comprehensive description of the leading seaweed and seagrass construction systems, their potential, and the challenges facing using seaweed in the construction industry are provided.

Fig. 2

Vosviewer Review



Results and discussion

General mapping of the selected literature

Research on the use of algae in construction has seen a significant upswing in recent years, with articles increasing from 5 to 22 in 2023. Research is primarily led by Germany with 11 articles, France with eight articles, and Malaysia, China, and India with five articles each, who have not only spearheaded the research but also made significant strides in the practical application of algae in construction. Among the various types of seaweed and sea grasses, as shown in **Fig 4** the most extensively studied is Neptune grass (*Posidonia oceanica*), closely followed by the diverse range of Sargassum family. As shown in **Fig 3** the research field in seaweed and seagrass in construction are particle boards, fire retardant, additives and thermic insulation.

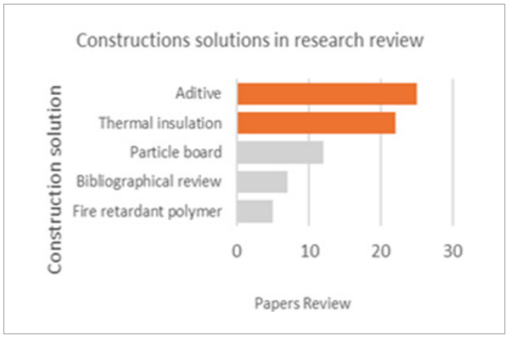


Fig. 3

Construction solution

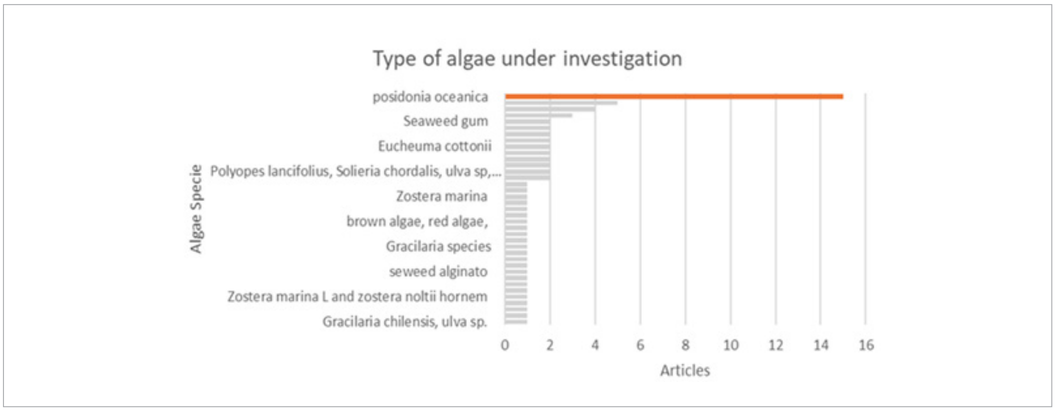


Fig. 4

Type of algae under investigation

Construction systems with seagrass or seaweed in history

Traditional construction systems are linked not only to cultural heritage but also to regional resources. Therefore, the available materials are valuable to communities. In these ancient buildings, seaweed and seagrass were frequently utilized; (Jun et al., 2012) the first recorded uses of seaweed in construction belong to the Chinchorro Culture in Chile. They are found in one of the oldest structures on the northern bank of the mouth of the Loa River in Antofagasta, Chile, more specifically between Pisagua and Chañaral. Its occupation dates between 2800 B.C. and 1800 B.C., known archaeologically as Sitio Caleta Huelén 42.

According to Llagostera's research, this site shows the presence of simple semicircular subterranean living structures (**Fig. 5**) with vertical stone walls made out of a mortar of ash, seaweed sand, and shells. Sealed floors are made out of clay and seaweed mortar which waterproofed the floor under which the bodies from their burials were spread out. (Llagostera, 1989 en Cocilovo et al 2005; Sanz et al 2014)

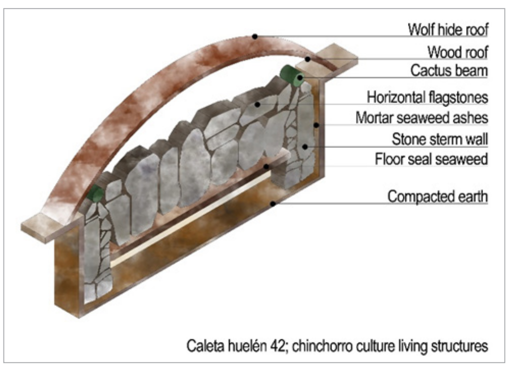


Fig. 5

Caleta Huelén 42; Antofagasta, Chile, Chinchorro culture structures

In Japan, the technique of Shikkui lime plaster from Korea, widely used since the 16th century, used seaweed glue, among other materials. Seaweed glue is more workable than the Shikkui mixture because it holds onto moisture and postpones the setting. In the case of the Shikkui mixture (shown in **Fig. 6**), the principal material is lime. In the Nori-Tsuchi technique, seaweed glues are added with sand and clay to prepare earth plasters. (Hasado, 2019) In the case of Japan and Korea, Carrageenan and Agar polysaccharides are obtained from red algae. In Chile, it is probably obtained from alginate due to the abundance of brown algae. In both cases, the algae is processed to obtain polysaccharides. This substance will serve as a gelling agent for clay coatings; the most common preparation consists of a process of soaking and cooking at temperatures between 60 and 100° C; however, in the case of Chile, ash is more frequently used in the mortar.

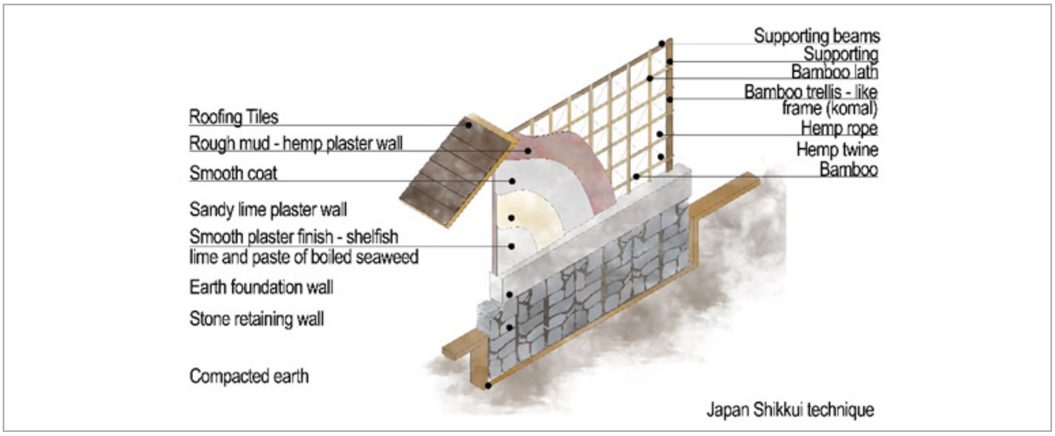


Fig. 6
Shikkui technique, Himeji castle, Hyōgo, Japan

The temperature allows releasing the molecules responsible for the stabilization, forming a gel that will be more fluid when stirred and will solidify in the resting state. In the presence of minerals such as clay or calcium ions, the sugar chains of the polysaccharides will interact as a glue connecting the mineral particles to connect the mineral particles, creating a kind of network. (Vissac et al. 2017)

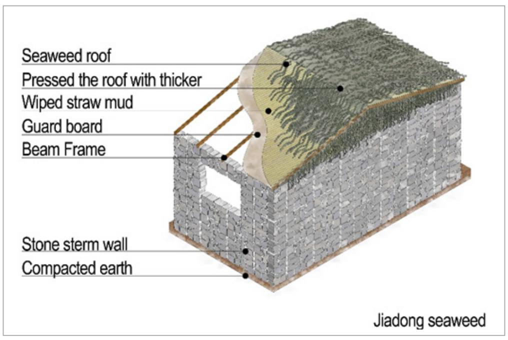


Fig. 7
Seagrass houses in Jiāodōng peninsula, Shandong province, China

Two examples of cultural heritage constructions are: 1) the thatched roof of seagrass, observed at roof houses in Jiāodōng Peninsula, Shandong province, China as shown in **Fig. 7** with a 1000-year history, and 2) the thatched roof of seagrass in the Island of Læsø roof houses in Kattegat strait, Jutlandia peninsula, Denmark as shown in **Fig. 8** from the XVII's century. In both cases, dwellings were built along some coastal areas using a seagrass roof covering that provides a durable, sustainable, and livable low–carbonroof envelope. The high concentration of salt and the antibacterial properties of eelgrass (*Zostera Marina's*) prevent insect attacks and improve the roofing fibers' corrosion and fire resistance. (Liu et al 2023; Vilas-Boas et al, 2017; Zhao et al., 2023; Zhenyu, and Wei, 2013) The air cavities of the seagrass and seaweed cellular structure and its thick epidermis enhanced the sound and thermal insulator. (Jun 2012; Ding and Zhang, 2018; Li et al 2023; Eybye, 2020; Kuang, 2013) The air-permeable capacity and construction breathability of the roof construction system increased the internal air quality of Laesø traditional houses (Unesco, 2023)

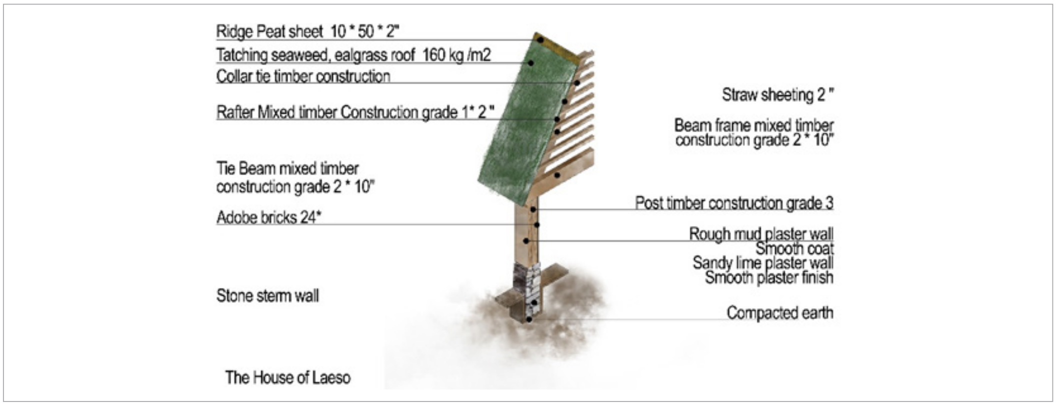


Fig. 8

Island of Læsø roof houses in Kattegat strait, Jutlandia peninsula, Denmark

Although seaweed is known to be used as a thermal insulator in timber-framed construction systems, the earliest evidence dates to 1683 at the Pierce dwelling in Dorchester, Massachusetts. The traditional timber-framed thermal insulation seaweed-based was manufactured in the beginning of XIX's century in thermal insulation quilts (as shown in Fig. 9) Industrialized products such as Cabot's quilt and seafelt were marketed in England, Canada, and the United States dwellings and skyscrapers applications. (Echeverria & Cox, 1999)

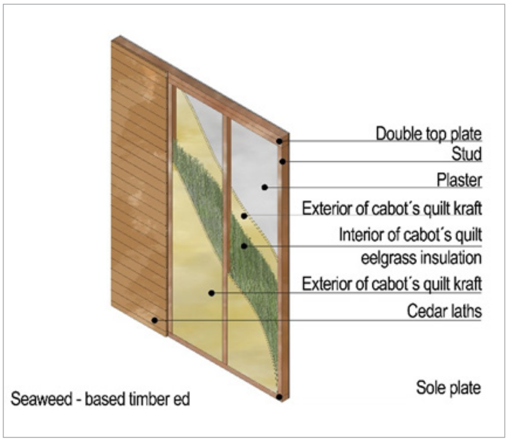


Fig. 9

Seaweed-based timber–framed thermal insulation section, Cabot´s quilt

Current experiences using seaweed thermal insulation are Modern Seaweed House in Læsø island and the 14 public dwellings in Platja dén Bossa, Balearic Islands, Iberian Peninsula, Spain. Eelgrass (*Zostera Marina*) and Neptune grass (*Posidonia oceánica*) are used in floor, facade, and roof structures. They are part of the core of a thermal insulation panel with a wooden structure as shown in Fig. 10. In the first one, it is also applied to the walls and roof as cladding. (Vandkunsten Architects, 2013; Widera, 2014) On the other hand, in Balearic dwellings, clay brick finish cladding was applied. The Balearic Islands' Housing Institute monitoring data reveal a thermal conductivity on the Neptune grass (*Posidonia Oceanica*) of λ = 0.044 - 0.041 W/mK depending on the density sample. As reference expanded polystyrene foam, a regular insulate material, has a thermal conductivity of λ = 0.035 - 0.037 W/mK. (Muñoz, 2015)

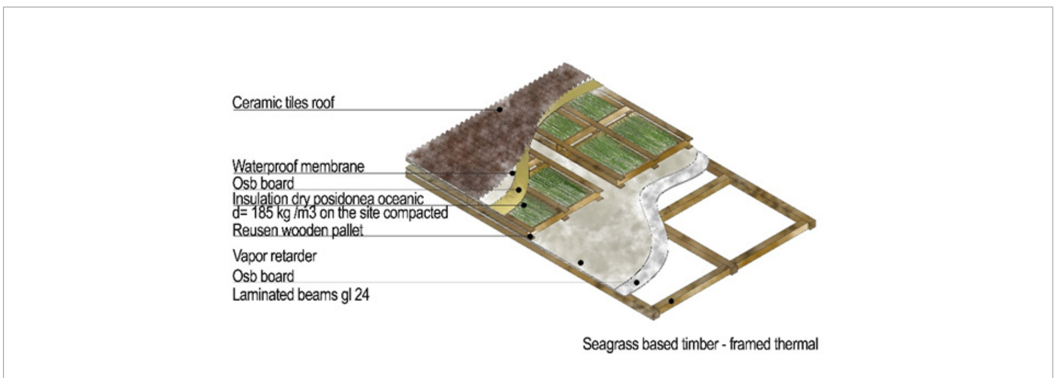


Fig. 10

Seagrass – based timber – framed thermal insulation section. Balearic Island dwellings in Iberian Peninsula, Spain

Research proposal construction systems of materials based on macroalgae and seagrasses

About the thermal insulation subject, consider twenty-three results. The investigation mostly considers thermal insulation panels with Neptune grass (*Posidonia Oceánica*). Main results indicate that for densities between 50 and 200 kg/m3, varied from 0,0360 to 0,0510 W/m.k, Neptune grass (*Posidonia Oceánica*) is mould resistant and has a more effective protection against biological attack. As well ,seagrass has a low heat release rate and does not ignite when exposed to a single flame, in consequence insulation boards are more fire resistant than those from wood fibers. (Muñoz, 2015; Kuqo & Mai, 2022; Rojas et al., 2023; Hamadoui et al., 2018)

Table 1

Thermal insultation panel results

Species	Autors	Thermal conductivity	Density
Neptune grass (Posidonia oceanica)	Muñoz, 2015; Kuqo & Mai, 2022	λ = 0.041 w/mk	215 kg/m3
Eelgrass (Zotera Marina)	Muñoz, 2015; Kuqo & Mai, 2023	λ = 0.050 w/mk	215 kg/m3
Pelillo (Gracilaria chilensis)	Rojas et al 2023; Hamadaoui et al 2018	λ = 0,036 w/mk	60 to 80 kg/m3
Lechuguilla (Ulva sp.)	Rojas et al 2023; Hamadaoui et al 2018	λ = 0,036 w/mk	50 to 70 kg/m3

As shown in **table 1** we can conclude that Lechuguilla (Ulva sp.) and Pelillo (Gracilaria chilensis) are the most suitable species because it has a lower thermal conductivity, and lower density.

Almost thirty investigations include seaweed or seagrass as an additive in concrete mortar, extrusion mortar, plaster composites, soil or clay composites, or biopolymers, although they mainly employ different types of brown seaweed. There are a few that research about Neptune grass (*Posidonia oceanica*) in fiber reinforced concrete or red seaweed species. The additive studied works by replacing cement or aggregates in percentages between 0,1% to 50% in fiber reinforced cases, percentages between 5% to 20% were observed. The best results stand out in the improvement of Co_2 absorption, increases of compressive strength and tensile strength of 27% with the addition of 10% fibers. Other results that stand out is the increase of loading strength in a thin cement sheet.

Table 2

Thermal insultation panel results

Species	Autors	Density
Brown seaweed, sargassum	Chahbi et al. (2024)	10% of replace cement by algae powder improve Compression strength in a 10%
Brown seaweed	Ramasubramani et al. (2019)	15% of replace cement by wet marine algae or dry marine algae improve compression strength, a 17% for wet algae and a 15% on dry algae. In flexural strength improve a 24% for wet algae and 28% in dry algae use.
Red seaweed, Eucheuma cottonii	Sarbini et al. (2019)	20% SC improve a 15% compression strength , the 20% SC improve a 81% the flexural strength
Red seaweed, Gracilaria species	Baloo et al. (2021)	Seaweed replacement cement 15% improve compresión strength in a 1%

As shown in **table 2** we conclude that the most significant result is the one obtained by Sarbini et al. (2019) because the 20% SC improves 81% the flexural strength.

Earth-insulated walls, using stranded Kelp (*laminaria digitata*) seaweed at 20% or replacing flax straw with Japanese sargazo (*Sargassum muticum*) algae decreased the thermal conductivity by 34% and 38%, respectively. (Bousaria, 2021; Affan et al, 2023; Olacia et al. 2020) The reinforcement of adobe blocks with 40% of Sargasso (*sargassum natans, muticum or sargassum fluitans*) improves the compressive strength from 7,5 to 11 MPa (Rossignolo, 2022; Duran et al., 2024), considering a usual compressive strength between 1,5 to 6,89 MPa (Rodriguez, 2020)

The results of Rocha et al. (2022) show an increase in mechanical properties. Srinivas et al. (2021) and Azimatum & Nurmala (2024), show that the production of biocement using microalgae as an additive has a crack healing potential . Another result shows microalgae potential in additive manufacturing, improving the ease of the extrusion process by reducing the yield stress, similar mechanical properties between algae composites and traditional print cementitious, and a microstructure characterized by smaller pores. (Allegue et al., 2015; Agnoli et al., 2019; Benjeddou et al., 2023) Likewise, research on using alginate as a base for aerogels shows a reduction of 93% in flammability and 10% in thermal conductivity (Berglund et al., 2022; Chahbi et al., 2023; Wichmann et al., 2022).

Particle board solutions include thirteen research works, mostly with Neptune grass (*Posidonia Oceánica*) seagrass fibers, secondly, Elkhorn (*Kappaphycus alvarezzi*) fibers, and Sargasso, (*Sargassum muticumm*) fibers, both seaweeds. In general, researchers agree that the addition of seagrass or seaweed fibers decreases strength but increases impact resistance, fireproofing, and thermal resistance. The principal challenge of seagrass or seaweed fibers for panels is their water absorption within the responses to pretreatment on the fibers, addition of complementary compounds as plaster or cellulose, and the incorporation of different types of fibers. The principal results show that the incorporation of 10% of seaweed or seagrass fibers does not significantly affect the mechanical properties of the boards. (Rammou et al. 2021)

According to Kuqo & Mai (2022), investigations indicate that the incorporation made from 50% wood particles and 50% of Neptune grass (*Posidonia Oceánica*) leaves showed the best relation between the advantages and disadvantages in seaweed or seagrass particle board use. Using Gracilaria verrucosa (*Gracilariopsis longissimi*) with 50% sawdust and 12% adhesive reaches the normative in physical and mechanical Japanese Industrial Standards for panel parameters. (Autem et al., 2023; Alamsjah et al. 2017; Dove et al, 2019; Khiari and Belgacem, 2017; Kuqo et al., 2019;)

Regarding fire retardant, this is the category with the fewest investigations, researchers using alginate from different brown seaweed show as main results the reduction of flammability, and thermal conductivity. Nanoclay and cellulose improve mechanical strength and thermal stability of alginate fire retardant. In addition cellulose enhances antibacterial capacity and hydrophobicity.

Conclusions

The primary focus of this article is to highlight the potential and advancements in using marine species to enhance sustainability and reduce the environmental impact of the construction industry. To achieve a comprehensive review of the existing literature on architectural projects and research on various species of seagrass and seaweed globally has been conducted.

In general, species used for construction purposes match the same ones that are stranded on the coasts. They can be harvested in a sustainable manner from the coast in a manual way, specifically by divers.

In this context, the species with the most splendid future are the Lechugilla (*Ulva sp.*), Sargazo (species from the family of *Sargassum muticum*), and Neptune grass (*Posidonia Oceánica*) been invasive and whose growth worldwide extends for several kilometers, generating ecological and financial damage to the coasts and interstitial zones of the sea.

Despite the rarity of the use of algae today, a diversity of examples of traditional architecture have been studied and validated the seaweed properties for use as coatings, thermal insulation, and additives. Researchers like Muñoz (2015), Kuqo & Mai (2022), Bousaria (2021), Affan et al. (2023), Rocha et al. (2022), and Azimatum & Nurmala (2024), among others, have reinterpreted these techniques in modern proposals for prefabricated systems and revaluation.

The use of seaweed in thermal insulation blankets in general optimizes the potential of Neptune grass (*Posidonia Oceánica*), its thermal properties (0.036 W/mk), its fire resistance, and its resistance to biological attacks, in this context, it is not necessary improve water resistance or mechanical resistance. In Chile we can conclude that Lechuguilla (Ulva sp.) and Pelillo (Gracilaria chilensis) are the most suitable species because they have a lower thermal conductivity, and lower density. The construction systems use wood framing systems due to the ease of implementation in the currently used industry, minimal processing, and reasonable cost.

For Particle board solutions, although there are studies that have replaced up to 50% of wood fibers, achieving a balance in the requirements of current boards, the best mechanical results are achieved with a maximum of 10% fiber replacement. In this case, the importance for optimization is the end use of the board as a covering or structural type. It is also important to note that some of the research observed includes the use of formaldehyde as a binder, a material that has been shown to cause cancer. (Tenney et al. 2024)

In the additives area and fire retardant, the alginate or algae subproducts are used in low percentages, improving mechanical resistance, fire resistance, moisture resistance, and cracking, but the energetic and environmental cost is not always lower than actual alternatives. However the most significant result is the one obtained by Sarbini et al. (2019) because the 20% SC improves 81% the flexural strength.

Transitioning from existing research and specific architectural projects to the industrial use of marine species as a construction material is crucial to secure financial support from governments. This support is essential for the initial pre-competitive stages of these initiatives and for developing prefabrication systems that meet the certification and regulatory requirements of construction materials in each country.

Equally important is the establishment of seaweed and seagrass cultivation methods that ensure the initiative's sustainability in the long run, involving incorporating the costs associated with their cultivation, harvesting, and processing into the sale price, thereby ensuring the economic viability of the initiative.

Improving seaweed production by incorporating added value in the harvesting area would make it possible to distribute the profits from its production in the localities affected by its stranding, cultivation, and production. From a regulatory perspective, construction materials worldwide must be certified and fulfill diverse regulations. Incorporating financial support for the early stages of development of these products, such as certifications and testing for compliance with regulations, would provide incentives to reduce the gap with other products more widely accepted in the market and increase the viability of their commercialization.

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About the authors

SUZANNE SEGEUR VILLANUEVA

Phd Student

Universitat Politécnica de Valéncia, Programa de Doctorado en Arquitectura, Edificación, Urbanística y Paisaje, Tecnología de la Construcción

Main research area

Materials characterization, biomaterials performance, algae construction

Address

Camino de Vera, s/n. 46022 – Valencia, España
E-Mail: susevil1@doctor.upv.es

PH.D. NATALIA CAICEDO

Researcher

Departamento de Planificación y Ordenamiento Territorial, Universidad Tecnológica, Metropolitana, Santiago, Chile

Main research area

Architecture, construction, native timber, structural behavior and biomaterials

Address

Dieciocho 390, Santiago, Chile
E-Mail: ncaicedo@utem.cl

PH. D. ENG. LUIS PALMERO IGLESIAS

Full Professor

Departamento de Construcciones Architectónicas, Universitat Politécnica de Valéncia

Main research area

Modern architecture, vernacular architecture and its environmental integration, recovery, restoration, and appreciation of existing constructions to achieve energy requirements

Address

Camino de Vera, s/n. 46022 – Valencia, España
E-Mail: lpalmero@csa.upv.es

PH. D. ENG. GRAZIELLA BERNARDO

Researcher

Dipartimento per l´Innovazione Umanistica, Scientifica e Sociale- (D.I.U.S.S.) of the University of Basilicata

Main research area

Eco-design for the ecological transition of buildings and the sustainability of architectural heritage conservation processes according to the new models of the circular economy

Address

Campus Universitario Via Lanera 20 75100 Matera, Potenza, Italy
E-Mail: graziella.bernardo@unibas.it