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ARTIFICIAL REEFS IN THE UAE COASTLINE: A SUSTAINABLE SOLUTION FOR MARINE BIO-DIVERSITY

Dredging and reclamation projects have played an important role in the UAE's rapid development, meanwhile efforts are continuously made to balance progress with marine ecosystem conservation. This paper explores the development of fish domes and 3D-printed artificial reefs, highlighting their role in providing marine habitats, promoting biodiversity and supporting sustainable development. Case studies from Abu Dhabi region demonstrate the effectiveness in restoring marine environment. By integrating innovative reef structures with sustainability goals, the UAE ensures that economic growth aligns with environmental conservation, fostering a resilient marine ecosystem for future generations.

History

The United Arab Emirates (UAE), established as a Federation of seven emirates in December 1971, is a desert dominated country with a relatively limited landmass. The country emerged against the backdrop of poverty and socio-economic underdevelopment. With a population of no more than 180,000 inhabitants in 1968, the UAE's economy was largely shaped by subsistence activities, including agriculture, pearling, fishing and trading.

In the late 1960s, infrastructure was nearly non-existent. Yet, within 53 years the UAE was able to evolve from a subsistence economy into a country with one of the most competitive and advanced economies in the world in terms of business regulations, infrastructure and technological advancement. The long-term government initiative, UAE Centennial 2071, holds a key emphasis on reducing reliance on oil through diversification.

The country also achieved record-breaking growth rates having 10.6 million inhabitants as of 2023 with a projected increase of 44% to 15.4 million by 2050. Thus, the UAE's vision and ambition for the future are deeply intertwined with its reliance on dredging and reclamation projects, as they are integral to the country's broader economic, environmental, and infrastructural goals.

Dredging and reclamation in the UAE

The UAE's vision focuses on sustainability, diversification, innovation, and global leadership, and dredging projects play a crucial role in realising these objectives. Dredging and reclamation are carried out for expanding and enhancing land use in coastal and waterfront areas, supporting urban development, infrastructure projects and environmental restoration. Dredging helps deepen and widen waterways, facilitating better shipping routes, ports and flood control, while reclamation creates new land for construction, agriculture and recreation. These processes are crucial for UAE since the country is with limited natural land availability.

Once a desert landscape, the country has transformed with towering skyscrapers, extensive infrastructure and high-tech industries, Figure 1 and Figure 2 show the drastic changes of Abu Dhabi and Dubai's coastline. Reclamation has been key to this development, particularly in creating land for infrastructure projects, such as airports, ports, residential complexes and tourism destinations like Palm Jumeirah.

FIGURE 1
Abu Dhabi region in 1984 (A) and 2025 (B). Source: Google Earth.

FIGURE 2
Dubai's coastline in 1984 (A) and 2025 (B). Source: Google Earth.

> Once a desert landscape, the country has transformed with extensive infrastructure.

Importance of marine environment restoration

While dredging and reclamation efforts have played a critical role in expanding the UAE's urban and industrial landscape, the successes of these projects must also be viewed in the context of broader environmental considerations. As the country develops its infrastructure and land resources, it is equally important to focus on the restoration of its marine environment. NMDC Dredging & Marine, founded as National Marine Dredging Company in 1976, takes it upon itself to contribute to the country's vision. In addition to undertaking major dredging and reclamation projects, NMDC D&M is committed to implementing sustainable practices in all operations of its business units.

In all practices carried out by NMDC, the global sustainability goals are upheld to ensure environmental protection, social equity and economic growth, contributing to a sustainable future. These sustainable practices involve short- and long-term initiatives, such as:

- water quality monitoring;
- sediment management;
- sustainable fuel use;
- habitat restorations;
- Environmental Impact Assessments (EIAs);
- local employment and training programmes; and
- research and development.

Marine ecosystems provide essential services, such as carbon sequestration, coastal protection and biodiversity, which are vital for maintaining ecological balance and supporting local communities. By integrating marine environment rehabilitation into the UAE's broader vision of sustainability, the country can ensure that its growth is both economically beneficial and environmentally responsible.

Dredging can cause disturbance to natural habitats, including coral reefs, seagrass beds and coastal wetlands. These ecosystems are vital to marine life as they provide food, shelter and breeding grounds for countless species. For example, coral reefs take thousands of years to form. With growth rates of 0.3 to 2 cm per year for massive corals, and up to 10 cm per year for branching corals, it can take up to 10,000 years for a coral reef to reach maturity. Their fragile balance can be easily disturbed by sedimentation, pollution and physical damage, leading to long-term ecological degradation.

Given the slow rate at which natural reefs form and their importance to marine biodiversity, restoring these environments is

FIGURE 3

Fish domes installed at different project locations in Abu Dhabi region.

vital. Artificial reefs, made from materials like concrete or other durable structures, help promote marine life by providing surfaces for coral growth and shelter for fish, mimicking the role of natural reefs. These efforts can help rebuild marine biodiversity and ecosystem services, creating a buffer for the ecosystems that dredging often threatens.

Fish dome projects in Abu Dhabi region

Project goals and objectives

In the past decade, several projects have been conducted with the following initiatives:

1. Marine habitat restoration: To create new habitats for marine life, including fish and corals, through the construction of man-made fish domes. The aim is to provide a safe refuge for fish to avoid predators and offer an ideal environment for their growth.
2. Fish attraction: One primary goal is to restore fish populations in areas impacted by offshore construction. The fish domes offer shelter for various species, promote coral growth and support the return of fish by providing a safe environment for reproduction. The long-lasting design also encourages coral blooms, helping to restore balance in ecosystems affected by dredging and reclamation activities.
3. Long-term sustainability: The project aims to enhance marine health by fostering the growth of fish populations and coral reefs. By creating stable habitats, marine ecosystems are restored, promoting long-term sustainability. These efforts will ensure the development of a resilient underwater environment, benefiting marine life for future generations.

LOCATION	YEAR	TYPE A	TYPE B	TYPE C	TYPE D	TYPE E	TYPE F	TOTAL
		Dome	Steel Pipe	Concrete Pipe	Concrete Box	Triangular Concrete	Colony Reef	
Sir Bani Yas Island	2023				3,998			**3,998**
Umm Al Nar - 1	2023	75	75		543	74		**767**
Umm Al Nar - 2	2021	30	866					**896**
Al Reem Island - 1	2021		30					**30**
Al Reem Island - 2	2023		32					**32**
Ras Al Mohsana	2023	648	648	1,296	648	648	17	**3,905**
Ramhan Island	2024				5			**9,628**

TABLE 1

Number of different dome types installed in different locations.

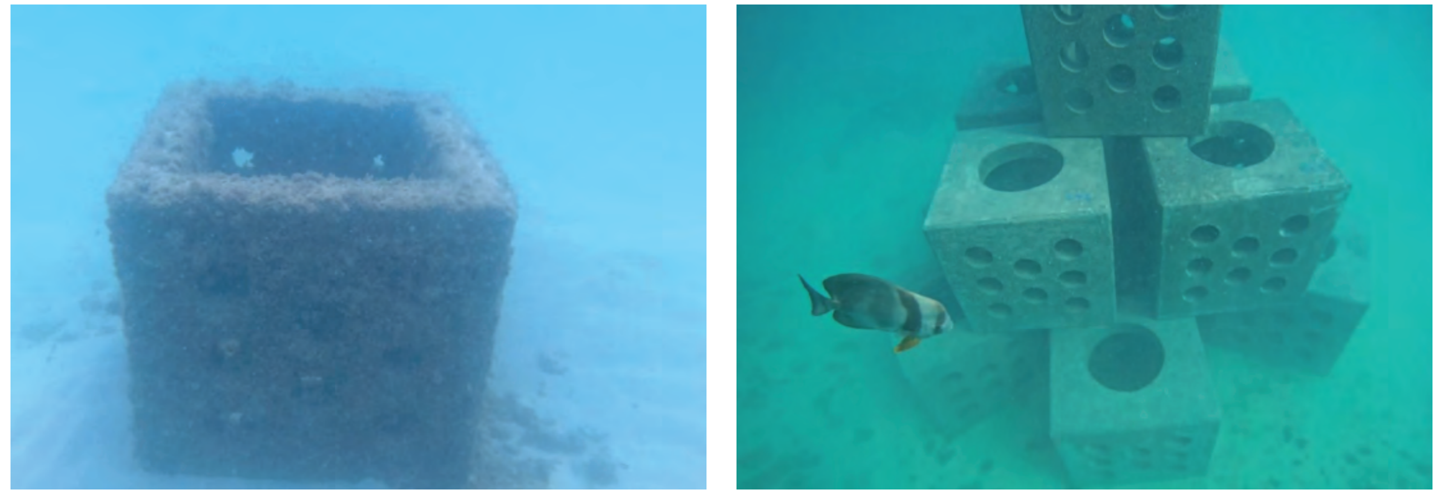


FIGURE 4

Type D fish domes: concrete boxes.

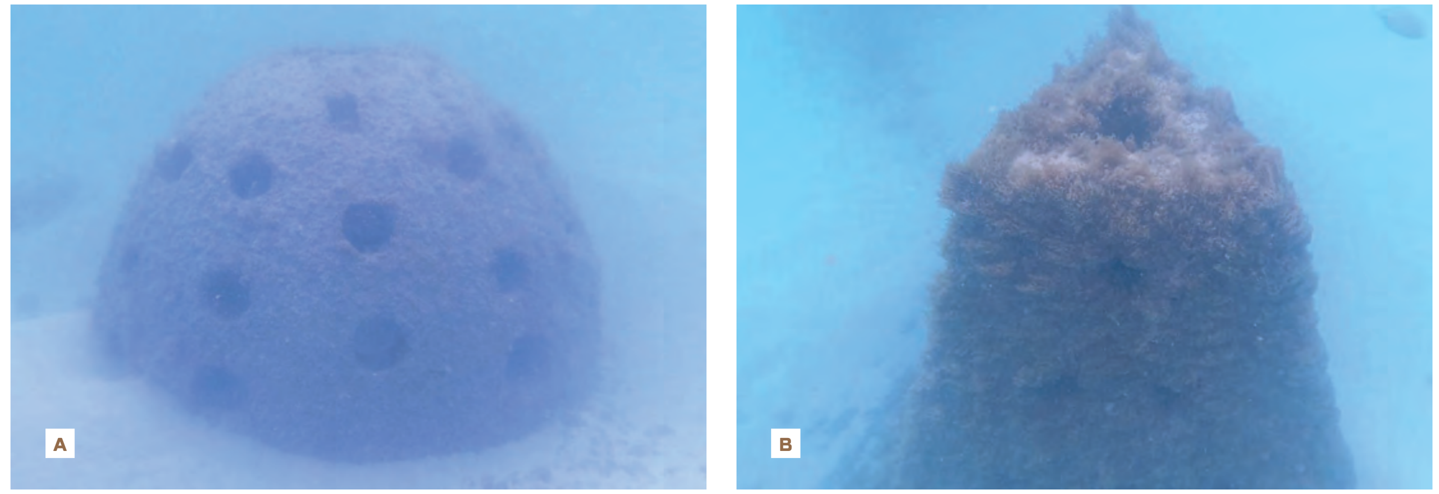


FIGURE 5

Type A fish dome: dome shaped (A) and type E fish dome: triangular concrete (B).

Overview of fish dome installations

Figure 3 illustrates the locations of various fish dome projects completed in Abu Dhabi region, UAE. While Table 1 provides an overview on the number of different types of fish domes used in each location.

Together with our project partners, NMDC follows several phases for each project.

Engineering phase

Scientific and mathematical principles are used to design and implement solutions in the safest and most economical way. The design of the shapes of reinforced concrete fish domes are inspired by nature. Although it is difficult to create exact replicas of natural shapes, the goal is to choose designs that are easy to manufacture and provide structural stability. These shapes provide the best support for marine life, while at the same time enabling designs to be produced economically and more easily.

Execution phase

During the execution of these projects, typically one month is required for the fabrication, quality control, storage, maintenance, transportation and underwater installation of one reinforced concrete fish dome. Considering the project scope, duration and demands, the necessary arrangements are made at the production site to ensure efficient mass production of concrete elements. The number of fish domes to be installed in the project determines the timeline. Weather conditions at sea are also considered when planning the installation time, as this is essential for safe and effective underwater installation.

Research and development phase

As the project continues, marine biologists are brought in to observe which types of fish domes work best in different marine project locations (see Figures 4 and 5). These studies help in understanding the needs of various fish species and other marine life and provide guidance on which dome designs are most effective. In this way, engineering principles are combined with natural inspiration and scientific research to develop the most effective, durable and economical solutions for each project.

FIGURE 6

Traditional fish habitat design.

The effect of fish domes on marine environment

These reinforced concrete fish domes are placed in designated project areas in order to reduce the environmental impact of offshore dredging and construction activities. The artificial fish domes are manufactured and installed to create and restore new habitats in areas where natural habitats have been disturbed or damaged. By installing these structures at sea, the project site attracts different species of fish back to the area, which benefits the overall health of the marine ecosystem. It has been witnessed that fish domes help restore biodiversity and create a more balanced environment for marine life.

It should be mentioned that these areas where fish domes are installed are protected areas where commercial fishing activities are not allowed. These protected areas provide a safe haven for marine life without the pressure of human activities, allowing underwater ecosystems to recover and develop.

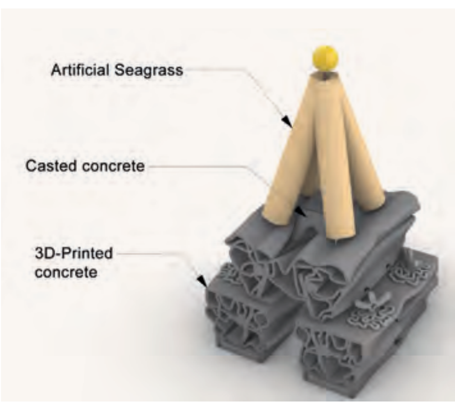
In addition, fish domes not only contain fish and corals but also other crustaceans, such as crabs and shrimps. These small creatures are a source of food for other larger creatures, which supports the formation of the food chain. The fish domes help creatures affected by dredging to return to their habitats.

Through these projects, marine life and ocean ecosystems are protected, creating sustainable environments that will support marine life for future generations.

3D-printed artificial reefs

Artificial reef design evolution

There has been relatively little development in the science behind artificial reef design since the Greeks and Romans started placing stones, pottery and other objects to attract fish into fishing areas. In more recent times, ships, trains, tyres, blocks and many other types of unwanted objects have been dumped to provide subsea habitats for marine life.



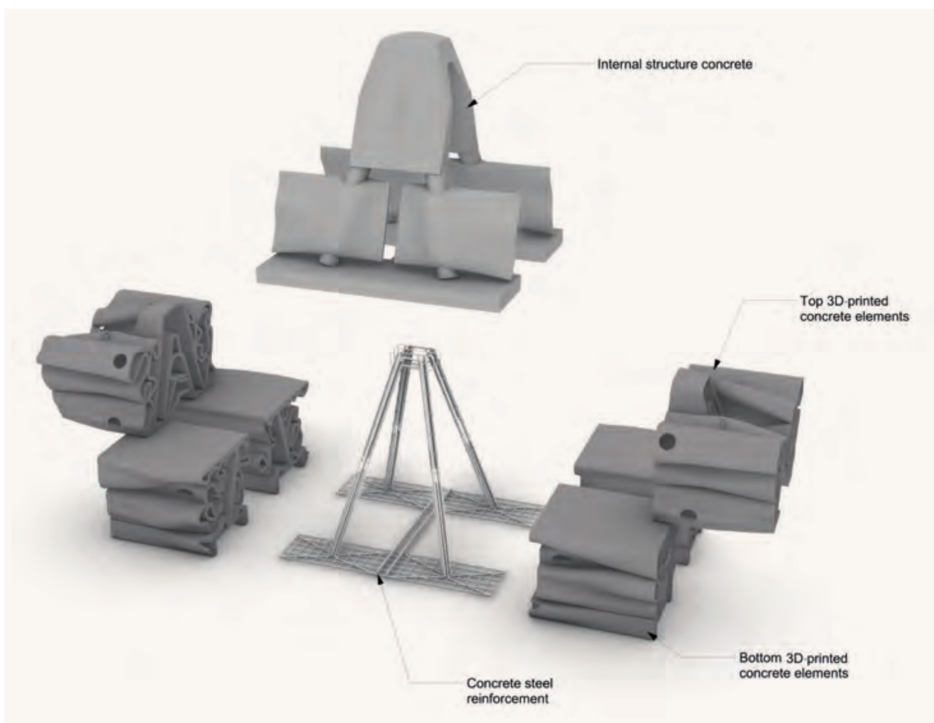


FIGURE 7

Computer model of 3D-printed reef. Image courtesy of Seaboost.

FIGURE 8

3D printing machine (A) and assembled reef unit (B).

The traditional artificial reef or fish habitat design comprises of low complexity precast concrete shells of various shapes and sizes. Some typical designs are shown in Figure 6.

Today with advances in 3D printing technologies, we can make highly complex artificial reef designs that are tailored to the marine life and engineered to support biodiversity. High complexity is desirable to more effectively mimic the characteristics of the natural marine environment. Numerous cavities can be created where the apertures, length, shape and orientation to the current are be tailored to target species. Typically, the traditional fish habitat only has one large cavity per unit. Figure 7 shows the computer model for the 3D-printed reef design being implemented for the proposed pilot project.

Comparison of the environmental benefits

3D-printed reefs are far superior to the traditional fish habitats. The large number of small closed ended cavities provide a much better habitat for juvenile and pre-adult fish communities. The 3D-printed reefs, in addition to providing shelter, are therefore more effective as a fish nursery, which helps support population growth not just attracting existing fish already in the area. Non-customised reefs can function as ecological traps, where the reefs inadvertently attract marine organisms to settle and thrive in areas that are ultimately detrimental to their survival and reproduction, leading to negative impacts on their overall fitness and survival (Komyakova et al., 2021).

Another environmental benefit of the 3D-printed reef design over traditional design is its ability to create enclosed cavities of varying shapes and sizes, providing separate habitats for different species across multiple trophic levels within a single reef unit. This means that species from different levels of the food chain can coexist within the same unit. Invertebrate species that typically like to hide in holes and crevices also benefit more from the more numerous cavities of different shapes and sizes.

Due to the additive concrete 3D printing process, the reef unit has a more complex, grooved and undulating surface. Together with the semi-porous texture, this makes it a suitable substrate for colonisation by corals and fixed species. Traditional artificial reefs tend to have smooth form finishes, which is not favourable to colonisation by fixed species. Not only this but the 3D-printed reefs have significantly more colonisable surface area to the traditional reefs of comparable size or weight.

3D-printed reefs offer remarkable customisation capabilities, allowing for adaptive shapes that can be tailored to the specific needs of local marine species. Additionally, the shape and complexity of the 3D-printed reefs can be adapted based on environmental conditions, such as water flow and sedimentation patterns, as well as to the location, if space is limited or if reefs need to occupy a specifically shaped area.

When considering the environmental impact from the manufacturing and installation process, 3D-printed reefs require less cement and concrete materials and since they provide

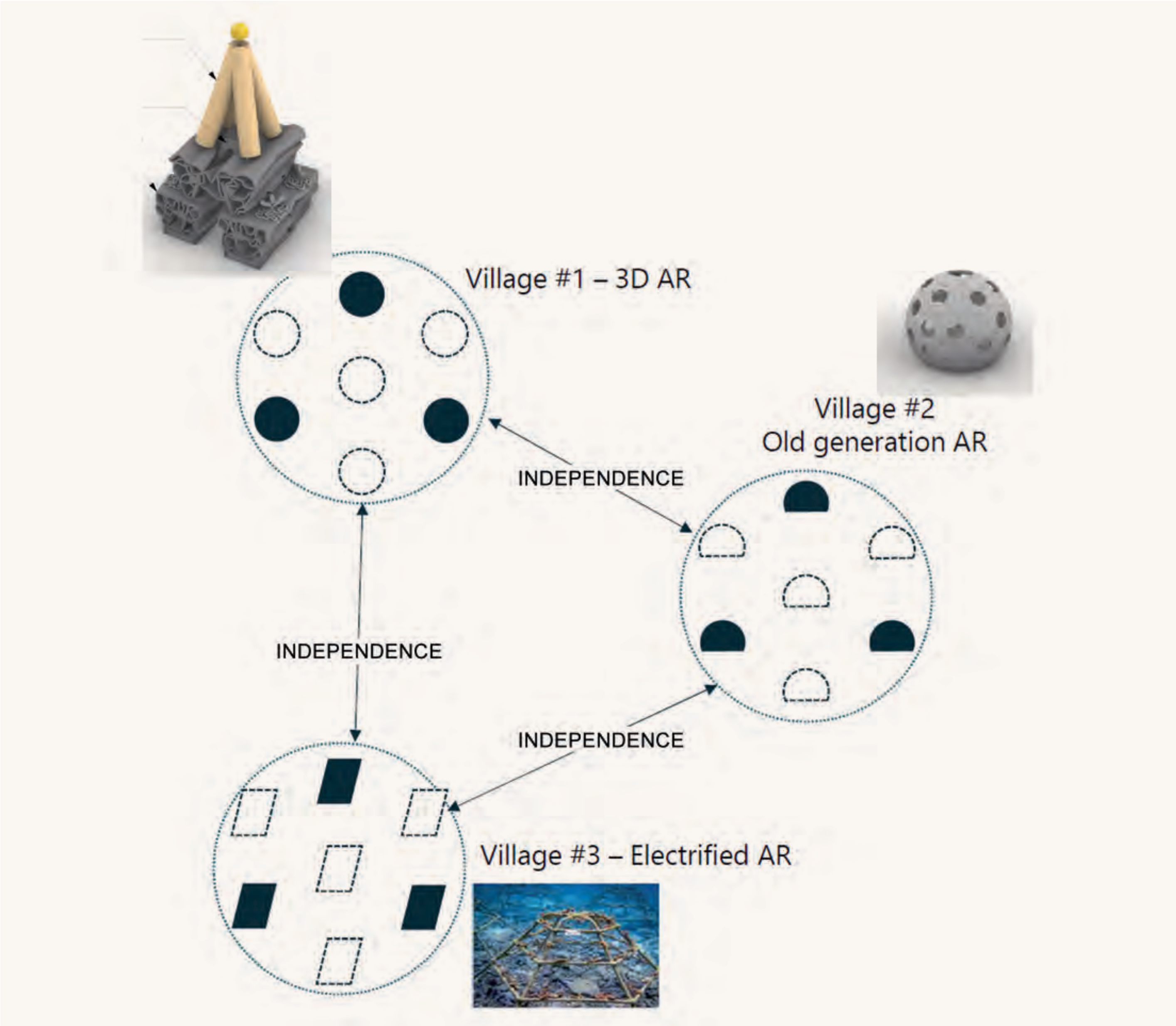


FIGURE 9

Arrangement of artificial reef villages.

more effective habitats, you need fewer of them compared to traditional artificial reefs for the same impact. In this way, the environmental cost of each 3D-printed unit is lower and at the same time the environmental benefits are far superior compared to the tradition design.

Pilot project on 3D-printed artificial reef

As part of one of its island reclamation projects, NMDC is undertaking a pilot to study the environmental benefits of 3D-printed reef compared to the more traditional dome shaped fish habitat. Electrified spider frame reefs are also being included in the pilot. The aim of the project is to demonstrate that the 3D-printed units provide significantly more effective habitat enhancement compared to either the traditional design or an electrified spider frame.

Figure 8 shows the 3D printing machine laying down the first few layers as well as the assembled unit ready for delivery. Figure 9 shows how villages of three units of each reef type are to be arranged with separation between to ensure independence.

The reefs will be deployed in sheltered waters approximately seven metres deep. Periodic marine ecology surveys will be undertaken to monitor growth in populations of marine fauna and coral in and around the reef villages. The results for each village will be compared both to each other and to two reference sites: one consisting of a natural coral reef in the area, and another similar to the deployment site but without reefs. The methodology will include diver-based surveys for fish counting and reef colonisation, as well as the use of marine camera traps.

Future opportunities

A favourable outcome from the pilot project is anticipated that will demonstrate the advantages of the 3D-printed reef. Developers are increasingly concerned about the impact of their projects on the marine environment and we expect there to be increasing demand for artificial reefs units in the future. Having already demonstrated the benefits of the 3D-printed reefs in the pilot project we hope to be better positioned to pursue these opportunities in future.

Conclusion

By conducting projects as fish domes and 3D-printed artificial reefs, NMDC is committed to advancing initiatives that align with the United Nations' Sustainable Development Goals (SDGs), as shown in Figure 10. The efforts of restoration significantly contribute to the following Sustainable Development Goals (SDGs):

- **SDG 9 Industry, innovation and infrastructure:** The creation and implementation of these structures require innovation, the use of sustainable materials and a focus on long-term ecological health. Additionally, the practice can stimulate local economies through sustainable tourism, as artificial reefs often attract divers and snorkelers interested in exploring these man-made marine ecosystems.
- **SDG 14 Life below water:** Artificial reefs, which are man-made structures placed in the ocean to mimic the functions of natural reefs, help to restore and enhance marine biodiversity, providing habitats for fish, invertebrates and other marine species. The goal seeks to prevent further degradation of marine ecosystems and artificial reefs play a key role in rebuilding coral habitats.
- **SDG 12 Responsible consumption and production:** By utilising recycled materials such as concrete and minimising environmental impacts during the deployment process. As part of corporate social responsibility (CSR) initiatives, the company makes tangible contributions to the global effort to protect and restore marine environments.

> The cost and environmental benefits of 3D-printed units are far superior to traditional design.

- **SDG 17 Partnerships for the goals:** The marine environment restoration work is a joint effort by several companies, organisations, and research institutes from various countries. Together we innovate and design specific, sustainable artificial reef structures. NMDC takes an active

FIGURE 10

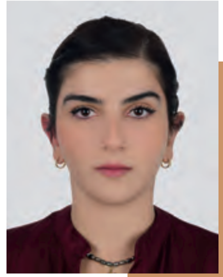
The United Nations Sustainable Development Goals.

role in fostering global partnership aimed at achieving sustainable development goals. This goal emphasises the importance of partnerships to drive progress across all goals, and the shared expertise and resources brought together through these collaborations help all the partners to advance innovative solutions for marine restoration.

In conclusion, the UAE's rapid transformation from a subsistence economy to a global powerhouse is deeply intertwined with its strategic use of dredging and reclamation projects. These efforts have been pivotal in expanding land for infrastructure and urban growth, particularly in a country with limited natural land availability. It is also recognised that, as the country continues to grow, the importance of environmental stewardship has never been more evident.

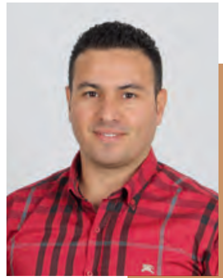
The commitment of the dredging community to sustainable practices, especially in marine habitat restoration, demonstrates how the dredging community can align with the UN Sustainable Development Goals. Through initiatives like the deployment of artificial reefs and the innovative use of 3D printing technology, we are not only addressing the environmental impacts of dredging but also actively contributing to the restoration of marine ecosystems.

By focusing on long-term ecological health and biodiversity, these projects ensure that the UAE's ambitious development plans are balanced with a responsibility to preserve the natural environment. This integrated approach highlights the potential for the dredging community to play a key role in advancing both economic growth and environmental sustainability, paving the way for a more resilient and sustainable future for the UAE.



Maryam Alyahyaei

Maryam is a Senior Dredging Production Engineer with over five years' experience in NMDC. With a master's degree in water and environmental engineering, she specialises in managing dredging projects, optimising production processes and ensuring operational efficiency. In addition to this, Maryam works in Research and Development, where she focuses on driving innovation and developing cutting-edge solutions to enhance operational efficiency.

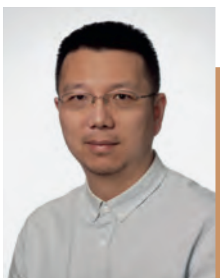


Volkan Ersozlu

With a degree in civil engineering, Volkan specialises in marine dredging, as well as onshore and offshore construction for international projects. He is currently serving as the Project Engineering Manager at NMDC in Abu Dhabi, UAE, where he leads a wide range of key projects.

Jonathan Keith

As Engineering Manager within NMDC Dredging & Marine business unit, Jonathan is responsible for managing engineering and design activities. Leveraging NMDC's own expertise as well specialists from our engineering partners, he delivers innovative solutions for tenders and awarded projects. Jonathan is actively involved in a number of initiatives to enhance the marine environments where we work.



Xiuhan Chen

Xiuhan works for NMDC as Dredging Development Manager, focusing on research and development tasks for dredging process and equipment. He is also actively involved in the World Organization of Dredging Associations (WODA), where he is general sectary to the WODA Technical Orientation Committee (TOC).

Mathilde Michaud

With a background in environmental engineering, Mathilde is a project manager at Seaboost, developing and managing nature inclusive maritime infrastructure projects. She is also a professional diver and follows projects from design to construction including underwater monitoring. Mathilde has been involved in several projects and development actions of Seaboost to implement habitat modules for marine infrastructures to boost their capacity to support marine life, innovative artificial reefs and coral transplantations.

Summary

With this article we examine the implementation of artificial reefs along the UAE coastline as a sustainable approach for marine biodiversity restoration. Together with the strategic dredging and reclamation projects reshaping the coastline, artificial reef structures, including fish domes and advanced 3D-printed reefs, have been deployed to mitigate ecological and environmental impacts.

These engineered habitats enhance marine biodiversity by providing shelter, promoting coral growth, and restoring fish populations. The study details the design, construction, and environmental benefits of these efforts, emphasising their role in ecosystem rehabilitation. By integrating innovative marine restoration techniques, the UAE aligns its coastal development with United Nations Sustainable Development Goals, ensuring long-term ecological resilience.

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