Building Artificial Reefs from Recycled Construction Materials: A Feasibility Study

Nicholas H. Lew
California Polytechnic State University
San Luis Obispo, California

Naturally occurring reefs are some of the world’s most biologically diverse ecosystems formed by jagged rocks tucked slightly below sea level. In recent years global warming began to pose a major threat to many reef habitats. Most relevant is the increase in surface seawater temperatures that cause coral to bleach, taking away major food sources for larger marine species. Researchers have combated this by deploying artificial reefs in substitution for naturally formed limestone rock formations in order to promote the expansion of coastal habitats. This project specifically aims to utilize construction waste towards the production of artificial reefs, effectively upcycling waste from one of the world’s largest waste-generating industries and providing proper habitat for marine organisms. Construction is one of the world’s major contributors to waste and carbon production, so this project aims to find creative solutions to utilize material that would otherwise end up in landfills and contribute to global warming. Furthermore, the elements of an effective habitat must also be outlined in order to ensure that the end product serves its intended purpose. Material properties and previous designs will need to be referenced in order to ensure that the reef is both non-toxic and effective at providing shelter and nurturing coral growth. A suitable location will also need to be established in order to ensure that the reef is serving its intended purpose. A conceptual design will be developed as a result of the findings. Materials used in the fabrication of this design will include recycled cement, reused concrete base rock, and miscellaneous piping.

**Key Words:** Artificial Reef, Construction Recycling, Upcycling, Design

**Introduction**

During the first Punic War, the Romans piled rock and rubble across the mouth of the Carthaginian harbor in Sicily in order to trap enemy ships within and to assist in driving the Carthaginian from the island (Williams, 2006). Unknowingly, the Romans were constructing what would become the first artificial reef in human history. Shortly after, the Persians would complete a similar project at the mouth of the Tigris River with the same goal of limiting the movement of enemy ships. It was later found that these human-made structures provided a wonderful habitat for offshore wildlife and facilitated some of the most flourishing ecosystems for marine life (Williams 2006).

Naturally occurring reefs in nature are often formed by a ridge of jagged rock or coral that is slightly above or below the surface of the sea. Coral are invertebrate animals that form compact colonies and slowly build reefs as they spread (Sherman 2002). Their hard exoskeletons are made of calcium carbonate and make for great reef starters. These formations of rock and coral provide hard surfaces for algae and invertebrates such as barnacles and oysters to latch to, which in turn attracts fish and other marine wildlife. A fully mature reef is essentially the perfect embodiment of a healthy ecosystem as it builds food chains from the ground up (Sherman 2002).
Although the Romans and the Persians were oblivious to the environmental benefits of their reefs, later civilizations took advantage of artificial reefs to increase fish yields. Reef-making became a widely applied practice among the profession of mariculture, or marine agriculture. Stating in the 17th century, Japan used rubble and rocks offshore to grow kelp (Eger, 2022). Similarly, people of the Philippines use a native fishing technique known as *gango*, in which mounds of rocks and waterlogged wood were used to form trenches that attract fish and crustaceans. These trenches were harvested every few weeks during low tide by surrounding these areas with fishing nets (Balgos, 1995).

**The World’s Natural Reefs**

Almost all naturally occurring reefs fall between the latitudes 40°N and 40 °S. This is due to the warmer water temperatures and sunlight exposure that supports algae growth. The only two continents with an absence of coral reefs are Europe and Antarctica, which can be attributed to the colder climates of the regions. Southeast Asia and Australia hold the largest share of reefs globally. The biggest group of managed reefs is found in the State of Florida, in both the Gulf of Mexico and the Atlantic Ocean (See Figure 1 below).

![Figure 1. Coral Reef World Map](image)

**The Degradation of Natural Reefs**

Coral reefs are being threatened by many global and local issues including overfishing, pollution, coastal development, and climate change. Some of these issues may cause irreversible damage to coastal ecosystems in locations all over the world. Of these issues, the rising temperature of sea water is the main stressor to coral health. When under stress, coral expels microscopic algae from their tissues, which is their natural food source. This in turn causes whitening of their exoskeletons, known as coral bleaching. Even the slightest changes to surface temperature can result in the degradation of entire habitats. Coral bleaching can only be reversed if the effects of environmental stress are
reversed. Based on results for an experiment conducted by the Office for Coastal Management, it is estimated that 51 percent of coral reefs are currently under stress from increasing sea surface temperatures (NOAA, 2022).

As a foundational species of coastal marine wildlife, the absence of coral would cause many species of fish, crustaceans, and even sea turtles to lose their habitats and food sources. If left unattended, this can trigger the mass extinction of coral along with all of the species that rely on them. Like many other issues affected by climate change, coral reef health yields immediate evidence to show how destructive global warming can be to wildlife.

**Modern Artificial Reefs**

In an effort to provide more reef habitats in tropical regions, marine biologists have experimented with different strategies to fabricate human-made structures that encourage coral growth. They have tried using sunken tires, modular steel and concrete structures, and most notably sunken vessels as seen in figure 2. Sunken vessels are effective habitats as the steel provides a good surface for marine life to latch on to. Ships also provide shelter and hiding space for different species of fish and invertebrates. The sunken vessel has become the flagship model for artificial reefs, even having been placed offshore doubling as snorkeling/scuba diving spots for tourism purposes.

![Figure 2. Sunken Vessel Artificial Reef](image)
Before a decommissioned ship can become an artificial reef, it must undergo preparation as outlined by the United States Environmental Protection Agency (USEPA, 2006). They include all requirements in the ‘National Guidance: Best Management Practices for Preparing Vessels Intended to Create Artificial Reefs’. Requirements include the siting of artificial reefs, along with the removal of potentially toxic material from the vessel prior to commissioning. Materials that have been found to be toxic to wildlife include oil, fuel, asbestos, PCBs, paint, and floatable debris. Organizations looking to form an artificial reef from decommissioned seacraft must ensure that these toxic materials have been abated prior to use.

The Global Impacts of Construction

The construction industry is estimated to generate about one-third of the world’s total waste (Conventry, 1999). Of this waste, concrete accounts for 50% of all total waste generated from construction materials. Other common waste from construction includes demolished concrete, bricks, masonry, wood, glass, insulation, and piping. This is largely due to the high demand for housing and structures all over the world. For context, cement is the world’s second most consumed product after potable water (ENR 2022).

Furthermore, the construction industry is disproportionately responsible for global Carbon Dioxide emissions when compared to other nations. Most emissions come directly as a result of material manufacturing rather than jobsite processes. Interestingly, the material that contributes most to carbon emissions is cement, the industry’s most consumed product. Most of this emission is a direct result of the pyro processing process which produces clinker, one of the main components of cement.

Developments in Construction Recycling

As of 2021, Construction professionals have developed many creative ways to reduce physical waste and carbon emissions as a direct result of material manufacturing. Vivian Tam suggests that recycling construction waste benefits companies in three ways. (i) reduce the demand for new resources, (ii) cut down on transport and production energy costs, (iii) utilize waste which would otherwise be lost to landfill sites (Tam, 2008). Tam continues by discussing how concrete contributes to waste generation. She argues that 100% of concrete waste is recyclable given modern technology. This is possible because concrete rubble can be separated and reused in new batches. The popularization of this method would mean that less aggregate would need to be procured and in turn, less aggregate would end up in our landfills.

Cement production can be made even more sustainable with the use of carbon capture technologies (ENR, 2022). These processes take the carbon flue gas emanating from clinkers production and process it in such a way that the carbon dioxide gas is separated from the air and liquefied before it gets the opportunity to escape into the atmosphere. The liquid carbon dioxide is then mineralized and used in future batches of concrete. The process that produces this concrete is described to have similar textures to coral reef limestone. A diagram of this process can be found in figure 3.
Methodology

The methodology of this research project will be carried out by interviewing professionals in the marine biology world and construction industry. A marine professional will be asked to identify elements of effective reef design. Representatives from general contracting and subcontracting firms will also be interviewed to source information regarding the current state of recycled materials on sites. This will help us identify which construction materials should be prioritized when developing a schematic for this artificial reef. By synthesizing new information from the marine biologist (which construction materials should be used), and the Construction Manager/Superintendent (what materials are abundant and need to be repurposed/recycled), we can effectively identify the needs of marine wildlife while repurposing the most common construction materials.

Using the identified parameters, a conceptual design for the artificial reef will be rendered. Furthermore, the placement of the reef will also be determined based on input from the marine biologist.

Findings

Representatives from three general contractors, one electrical contractor, one demolition contractor, and one plumbing contractor were interviewed about their recycling and demolition processes. They were asked the following questions in a ten-minute interview.

- What construction materials are typically recycled on jobsites?
- Which construction materials are most likely to end up in landfill?
- What type of construction waste is the most common in your trade?
- Which construction materials need to be abated for reuse?
This is done in an effort to narrow down plausible construction materials for reef building purposes. The most relevant findings are listed below.

Upon speaking with multiple marine science professors, data was also collected regarding effective reef design practices that foster both the development of reefs and are safe for the marine environment.

**Typically Recycled Construction Materials**

Three of the construction representatives made remarks about the abundance of copper pipe, steel pipe and metal studs recycled during the course of demolition. Pipes, especially those previously carrying cold and hot water supply are typically uncontaminated and can be repurposed. Metal studs are capable of being recycled but are oftentimes not due to the costly process of removing zinc from the surfaces. Another suggestion comes from the heavy civil representatives, who recalls concrete batches being repurposed into new base rock at recycling plants. Alongside advances in carbon capture cement production, concrete can be developed from entirely carbon neutral materials. Carbon capture programs trap flue gas from cement production and liquefy the carbon dioxide. This liquefied carbon dioxide is then processed into a Calcium carbonate which substitutes for calcium components of the cement. By combining this cement production strategy with recycled aggregate from demolition, carbon neutral concrete is within possibility.

Other common recycled construction materials identified by the respondents include conduit tube piping from the electrical representative, water supply line pipe from the plumbing subcontractor, and acoustical ceiling tile from two general contractors.

**Artificial Reef Design Philosophies**

As observed in previously deployed artificial reefs, many material types can make for great marine habitats. Despite the many examples of reefs, some are generally more effective than others due to the properties of the materials used. Some basic criteria were outlined for effective habitat materials. Artificial reefs need to be made from hard, durable materials that will resist weathering from the sea water. Furthermore, they need to be heavy or anchored down to prevent currents from sweeping the structure away. Lastly, materials should be abated of all toxic materials to ensure the health of organisms looking for a habitat. PCBs, zinc, and asbestos need to be properly removed from materials prior to use.

In terms of the physical form of artificial reefs, environments must be constructed from the bottom of the food chain. In this case, the algae and coral must find suitable areas to latch onto. This is the basis of attracting other species. Next step up the food chain, other invertebrates need pockets and coves to hide in. In previously deployed reefs, divots and bottles have been used to establish a habitat for this level of the food chain. The final element that makes a good reef are holes and coves for fish and larger species to burrow through. This is often why shipwrecks are popular among marine species.
Proposed Design

Utilizing the philosophy of designing from the bottom of the food chain up, a concrete comprised of recycled aggregate and carbon capture cement was selected for the main frame of the structure. The limestone-like properties of calcium carbonate fabricated from captured liquid carbon dioxide serve as a great attaching agent for coral and algae. This will be cast in a structure characterized by cubes, with passageways and hollow areas in the interior to provide shelter for fish and invertebrate species.

Among the common recycled materials identified through the interviews, conduit and steel pipe can serve as strong substitutes for glass bottles, which house cone-like invertebrate species and worms as long as they are abated properly prior to use. Adopting previous reef design strategies, recycled sections of slightly bent conduit will be cast into the concrete in order to form small tubular openings facing in different directions.

Lastly, the concrete structure will feature a passageway in the form of a hole to facilitate the fish population. Due to the inflexibility of steel and the likelihood of deformation caused by demolition, it was found that usage of structural steel is both inconsistent and suboptimal if the design were to be replicated for future batches. Please refer to figure 4 below for the modeled schematic of the artificial reef.

Figure 4. Artificial Reef Preliminary Model
Conclusions and Future Research

The initial reef design produced as a result of this project provides a good look into how recycled materials can be utilized to revitalize struggling ecosystems. Features of the preliminary design foster growth of organisms from the bottom of the food chain all the way up to the apex predators. The rough limestone-like finishes of the concrete provide favorable surfaces algae and coral. Tubes provide spaces for invertebrates to burrow, and openings give fish and crabs shelter. The presence of fish in turn attracts sharks and other predators. Elements of the design that haven’t been fully developed include rebar configuration and the design of the mold/form that will allow for consistent replication of the model. Specific locations along the Florida coastline have not been looked into either, and would likely require communication with local jurisdictions. Once a specific location is finalized, rigging and deployment procedures have to be developed to ensure that that artificial reef is undamaged during installation. Lastly, parameters for the effectiveness of the reef should be developed in order to track the progress of habitat growth.

References


ENR. (2021). New Technologies for Reduced Carbon Concrete are on the Horizon. URL: https://www.enr.com/articles/54809-new-technologies-for-reduced-carbon-concrete-are-on-the-horizon


