Final Evaluation Report

Your Details	
Full Name	Chee Su Yin
Project Title	Lightweight eco-concrete with reduced carbon footprint to enhance the ecological value of artificial coastal structures in Penang, Malaysia
Application ID	27600-B
Date of this Report	10/12/2023

1. Indicate the level of achievement of the project's original objectives and include any relevant comments on factors affecting this.

Objective	Not achieved	Partially achieved	Fully achieved	Comments
i) The eco-concrete resulting from this project will aim to provide substrate of better habitat suitability compared to ordinary concrete and support significantly more live cover, higher taxon richness, and overall species pool, than standard concrete made of Portland cement.			/	The objective was fully achieved upon our field survey reaching the 12th month. The panels supported more species compared to the previous report whereby field survey was only until the 9th month. The comparisons between our eco-concrete mix with conventional Portland cement did not show a significant difference in providing substrate of better habitat suitability for the marine organisms at our study site based on the three treatments we have tested: (a) complex panels, (b) blank panels, and (c) artificial pools. Though material composition did not pose a significant difference on the

				aforementioned, complexities that were present on our complex panels successfully hosted a higher number of species compared to the blank panels. There was also no significant difference in the taxon richness and live cover between the eco-concrete and the standard Portland concrete.
ii) The light weight of the eco-concrete will ease handling of large eco-engineered enhancements installed post-construction on marine infrastructure and in areas where the need for lightweight material arises.	/			The results from the weight of our eco-concrete mix designs using seashells have shown that they are not considered lightweight in regards to the standard provided by BS EN 206-1 and had almost the same weight as conventional concrete. Handling the tiles during installation works was similar to conventional concrete. However, we have successfully developed a higher concrete strength

				using our eco-concrete mix.
iii) The replacement of Portland cement with recycled GGBS and coarse aggregates with natural fibres and seashells will reduce environmental footprints compared to ordinary Portland cement-based concrete.			/	This study concentrated on creating a designated concrete mixture using seashells as a fine aggregate replacement to produce the lightweight eco-concrete which reduced the environmental footprint by 60% (~140 CO^2 per tonne). Natural fibres were not used in this project as preliminary studies show that kenaf produced weaker concrete.

2. Please explain any unforeseen difficulties that arose during the project and how these were tackled.

Due to the COVID-19 pandemic which started at the beginning of 2020 in Malaysia, we were faced with a few challenges:

1) Delay in the progress of the project due to limited movement and access to laboratories and project location.
2) Land-use change for the original project location (Clan Jetties) as there was a proposed development for the area.
3) Delay in field installations on our industrial partners' side which we originally proposed for field installations to be completed by the end of August 2022.

We have resolved the challenges by:

1) Extending the project duration to 30th June 2023 (with The Rufford Foundation) and 31st March 2024 (USM internal matching fund) in response to the delays for both the limited accesses during COVID-19 as well as field installations.

2) Relocated the original project location (Clan Jetties) to another project site at The Light Waterfront, Penang (refer to Appendix 1).

3. Briefly describe the three most important outcomes of your project.

1) Lightweight eco-concrete

(i) Reduced carbon footprint

We have successfully developed the eco-concrete with reduced carbon footprint using only crushed seashells as replacement for coarse aggregates in the concrete mix instead of another combination with kenaf fibres as it resulted in a weaker concrete. The eco-concrete mix which was formulated using food (crushed seashells) and construction waste (GGBS and quarry dust) had approximately 60% reduction in carbon footprint compared to conventional concrete (Fig. 1).

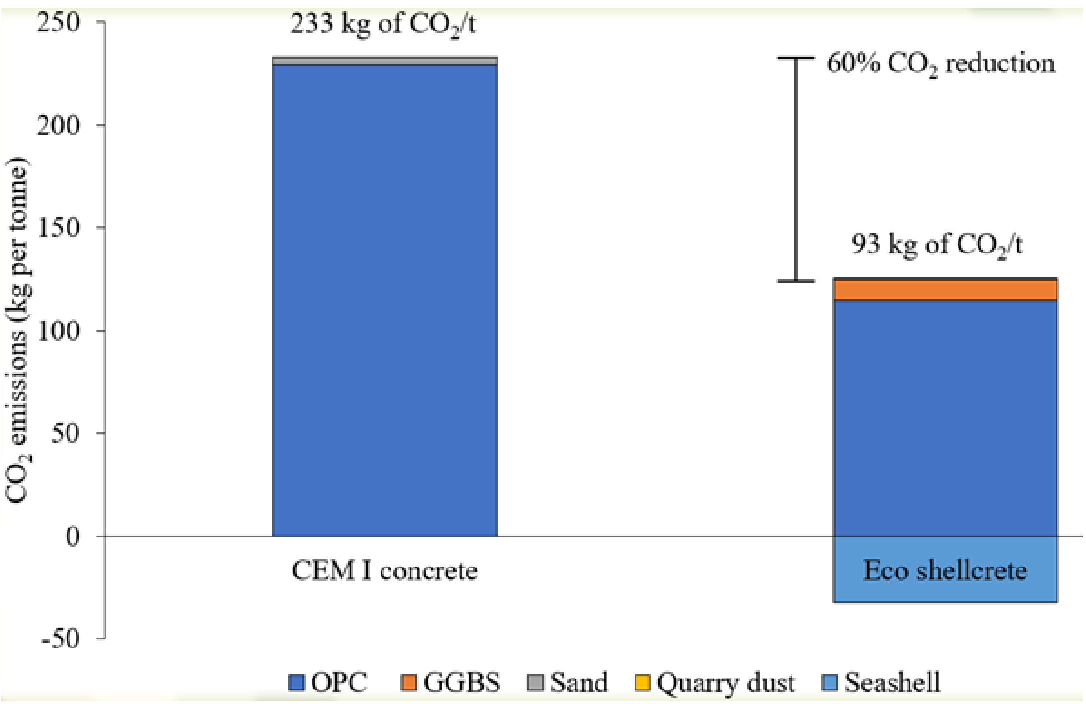


Figure 1. Carbon dioxide emissions of Portland cement concrete and eco-concrete. CEM I concrete = Portland cement concrete.

(ii) Lightweight measurements

However, lightweight was not achieved in our eco-concrete for this project as defined by BS EN 206-1, which specified that an oven-dry density ranging from 800 to 2000 kg/m^3 is considered a lightweight concrete. Based on the three mix designs we have conducted: (1) conventional concrete using river sand aggregate, (2) concrete with 50% partial replacement of seashell, (3) and concrete with 100% total replacement of seashell which measured 2165 kg/m^3, 2158 kg/m^3, and 2146 kg/m^3, respectively, the results did not fall within the range as specified by BS EN 206-1. Seashells are also not generally considered as lightweight aggregates, as their bulk density and specific gravity are similar or slightly lower than those of traditional aggregates. In fact, the bulk densities of the cockle shells used in this project fell within the range specified for normal weight aggregates (1280-1920 kg/m^3) according to ACI guidelines. Whilst using seashells did not achieve light weight concrete, we have successfully developed a seashell-integrated concrete of higher concrete strength performance. As a result, we opted to use seashells as a replacement for fine aggregate to produce normal weight concrete.

2) Species Richness of Portland Cement Concrete vs Lightweight Eco-concrete

In this project, we have created three different treatments of: (1) complex panels (with complexities), (2) blank panels (smooth-surfaced), and (3) artificial pools mimicking natural rock pools, using Portland cement and our eco-concrete mix respectively (Fig. 2) that were deployed at The Light Waterfront. The results from the following treatments were based on our 12 months of field survey. Marine organisms observed on the treatments were identified to species level while species that cannot be identified unless through destructive sampling were assigned to their morphospecies. The surface temperatures of the treatments were recorded using the type-J probe thermocouple.

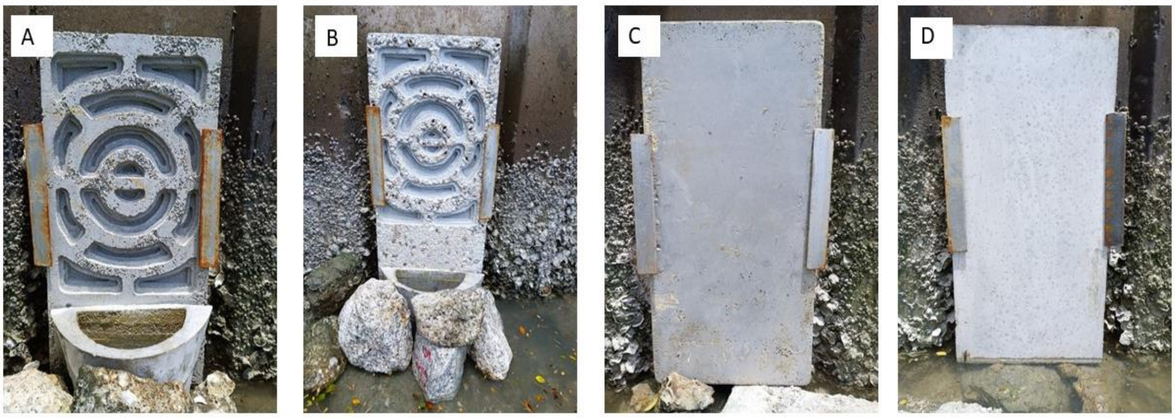


Figure 2. (A) complex Portland Cement panel with Portland Cement artificial pool, (B) complex eco-concrete panel with eco-concrete artificial pool, (C) blank Portland Cement panel, (D) blank eco-concrete panel installed at The Light Waterfront.

(i) Complex Portland Cement panels (CC) vs complex eco-concrete panels (CE)

There was no significant difference between the mean species richness between the CC (8.50 ± 3.61) and the CE (8.33 ± 4.52). The results from the independent samples t-test, also showed no significant difference between the

CC and CE panels, t (22) = 0.100, p = 0.921. Based on the species accumulation curve, the CE panels have shown a steady increase in the number of species despite the slight drop from November to December 2022 (Fig. 3). Although the number of species were higher in CC panels, field survey from the latest month in September 2023 showed that the number of species were higher than the CC panels. There was an increase in the number of species on the CE panels until the 12 months duration of field survey.

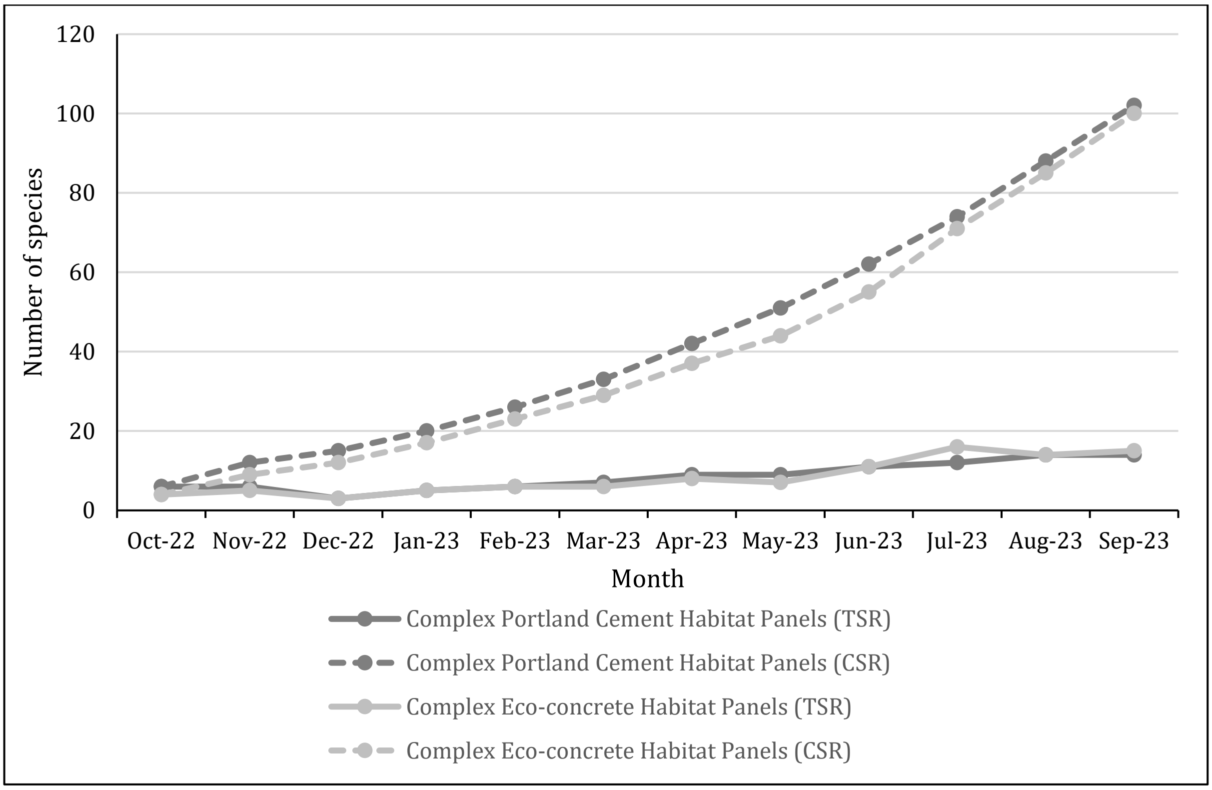


Figure 3. Cumulative Species Richness (CSR: Dashed lines) and Total Species Richness (TSR: Solid lines) recorded on complex Portland Cement panels (dark grey) and on complex eco-concrete panels (light grey) over 12 months.

During the 12 months of field survey, the presence of complexities on our panels have provided benthic marine organisms refuge from heat and predation during low tide which were otherwise absent on the study site's seawall. Additionally, our complexities also acted as a breeding space for limpets to reproduce (Figure 4). The incorporated designs have largely supported grazing molluscs and barnacles, especially *Littoraria articulata* that were commonly found congregated in the between the limited recesses of the seawall at the study site and *Amphibalanus amphitrite*. There were also frequent sightings of numerous grazing false limpets (*Siphonaria guamensis*), Javan false limpet (*Siphonaria javanica*), lined nerite snails (*Nerita lineata*) on both panels throughout the 10th to 12th months of field survey. New recruiting marine organisms present on the CE panels throughout that duration included dog winkles (*Thais* sp.), the rayed wheel (*Cellana radiata*), and the colonial tunicate (*Didemnum psammatodes*) observed in small abundances on the designs.

Other marine organisms that have utilised the complexities on both the panels also included crabs, onch slugs, and toothed top shell (Fig. 4).

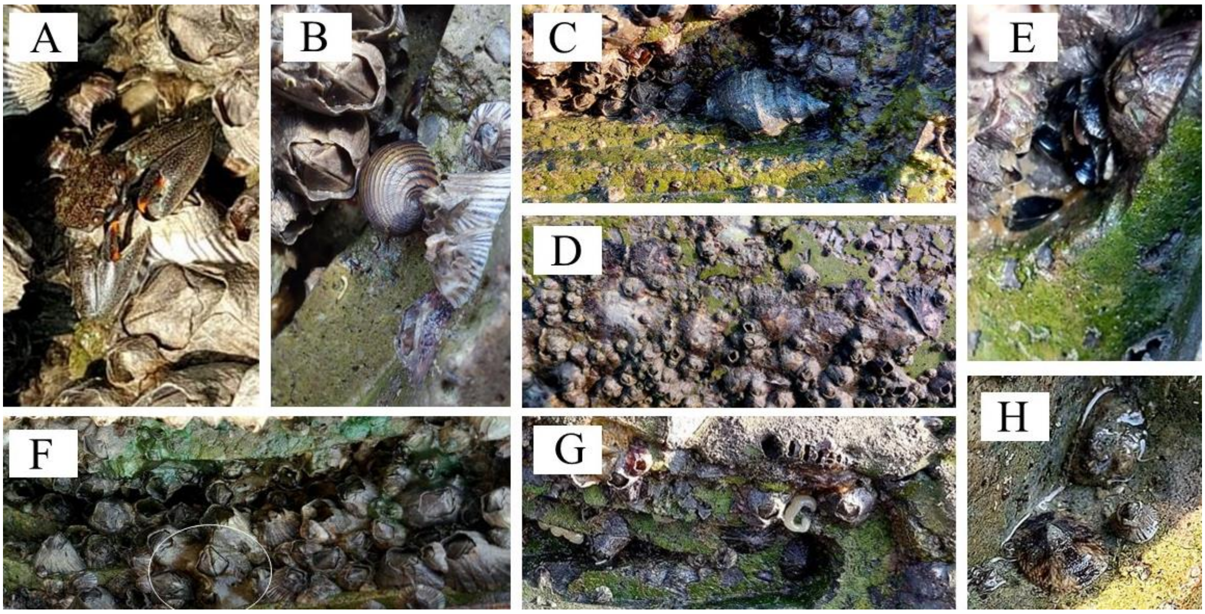


Figure 4. (A) Foraging crab, (B) grazing *Nerita lineata*, (C) grazing *Thais sp.*, (D) an abundance of hooded oysters (*Saccostrea cucullata*), E) clusters of black mussels (*Xenostrobus sp.*), F) small abundances of *Didemnum psammatodes*, G) limpets and limpet eggs, H) and rayed wheel limpet (*Cellana radiata*) on the designs of the CE panel.

Overall, the CC and CE panels have also hosted a gradual rise in the abundance of oysters (*Saccostrea cucullata*) and mussels (*Xenostrobus* sp.) during the 5th month (February 2023) until the latest field survey (September 2023). Both the panels also hosted three barnacle species: (i) *Amphibalanus amphitrite*, (ii) *Chthamalus malayensis*, and (iii) *Chthamalus* sp. (Fig. 5). Throughout the survey, empty barnacle shells in the panels have provided additional niche spaces for *Littoraria articulata* to thrive too. There were also increased sightings of young crabs foraging on both the complex panels throughout the 10^{th} to 12^{th} month of field survey. We expect to observe an increase in species number on both the complex panels which we will continue to monitor.

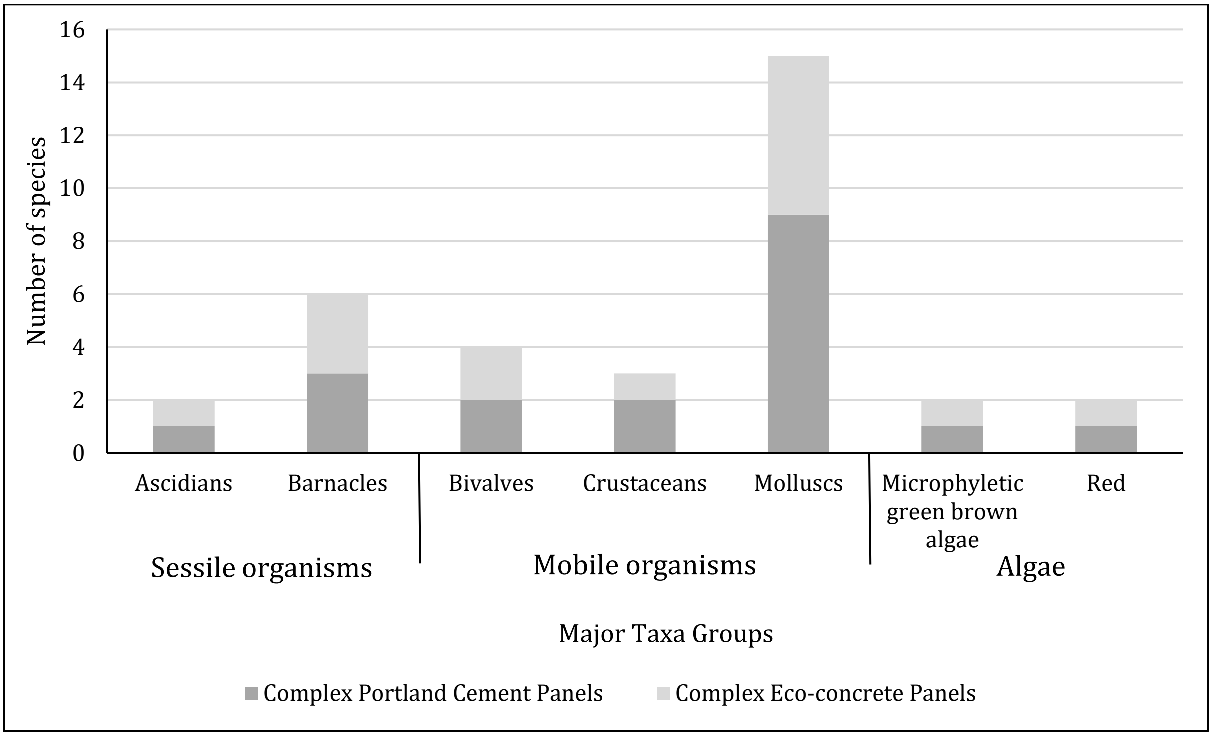


Figure 5. Total number of species in major taxa groups recorded on the complex Portland Cement panels (Dark Grey Bars) and additional species recorded on the complex eco-concrete panels (Light Grey Bars) at The Light Waterfront.

(ii) Artificial Portland Cement Pool (CP) vs Artificial Eco-concrete Pool (EP)

Based on the results of the independent t-test, there is no significant difference between the CP (11.08 ± 2.71) and EP (12.0 ± 4.29), $t(22) = -0.626$, $p = 0.538$. Although the material in which both the artificial pools were composed of did not significantly show differences in the number of species they support, the number of species recorded in the EP was more compared to the CP. As depicted in Figure 6, there was a fluctuation in the number of species in both the artificial pools before reaching a constant trend from April 2023 to the latest field survey (September 2023). Marine organisms such as *Didemnum psammatodes* and the orange tunicate crust that were found on the sides of the EP pool in February and March 2023 were absent from April to June 2023 which resulted in a decrease in the number of species as the pools containing these two organisms were overturned due to strong waves in April 2023 (Fig. 6). Orange and blue encrusting sea sponges which were found in the EP in August 2023 prompted the rise in the number of species which led to a higher number of species compared to CP in September 2023. The presence of grey knight gobies (*Stigmatogobius sadanundio*) dominating the bottom of the EPs in May and June 2023 was also part of the cause in the reduction of species number as crabs such as *Grapsus albolineatus* were occasionally seen in foraging in this area. They were found utilising the EP as a breeding ground as well.

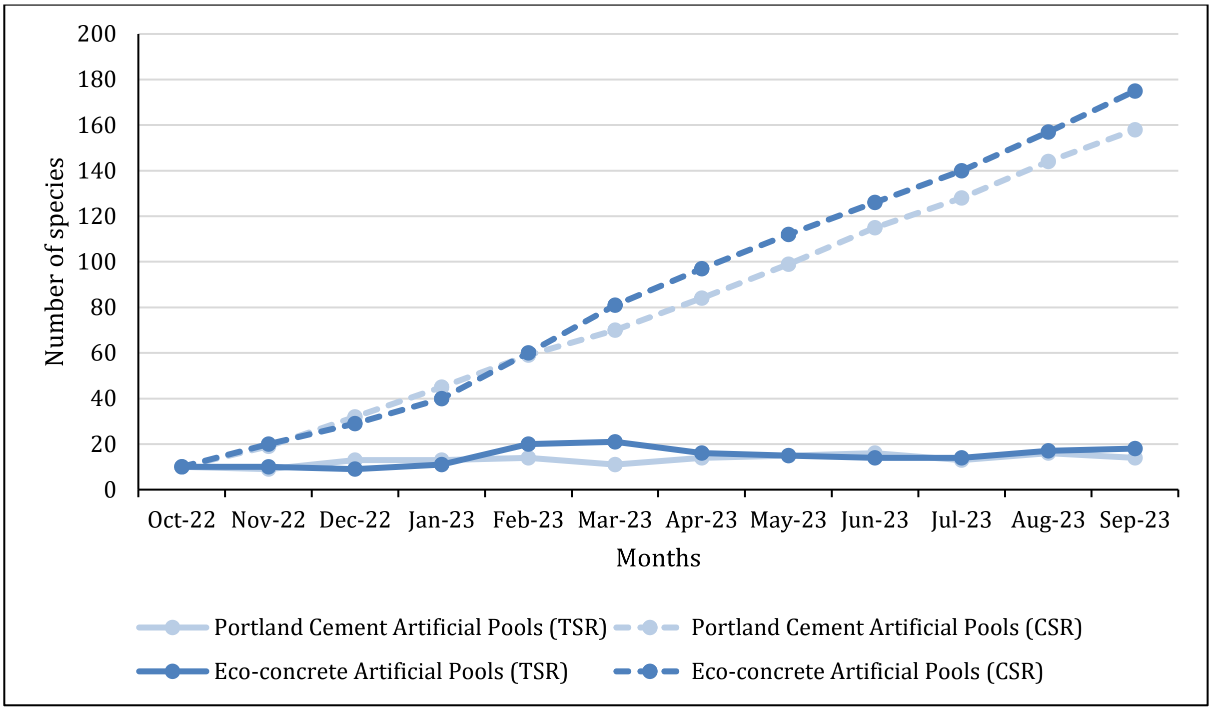


Figure 6. Cumulative Species Richness (CSR: Dashed Lines) and Total Species Richness (TSR: Solid Lines) recorded in Portland Cement artificial pools (light blue) and in eco-concrete artificial pools (dark blue) over 12 months.

Both the artificial pools were occasionally occupied with fish species such as the sand goby (*Pomatoschistus minutus*) and grey knight goby (*Stigmatogobius sadanundio*) while Kabili bumblebee goby (*Brachygobius kabiliensis*), Java fat-nose goby (*Pseudogobius javanicus*), and blennies where also found in EP. Sand gobies and grey knight gobies were among the frequent fish occupants in both the artificial pools. However, in comparison to CP, EP has supported more fish species (five) compared to CP which only supported two and also hosted both spionid worms and *Sabellastarte* sp. (Fig. 7). Both pools remained largely dominated by diatoms with minimal percentages of the same green algae species and red encrusting algae present only at the top sides of the artificial pools. Macroalgae was not recorded in all the artificial pools throughout the 12 months of field survey. Limpets (*Siphonaria guamensis*), *Littoraria articulata*, and onch slugs were occasionally seen grazing on the sides of the artificial pools. There were also sightings of *Pictocolumbella ocellata* in CP and EP in the 1st month (October 2022) and in the 2nd month (November 2022) only occurring in EP. The artificial pools also supported a steady growth in oysters (*Saccostrea cuccullata*) throughout the 12 months duration. Organisms such as shrimps, oysters, and barnacles were commonly found in both artificial pools during field surveys. The artificial rock pools also supported several species of mobile organisms that were not otherwise living on the seawall and panels (e.g., sea sponges, tunicates, polychaetes, fishes, as well as some mollusc species). Examples of tunicates that were present in the artificial pools included *Sabellastarte* sp., *Distaplia* sp., *Didemnum psammatodes*, and an orange tunicate crust. Orange and blue encrusting sea sponges were among the newly recruited marine organisms found on the sides of the EP in August 2023 (Fig. 8). The receptivity of marine organisms towards the artificial pools has led us to expect further increase in species richness in months to come which we will continue monitoring.

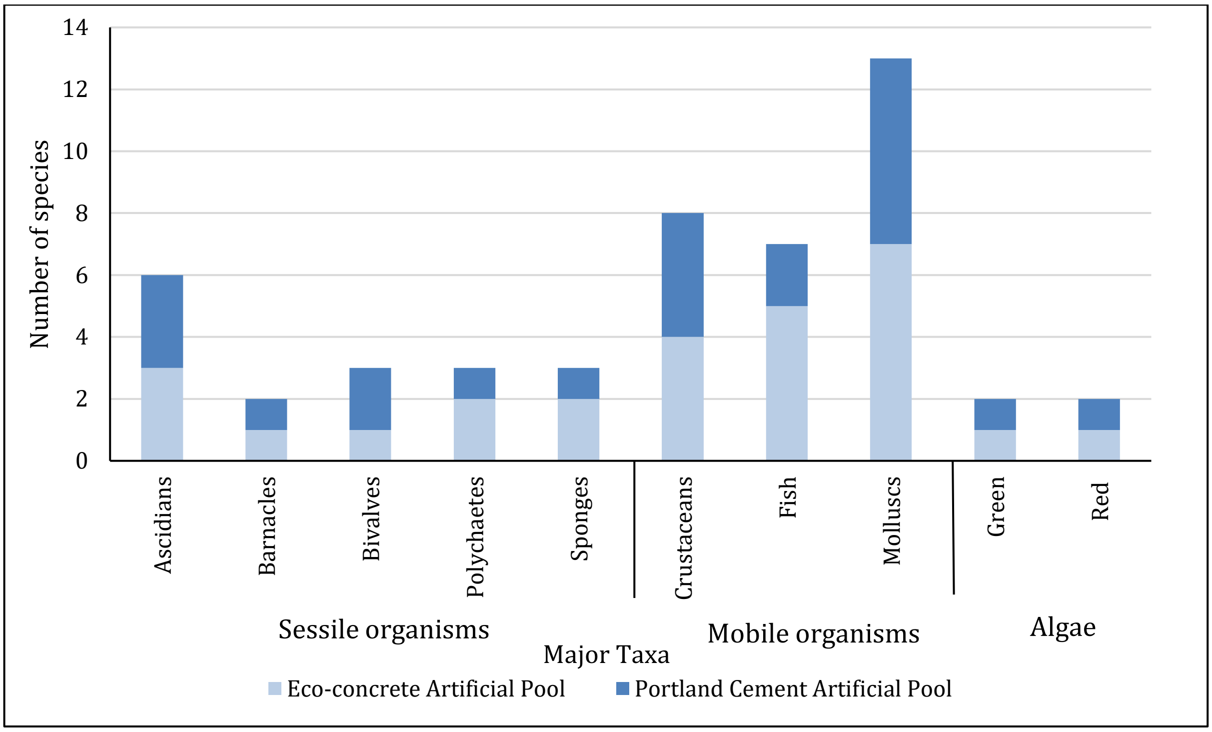


Figure 7. Total number of species in major taxa groups recorded in the Portland Cement artificial pools (light blue bars) and Additional Species Recorded in the eco-concrete artificial pools (dark blue bars) at The Light Waterfront.

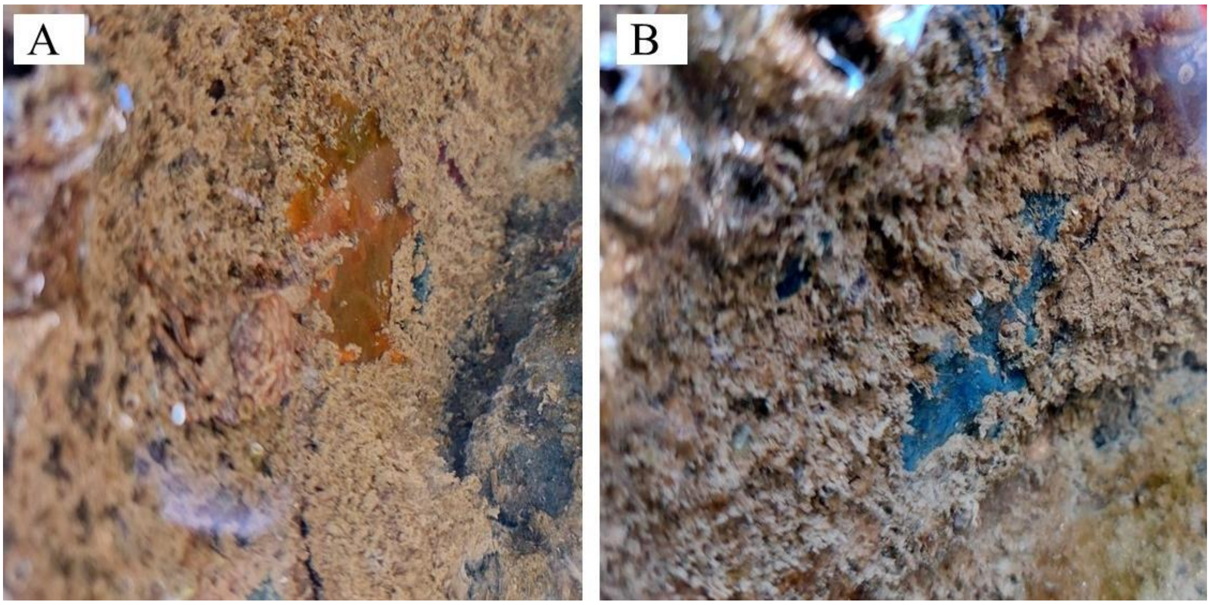


Figure 8. (A) An orange encrusting sponge and (B) encrusting blue sponge located at the side of the eco-concrete artificial pool.

(iii) Blank Portland Cement (BC) vs Blank Eco-concrete (BE)

Based on the results on the independent t-test, the mean species richness in the BC panels (3.67 ± 1.07) was not significantly different from the mean species richness in the BE panels (3.83 ± 1.19), $t(16) = -0.277$, $p = 0.785$. Similarly, the site's seawall and the panels were typically colonised by one barnacle species (*Amphibalanus amphitrite*) and mollusc (*Littoraria articulata*) (Fig. 9). The absence of complexities has forced the aforementioned organisms to occur in small abundances on both panels. Malaysia's dry season has also affected the blank panels which resulted in a drop in the number of species in December 2022 and January 2023 (Fig. 10). However, the number of species on the blank eco-concrete panels increased in April and June 2023 whilst it was the same for the blank Portland cement since February 2023. *Saccostrea cucullata* which was first recorded in the latest field survey in June 2023 only on the BE panels were also found growing on two of the BC panels on the 10th month of field survey (July 2023) (Fig. 11). There was a growth in number of *Saccostrea cucullata* colonising the BE panels until September 2023 and it is expected to increase with time.

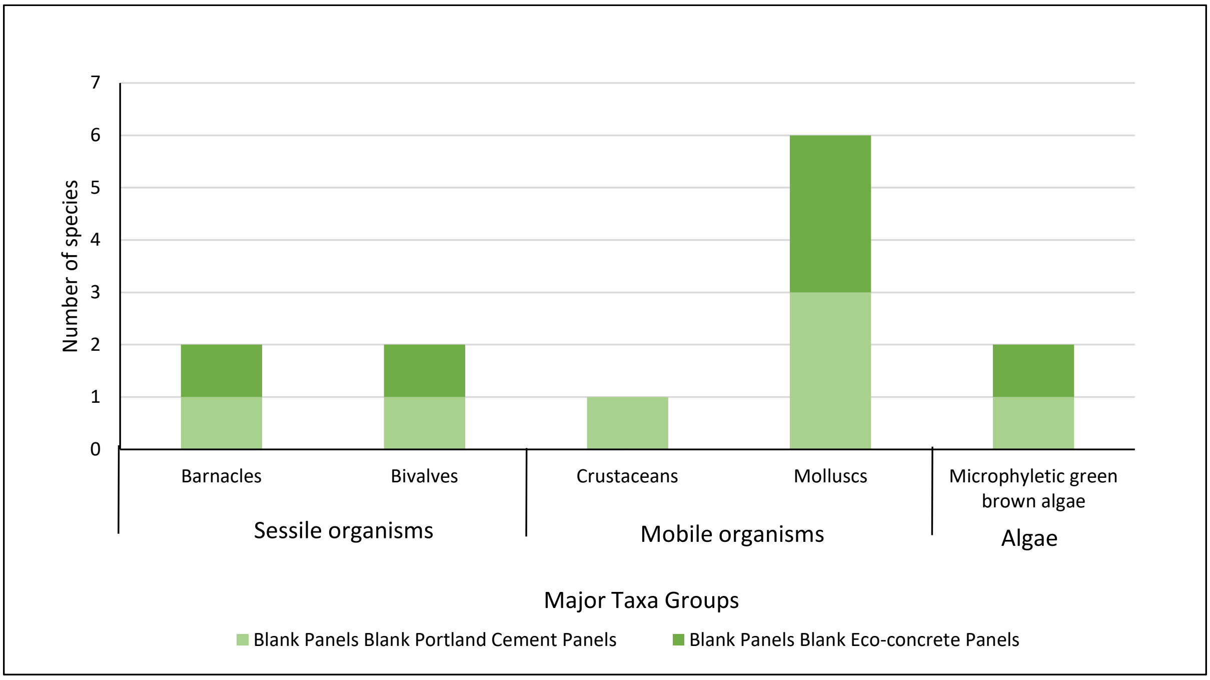


Figure 9. Total number of species in major taxa groups recorded on the blank Portland Cement panels (light green bars) and additional species recorded in the blank eco-concrete panels (dark green bars) at The Light Waterfront.

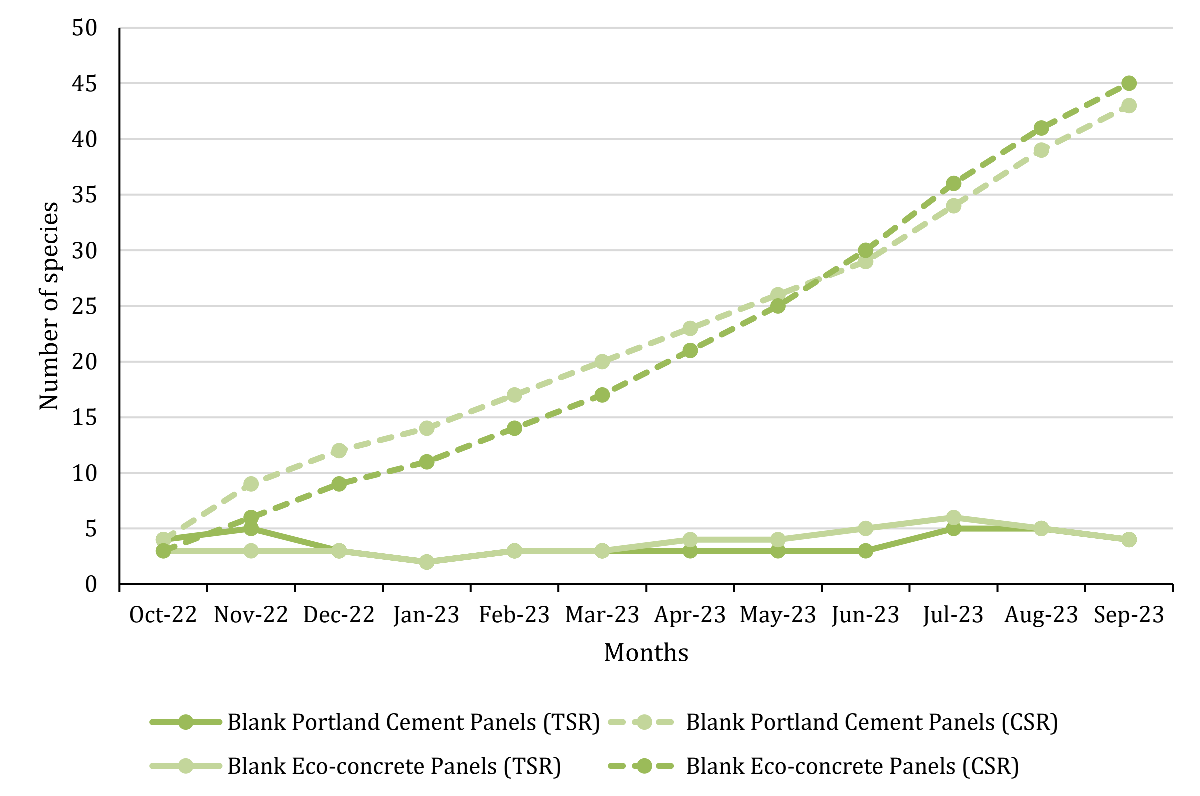


Figure 10. Cumulative Species Richness (CSR: Dashed Lines) and Total Species Richness (TSR: Solid Lines) recorded in blank Portland Cement panels (light green) and in blank eco-concrete panels (dark Green) over 12 months.

Figure 11. (A) *Saccostrea cucullata* on the blank Portland cement panels (BC) and (B) on the blank eco-concrete panels (BE).

(c) Comparisons between blank and complex treatments of both Portland Cement and eco-concrete panels

Although the following did not fall within the objectives of this study, we have found that the complex treatments supported more species richness compared to the blanks.

(i) Blank Portland Cement (BC) vs complex Portland cement (CC) panels

Based on the results on the independent t-test, the mean species richness in the CC panels (8.50 ± 3.61) was significantly different from the mean species richness of the BC panels (3.67 ± 1.07), $t\,(12.934) = 4.451$, $p = 0.001$. Overall, the CC panels hosted a significantly higher number of species (14) compared to BC panels (seven) throughout the 12 months of field survey.

(ii) Blank eco-concrete (BE) vs complex eco-concrete (CE) panels

Based on the results on the independent t-test, the mean species richness in the CE panels (8.33 ± 4.52) was significantly different from the mean species richness of the BC panels (3.75 ± 1.14), $t\,(12.390) = 3.407$, $p = 0.005$. Overall, the CE panels hosted a significantly higher number of species (19 species) compared to the BE panels (6 species) throughout the 12 months of field survey.

Overall, the macrobenthos and mobile species favoured the complex treatments over the exposed blank panels which provided them no refuge. The difference in material composition did not pose a significant difference to how the marine organisms behave on all the treatments. In comparison, the artificial pools have shown also to support more species compared to the other treatments.

4. Briefly describe the involvement of local communities and how they have benefitted from the project.

Local communities were not involved directly in the project, but they were engaged in the following manner:

1) SEAS Camp (24/09/2022)

Concept of the current project was shared to 30 underprivileged secondary school students to educate them on the importance of having textures and complexities on Malaysia's coastal defence structures.

2) Engagement with locals at the seafood factory (2019)

Seashells were obtained from local seafood factories located at Kuala Juru, Penang and Kuala Gula, Perak as materials to partially replace Portland cement in this project. A sharing session regarding the purpose of using seashells in this project was made with the locals there.

3) Engagement with local communities at the project site (2022-2023)

As sampling site was publicly accessible, we had the chance to encounter visitors/locals who place interest in our work. A simplified information was used to explain to them to improve their current knowledge towards Malaysia's coastal defence structure and conservation status.

4) Engagement with our industrial partners (2022-2023)
The ideas and concepts of the project were presented to our local development company, IJM Corporation Berhad, prior to field installations and permit agreement. We discussed Malaysia's ecological engineering prospects. They have also shown their interest in the progress of the project and were updated on the status of marine organisms colonising the panels periodically.

5) Salvation Army Penang Children's Home, Georgetown, Penang (October 2020)
We organised a workshop comprising 20 children from the orphanage and educated them on the importance of having ecological engineering complexities. The children learnt how to DIY their own complex habitat units using plaster of Paris and additional materials that were provided such as beads.

6) St Joseph's Home, Georgetown, Penang (9/06/2022)
We organised a workshop comprising 30 children from the orphanage and educated them on the importance of how the presence of complexities can help promote biodiversity on Malaysia's coastlines (refer to Appendix 2).

7) Webinars (2019-2023)
Webinars educating on the concepts of the project were also made on the online platforms which reached about 500 people:
1. PowPowEarth. Profile Interview of Earth People in Action. 1 May 2023. https://www.youtube.com/watch?v=F1GDhRJwUGI

2. MyMangrove Monthly Discourse March 2022. 16 March 2022. https://www.youtube.com/watch?v=G4HSiwU5prY&t=9s

3. Akademi Sains Malaysia. 1 June 2022. Healing Our Coastlines with Ecological Engineering | FAScinate™ https://www.youtube.com/watch?v=bEjPnA5zDX0&t=14s

4. The Vibes. Erosion wreaks havoc on once charming Batu Ferringhi beach. 28 April 2021. https://www.thevibes.com/articles/news/25431/Erosion-wreaks-havoc-on-once-charming-Batu-Ferringhi-beach

5. Webinar on launch of key policy briefs on Nature Based Solutions (NbS) and Integrated Grey to Green Infrastructure (IGGI). 18 May 2021. https://www.facebook.com/nexams.my/posts/203024358316542

8) Articles in mass media (2020-2023)

Articles in mass media describing the concepts of the project were also made:

1. Chee, S.Y. and Ikrami, M.A. 2022. The Power of Arts in Communicating Science. https://simplyspeaking.usm.my/index.php/category/sustainability/81-the-power-of-arts-in-communicating-science

2. Chee, S.Y. 2021. Raising The Profile of Nature-Based Solutions for Climate Resilient Coastlines in Malaysia.

https://simplyspeaking.usm.my/index.php/category/sustainability/70-raising-the-profile-of-nature-based-solutions-for-climate-resilient-coastlines-in-malaysia

3. Chee, S.Y. 2020. Pemeliharaan Pantai Berasaskan Penyelesaian Alam Semula Jadi (Nature-based solutions for coastal conservation). Majalah Sains, https://www.majalahsains.com/pemeliharaan-pantai-berasaskan-penyelesaian-alam/

4. Chee, S.Y. 2019. Designing Sustainable Seascapes for New Coasts. IMPAKTER, https://impakter.com/designing-sustainable-seascapes-for-new-coasts

5. Are there any plans to continue this work?

Yes. We plan to upscale the application of the eco-concrete in new designs of coastal reefs and other habitat enhancements in other states in Malaysia. A potential application site has been identified along Pasir Pandak, Kuching, Malaysia. There are ongoing discussions with IMDC, Belgium and ECOncrete on applying the eco-engineering knowledge from this project in Malaysia and abroad. The datasets until month 12 have provided us valuable knowledge in green engineering design components in the tropical climate which can be applied to more efficient, future eco-concrete production relevant to Malaysia's weather conditions. This locally produced product aimed with reduced carbon footprint will suit our interest in better promoting native biodiversity, faster reef-forming, and wave energy reduction, which will contribute to a multi-functional seawall prototype. In response to the rapid coastal developments in Penang Island, Malaysia, especially with the ongoing development of an artificial island, there is also potential to incorporate eco-engineering knowledge with liaising stakeholders onto these structures.

6. How do you plan to share the results of your work with others?

The following plans were how we shared our results in the past:

1) We have created a website (https://natbaselab.wixsite.com/mysite-1) that is still being updated, showcasing the project and other works related to ecological engineering for public viewing.
2) Our work has also reached numerous webinars related to coastal conservation, biodiversity, and climate-related issues where we further emphasised on the importance of ecological engineering in Malaysia's coastlines.
3) We have also published several articles regarding the project in local magazines such as the Penang Monthly.
4) The results of our work titled "Recycled seashells as materials for green artificial reef" was shared virtually in a conference called "The Omics in the Ocean" which was the 9th International Symposium for Marine Biology and Biotechnology.

We will continue to share the results of our project using similar platforms in other opportunities that arise:

1) Several research papers will be published in high impact journals to share the results of this project with other academicians for ideas exchange.
2) We have also ventured into publishing in arts and design journal papers to gain more exposure for our work (*in review, Title: A comparative study on the materials and process for casting eco-concrete mixture for artificial marine habitats.; Author(s): Amanda Kar Mun, Chong; Mohd Alif Ikrami Bin Mutti; Chee Ban, Cheah; Yee Jean, Chai; Su Yin, Chee**).
3) The results of the project have already been included in several conferences such as the International Biodiversity Symposium 2023 (IBDS 2023), 11th International Conference on Multidisciplinary Research (iCMR 2023) and the 3rd International Conference on Sustainable Development Goals 2023 (ICSDG 2023).

7. Timescale: Over what period was the grant used? How does this compare to the anticipated or actual length of the project?

The original duration of the project was 1st September 2019 to 30th November 2021 but was extended twice to 30th June 2023 due to COVID-19.

8. Looking ahead, what do you feel are the important next steps?

There is still a need to further research on suitable designs and complexities in creating habitat enhancement units at selected sites which will fit Malaysia's coastal conditions and weather to promote native biodiversity in the long run. Prototype development for commercialisation is also critical as Malaysia's coastline is being hardened at a fast pace. The importance to upscale the gist of this project to other parts of Malaysia is important in order to get as many case-by-case basis results that can be used for decision making in terms of sustainable coastal development.

9. Did you use The Rufford Foundation logo in any materials produced in relation to this project? Did the Foundation receive any publicity during the course of your work?
Yes.

The following are the materials produced in relation to the project with The Rufford logo used:

(a) Presentation slides:
   - (i) Greening of Grey: Creating space for nature on artificial coastlines in Penang (refer to Appendix 3).
   - (ii) Nature based solutions in marine and coastal environments in Malaysia: Past efforts, lessons learned, and way forward (refer to Appendix 4).
   - (iii) Artificial pools promote higher species richness on artificial coastal structures in Penang Island, Malaysia (refer to Appendix 5).
   - (iv) Incorporation of complexities on artificial coastal structures enhances the species richness of thriving benthic organisms through installed habitat panels (refer to Appendix 6).

The Rufford Foundation also received publicity through:

Acknowledgements during our participation in the 9th International Symposium for Marine Biology and Biotechnology virtual conference in July 2022 titled "Recycled seashells as material for green artificial reef" by Yee Jean Chai (refer to Appendix 21)

10. Please provide a full list of all the members of your team and briefly what was their role in the project.

Name	Role	Affiliation
Assoc. Prof. Dr. Cheah Chee Ban	Assoc. Prof. Dr. Cheah Chee Ban has provided us space and equipment in his laboratory to conduct concrete experiments and concrete casting throughout the duration of this project. He has also guided us in concrete-related matters with his expertise whenever needed.	School of Housing, Building, and Planning (HBP), Universiti Sains Malaysia.
Dr. Tay Guan Seng	Dr. Tay Guan Seng has assisted in this project by giving advice on the research related to kenaf.	School of Industrial Technology, Universiti Sains Malaysia.
Amanda Chong Kar Mun	Ms. Amanda Chong Kar Mun is responsible for the fieldwork coordination and primary data entry.	Centre for Global Sustainability Studies, Universiti Sains Malaysia.
Mr. Mohd Alif bin Mutti	Mr. Mohd Alif bin Mutti has provided advice on the tiles design using his expertise and also gave us additional insights on other alternatives to cast the tiles using suitable materials and methods other than steel moulds.	Product Design Department, School of Arts, Universiti Sains Malaysia.
Yee Jean Chai	Throughout this project, Mr. Yee Jean Chai has guided us by formulating the eco-concrete with reduced carbon footprint and conducted further tests on it to determine its strength prior to casting and installation works. He has also assisted in casting works, field surveys at the	Centre for Global Sustainability Studies, Universiti Sains Malaysia.

	project site, and provided data analysis of the eco-concrete.	
Dr. Ally Evans	Dr. Ally Evans aided as a fieldwork consultant and provided us her expertise on marine biodiversity throughout this project.	Prifysgol Aberystwyth University, Penglais Campus, United Kingdom.

11. Any other comments?

Although the results obtained until month 12 have provided sufficient data in fulfilling the objectives of the project, we will continue monitoring the project to ensure that a comprehensive data set is achieved to enhance our validity and robustness of our results.

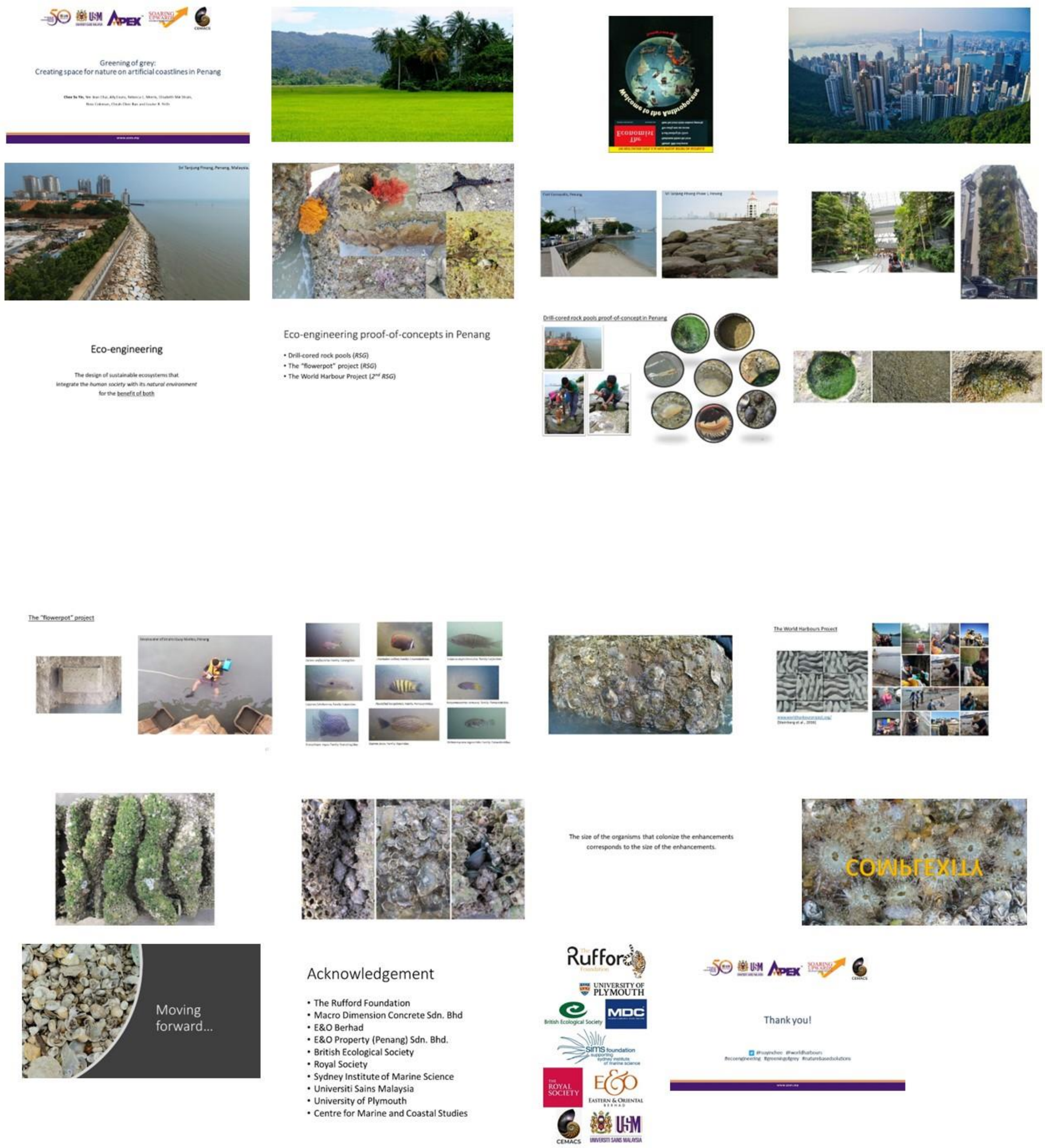
Appendix 1

New study site: The Light Waterfront, Penang.

Appendix 2

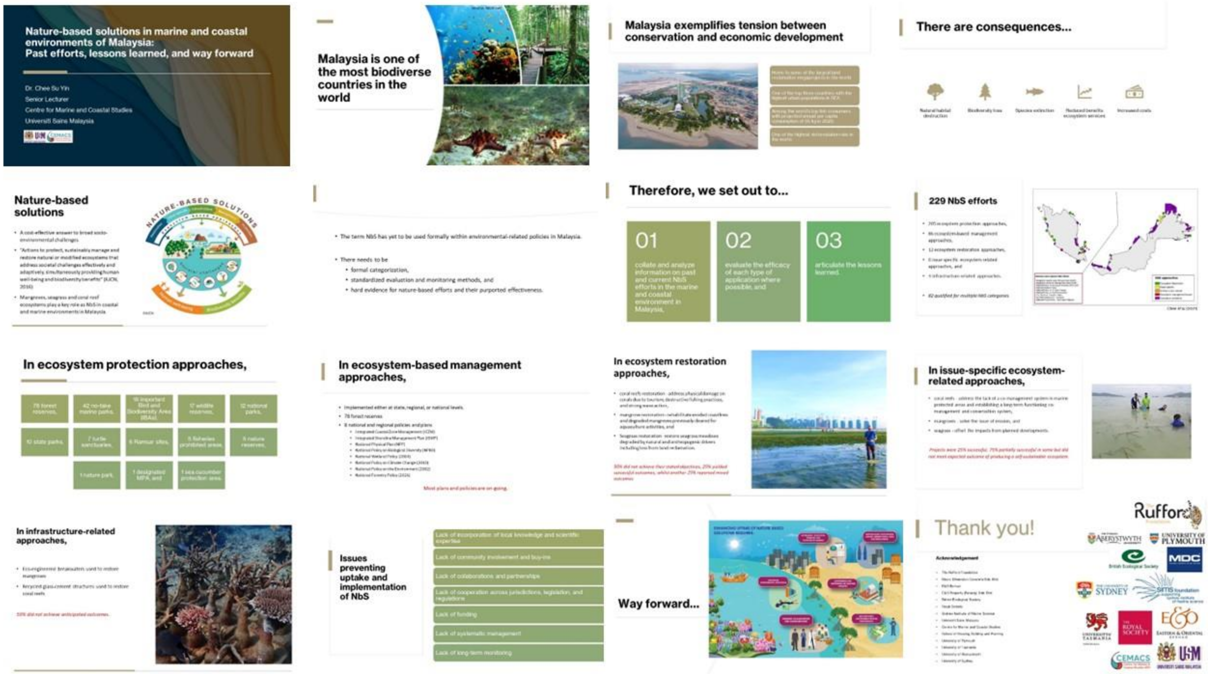
St Joseph's Home, Georgetown, Penang workshop.

Appendix 3



The Rufford Foundation logo used in Greening of Grey: Creating space for nature on artificial coastlines in Penang presentation.

Appendix 4



The Rufford Foundation logo used in: Nature based solutions in marine and coastal environments in Malaysia: Past efforts, lessons learned, and way forward presentation.

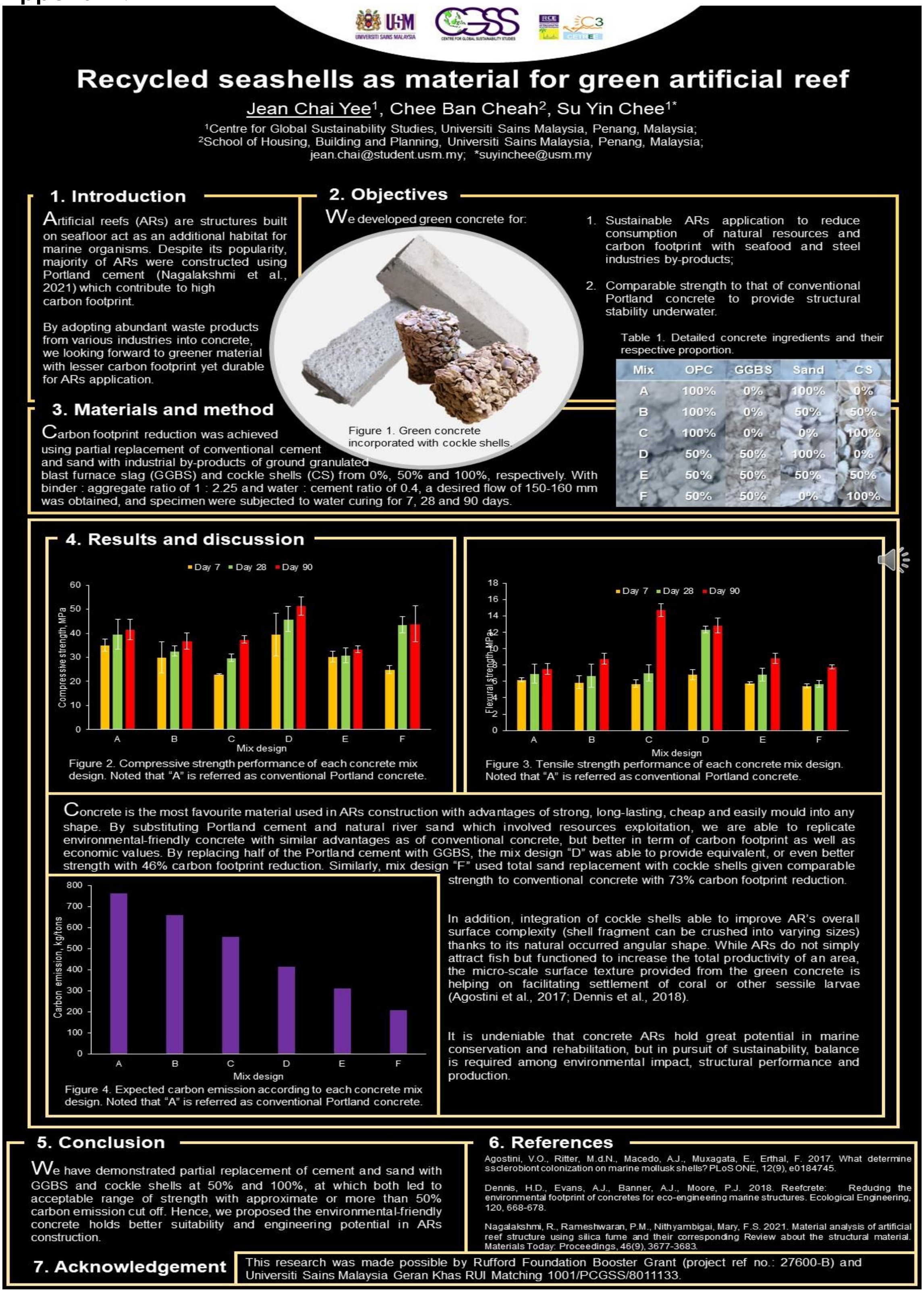
Appendix 5

The Rufford Foundation logo used in: Artificial pools promote higher species richness on artificial coastal structures in Penang Island, Malaysia presentation.

Appendix 6

The Rufford Foundation logo used in: Incorporation of complexities on artificial coastal structures enhances the species richness of thriving benthic organisms through installed habitat panels presentation.

Appendix 7



Recycled seashells as material for green artificial reef

Jean Chai Yee[1], Chee Ban Cheah[2], Su Yin Chee[1*]

[1]Centre for Global Sustainability Studies, Universiti Sains Malaysia, Penang, Malaysia;
[2]School of Housing, Building and Planning, Universiti Sains Malaysia, Penang, Malaysia;
jean.chai@student.usm.my; *suyinchee@usm.my

1. Introduction

Artificial reefs (ARs) are structures built on seafloor act as an additional habitat for marine organisms. Despite its popularity, majority of ARs were constructed using Portland cement (Nagalakshmi et al., 2021) which contribute to high carbon footprint.

By adopting abundant waste products from various industries into concrete, we looking forward to greener material with lesser carbon footprint yet durable for ARs application.

2. Objectives

We developed green concrete for:

1. Sustainable ARs application to reduce consumption of natural resources and carbon footprint with seafood and steel industries by-products;
2. Comparable strength to that of conventional Portland concrete to provide structural stability underwater.

Figure 1. Green concrete incorporated with cockle shells.

Table 1. Detailed concrete ingredients and their respective proportion.

Mix	OPC	GGBS	Sand	CS
A	100%	0%	100%	0%
B	100%	0%	50%	50%
C	100%	0%	0%	100%
D	50%	50%	100%	0%
E	50%	50%	50%	50%
F	50%	50%	0%	100%

3. Materials and method

Carbon footprint reduction was achieved using partial replacement of conventional cement and sand with industrial by-products of ground granulated blast furnace slag (GGBS) and cockle shells (CS) from 0%, 50% and 100%, respectively. With binder : aggregate ratio of 1 : 2.25 and water : cement ratio of 0.4, a desired flow of 150-160 mm was obtained, and specimen were subjected to water curing for 7, 28 and 90 days.

4. Results and discussion

Figure 2. Compressive strength performance of each concrete mix design. Noted that "A" is referred as conventional Portland concrete.

Figure 3. Tensile strength performance of each concrete mix design. Noted that "A" is referred as conventional Portland concrete.

Concrete is the most favourite material used in ARs construction with advantages of strong, long-lasting, cheap and easily mould into any shape. By substituting Portland cement and natural river sand which involved resources exploitation, we are able to replicate environmental-friendly concrete with similar advantages as of conventional concrete, but better in term of carbon footprint as well as economic values. By replacing half of the Portland cement with GGBS, the mix design "D" was able to provide equivalent, or even better strength with 46% carbon footprint reduction. Similarly, mix design "F" used total sand replacement with cockle shells given comparable strength to conventional concrete with 73% carbon footprint reduction.

Figure 4. Expected carbon emission according to each concrete mix design. Noted that "A" is referred as conventional Portland concrete.

In addition, integration of cockle shells able to improve AR's overall surface complexity (shell fragment can be crushed into varying sizes) thanks to its natural occurred angular shape. While ARs do not simply attract fish but functioned to increase the total productivity of an area, the micro-scale surface texture provided from the green concrete is helping on facilitating settlement of coral or other sessile larvae (Agostini et al., 2017; Dennis et al., 2018).

It is undeniable that concrete ARs hold great potential in marine conservation and rehabilitation, but in pursuit of sustainability, balance is required among environmental impact, structural performance and production.

5. Conclusion

We have demonstrated partial replacement of cement and sand with GGBS and cockle shells at 50% and 100%, at which both led to acceptable range of strength with approximate or more than 50% carbon emission cut off. Hence, we proposed the environmental-friendly concrete holds better suitability and engineering potential in ARs construction.

6. References

Agostini, V.O., Ritter, M.d.N., Macedo, A.J., Muxagata, E., Erthal, F. 2017. What determines sclerobiont colonization on marine mollusk shells? PLoS ONE, 12(9), e0184745.

Dennis, H.D., Evans, A.J., Banner, A.J., Moore, P.J. 2018. Reefcrete: Reducing the environmental footprint of concretes for eco-engineering marine structures. Ecological Engineering, 120, 668-678.

Nagalakshmi, R., Rameshwaran, P.M., Nithyambigai, Mary, F.S. 2021. Material analysis of artificial reef structure using silica fume and their corresponding Review about the structural material. Materials Today: Proceedings, 46(9), 3677-3683.

7. Acknowledgement

This research was made possible by Rufford Foundation Booster Grant (project ref no.: 27600-B) and Universiti Sains Malaysia Geran Khas RUI Matching 1001/PCGSS/8011133.

OMICS Conference Poster mentioning The Rufford Foundation in acknowledgements.

Appendix 8

(Chee et al., 2020)
Drill-Cored art rock p

Published TCS Paper