Killala Bay Underwater Museum - Design Study

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DISCLAIMER

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1 INTRODUCTION

GDG have been commissioned by River Moy Search and Rescue Ballina CLG to provide a concept design study for an underwater museum to be located at Killala Bay, Co. Mayo. It is the intention that the facility will attract divers, snorkelers, and swimmers from across Ireland (and further afield) by providing an interesting and engaging experience.

Figure 1-1: Location of Killala Bay

1.1 OBJECTIVES

The facility will be one of a handful of similar attractions across Europe, with the intention that the Killala Bay underwater museum can be a key tourist destination for divers, snorkelers, and swimmers.

From review over the clients work requirements, GDG have identified the following as key objectives for the project:

- Identify a location suitable to support the activity which has suitable natural attributes, avoids negatively impacting on environmentally sensitive areas and has the potential to provide suitable landside facilities.
- Provide a high-quality experience which can attract divers from all over the globe to the Killala Bay facility. Given the facility will be the first of this type in Ireland (and the UK), it must be interesting and unique enough to attract Irish divers, given they will be used to diving in natural reefs and shipwrecks.
- Enhance local biodiversity through sensitive selection of materials and provision of specific reef type elements to encourage growth of marine life.
- Consider the facility to be open year-round as opposed to seasonal.

1.2 SIMILAR FACILITIES

There are several underwater museums across the globe with several key examples in Europe. The following will identify similar experiences from which the Killala Bay underwater museum can draw inspiration.

The examples typically make use of local history, heritage, and culture to provide a location specific offering for guests. The proposed design for Killala Bay should seek to leverage certain aspects of Irish history and folklore to provide an experience unique to Co. Mayo and Killala Bay.

1.2.1 MUSEO SUBACUÁTICO DE ARTE (MUSA), (MEXICO)

There are two stages to the underwater museum located in Mexico, the first, Punta Nizcu, Cancun features 28 sculptures and ranges from 2-4m in depth. This stage is primarily for visitors who are snorkelling rather than scuba diving. The museum includes work produced by Cuban artist Elier Amado Gil and Mexican artist Roberto Diaz Abraham, who also co-founded this exhibition.

The second exhibition is located about 20km Northeast of the first, at Manchones. The depth in this stage ranges from 8 to 10m and features 473 sculptures, this is a diving only section of the museum. The majority of this section is made up of the "The Silent Evolution" piece designed by British artist Jason deCaires Taylor and comprised of 450 human sized structures [1].

Figure 1-2: Jason deCaires Taylor Sculptures in MUSA (https://musamexico.org/product/diving-for-certified-divers-departing-from-cancun/)

1.2.2 MUSEO ATLÁNTICO (LANZAROTE)

Opened in 2016, the Museo Atlántico is the deepest underwater museum currently in the world with displays at 12- 14m depth. It houses more than 300 life-size moulds. The exhibit is designed as an artificial reef, broken up into 10 sections, the themes of the museum probe at the problems faced by humans in the modern world, a piece entitled “Raft of Lampedusa” was created to highlight the refugee crisis in Europe, they also take inspiration from the locals and the environment, as in the piece “Rubicon” the 35 sculptures were modelled after residents of Lanzarote. [2]

The exhibition is credited with increasing the biodiversity of the marine in the area by over 200% since the first addition of sculptures. The sculptures, constructed with Ph neutral concrete, act as a shelter for marine life. [3]

Figure 1-3: Sculptures in Museum Atlántico, Lanzarote (https://www.travelawaits.com/2716996/worlds-most-amazing-underwater-museums/)

1.2.3 MUSEUM OF UNDERWATER ART (AUSTRALIA)

The museum of Underwater Art is located in Townsville North Queensland, it was the first underwater museum in the southern hemisphere. The purpose of this museum was to highlight the need for reef conservation, restoration and education surround the reef. It is located approximately 80km offshore in the Great Barrier Reef marine park. The art installation consists of three major components, the Ocean Siren, the Coral Greenhouse and the Ocean Sentinels, the major elements were designed by British sculptor Jason deCaires Taylor. [4]

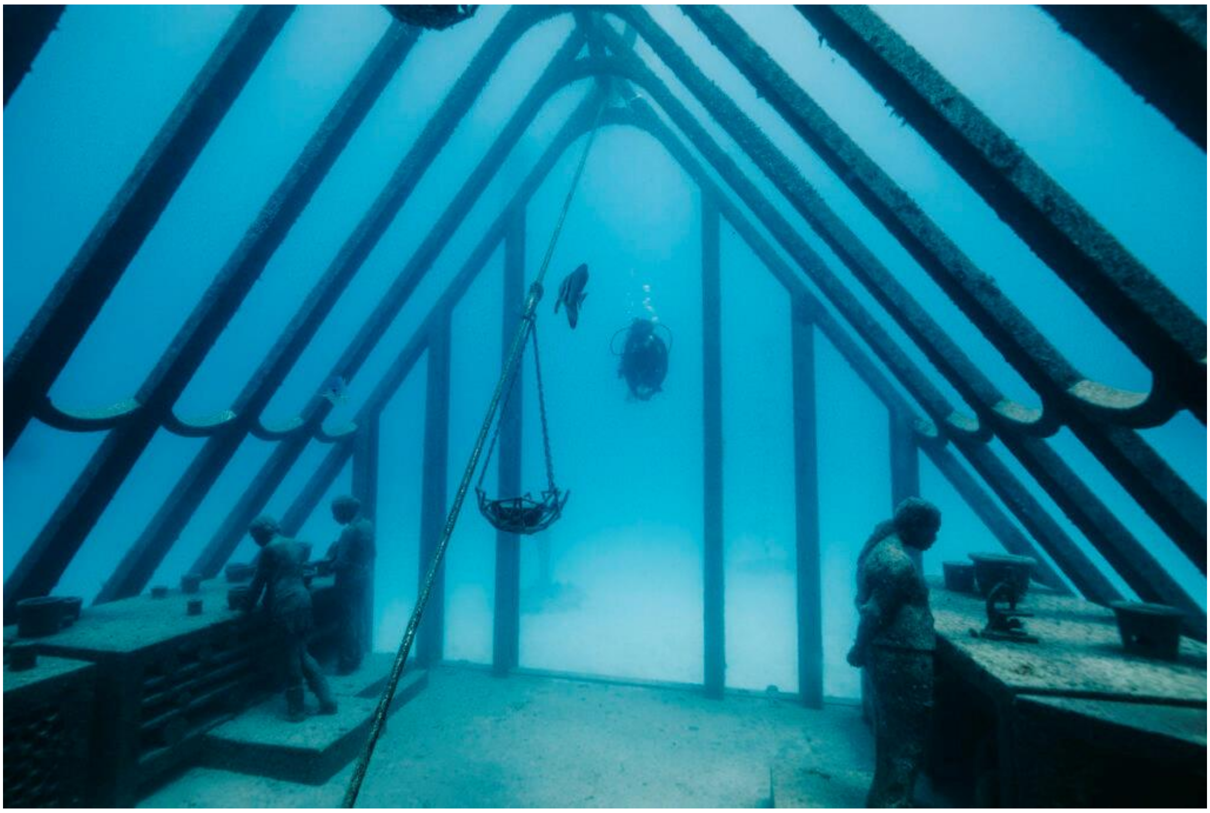

Figure 1-4: Underwater Museum Townsville, Australia (https://www.travelawaits.com/2716996/worlds-most-amazing-underwater-museums/)

1.2.4 UNDERWATER ARCHEOLOGICAL PARK OF BAIA,(ITALY)

The museum of Baia takes its inspiration from its origins as a large city as part of ancient Rome. Volcanic activity in the area caused some parts of the city to sink into the water. Parts of the ancient city have been uncover in the water such as mosaics, statues, and ruins. In 2002 the area became protected as am Archaeological Marine Park. The park has depths between 5 and 13 metres and is suitable for both snorkelling and scuba diving.

The park is broken into 8 major sites, "Claudio Nymphaeum" pictured in Figure 1-5, is the first site on the tour and features a floor of a Roman bath along with accurately reproduced statues. At the bottom of the park is the "Smokey Reef", here there are 12 pillars which used to support the jetty at Portus Julius. Volcanic activity on the seabed emits gaseous displays and encourages marine life to flourish amongst the ruins.

Figure 1-5: Roman Sculptures in Baia, Italy Underwater Museum (https://subaia.com/en/archaeological-park-baia#&gid=1&pid=2)

1.3 POTENTIAL BENEFITS TO LOCAL AREA

The creation of an underwater museum facility in Killala Bay would be the first facility of this type in Ireland and the UK. The uniqueness of the project will likely produce significant interest both locally and further afield, with the project likely to benefit the local community through a number of means.

This project will boost tourism in one of the most remote areas of northeast Mayo – Kilcummin. Kilcummin is an isolated community, and its major asset is its coastline and pier / slipway, unaffected by the tides and giving access to deep water all day long. An estimate of economic potential of the area was produced in the document, "Moy Estuary Development Strategy, A Shared Vision, June 2020" commissioned by Ballina Lions Club [5]. In this document the economic potential of a diving reef in Killala Bay was discussed seven times and its economic benefit to the area was calculated. The expected economic value per year is >€750,000 and the expected number of visitors per year are listed below for the first six years.

- Year 1 – 1,500
- Year 2 – 1,725
- Year 3 – 1,932
- Year 4 – 2,125
- Year 5 – 2,295
- Year 6 – 2,433

GDG have highlighted the following as potential benefits to the local area from provision of an underwater museum facility:

- Potential benefits to local suppliers and contractors if utilised during construction phase.
- Increased biodiversity at Killala Bay through placement of reef blocks and sculptures made with materials that promote growth of marine life.

- Increased biodiversity can attract greater numbers anglers to the area, offering an indirect economic benefit of the facility.
- Potential to provide local youth clubs and schools with educational initiatives for understanding biodiversity and the importance of conservation.
- Increased footfall in Co. Mayo and the Killala area. Benefits to local pubs, restaurants, cafes, shops and accommodation providers. This is an isolated area that would benefit greatly from increased traffic.
- Creation of multiple full-time and part-time jobs.
- Local communities can benefit from having a diving facility, potential to establish a local dive community.
- Positive impact on local community with a unique facility being sited within Killala, providing a sense of pride and ownership.

2 LOCATION

A site selection process was undertaken alongside the client to understand the most suitable location for the underwater museum within Killala Bay. The following were key constraints in the selection of the location:

- Access from shore
- Road access and potential for landside infrastructure (and ownership of land)
- Shelter
- Water depths
- Nature of bed
- Proximity to environmental designations.

Kilcummin Harbour has been selected on the basis of favourable conditions in respect of the above.

2.1 KILCUMMIN OVERVIEW

The existing harbour infrastructure at Kilcummin provides a level of protection as does the headland. From the aerial imagery, the level of shelter from the north and north easterly directions is easily understood.

In addition to the shelter provided, there is existing road access out to the harbour, whilst the condition of the road isn't understood at this point there would be no need for development of new access routes.

There is potential for development of landside facilities in proximity to the harbour at Kilcummin. GDG also understands that the existing landowners in proximity to the harbour may be open to offers for sale of certain parcels of land to develop facilities.

Figure 2-1: Aerial View of Kilcummin Harbour

Water depths within the bay are favourable for the proposed activity and can provide a suitable variation in depths over chainage to facilitate the change from swimming/snorkelling to diving activities. An extract of the bathymetry in proximity to Kilcummin harbour has been included in Figure 2-2. The client, River Moy Search and Rescue Ballina CLG has significant local knowledge and experience of diving within the area and could indicate that the bed strata at Kilcummin is typically sandy and suitable for placement of sculptures and elements with limited preparation. It is noted this is anecdotal information only and specific investigation/dive truthing may be required prior to detailed design and construction.

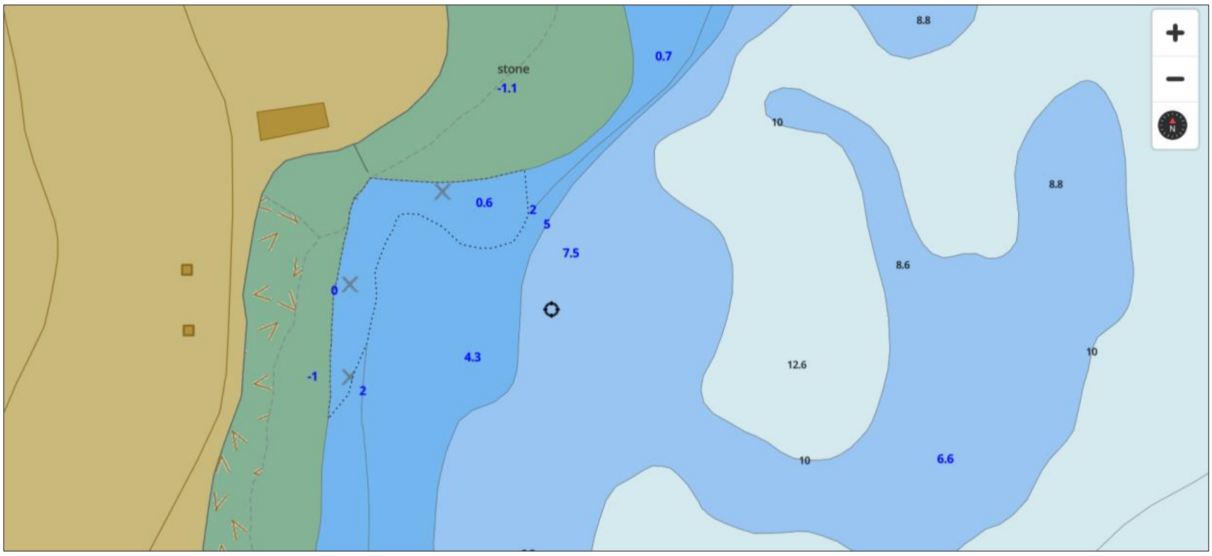

Figure 2-2: Bathymetry in Proximity to Kilcummin Harbour (https://fishing-app.gpsnauticalcharts.com/i-boating-fishing-web-app/fishing-marine-charts-navigation.html#15.74/54.2736/-9.2050)

The NPWS designations viewer (shown in Figure 2-3) illustrates that the selected location at Kilcummin harbour sits outside of any of the specific designations in the area.

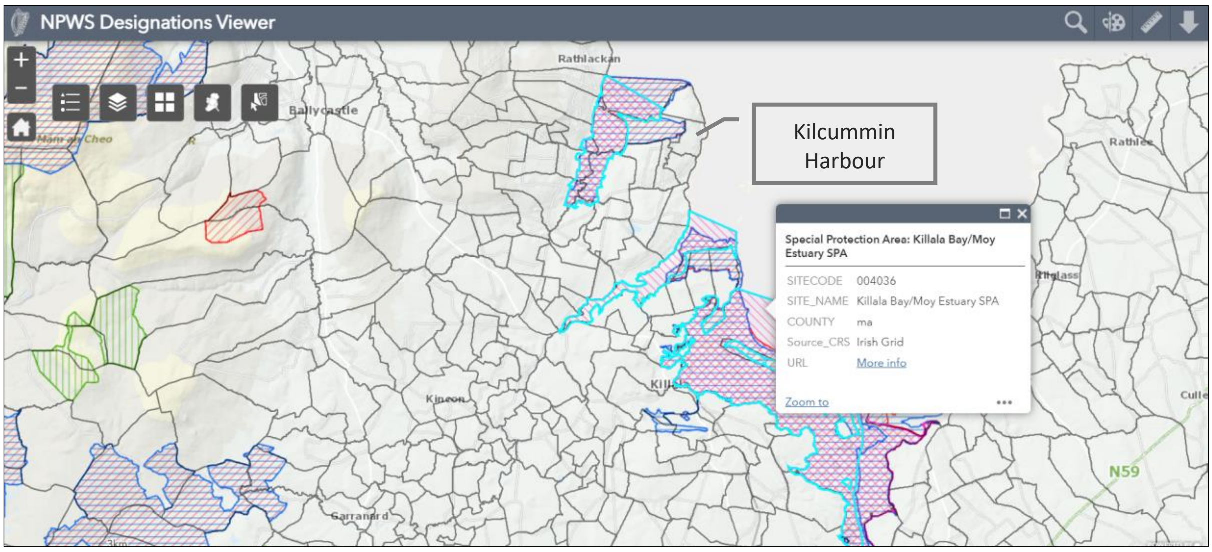

Figure 2-3: NPWS Viewer Identifying Designations in Proximity to Killala Bay

3 Design Basis Statement

3.1 Design

3.1.1 Depth Ranges

The following has been proposed by the client for the depth ranges and zones within the museum. The proposed design should follow this profile.

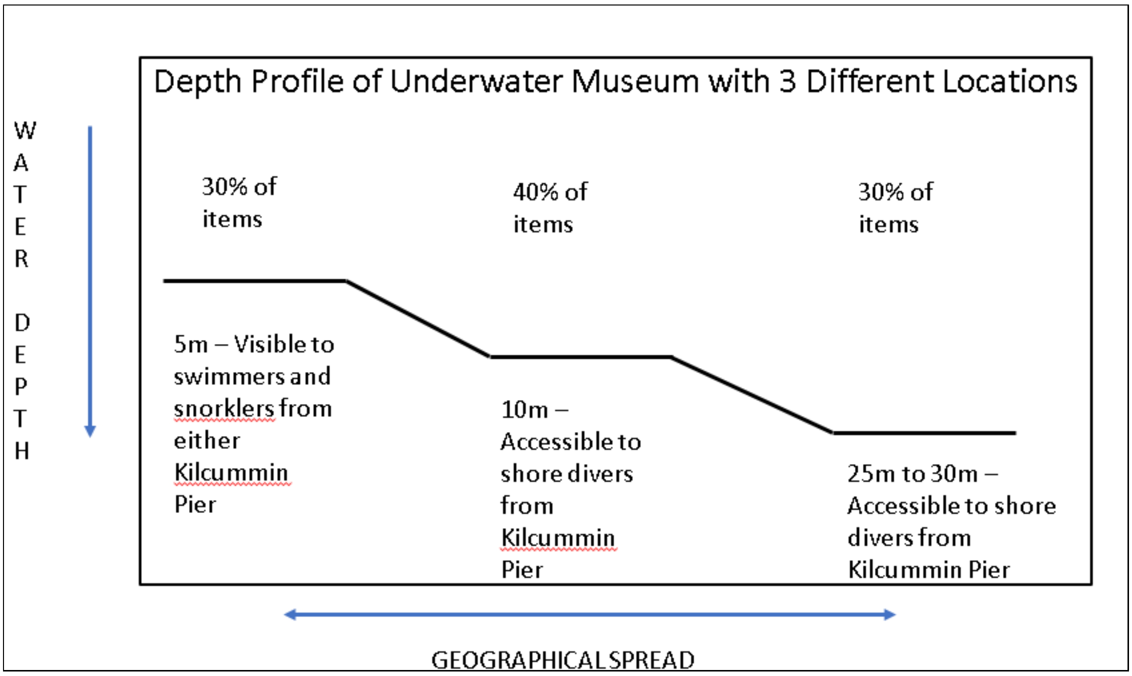

Figure 3-1: Depth Profile and Zones for Underwater Museum – Killala Bay (Client's Works Description document)

The museum will be required to provide three distinct depth zones, they should be accessible to the following groups;

a) swimmers / snorkelers at 5 meters water depth from Kilcummin Pier or shore,
b) beginner divers swimming from Kilcummin Pier at 10 to 15 meters water depth and,
c) to experienced divers at +25 meters depth.

3.1.2 Tidal Range

The tidal range for Killala Bay is as follows:

MHWS: +3.8mCD

MHWN: +2.7mCD

MLWN: +1.3mCD

MLWS: +0.4mCD.

3.1.3 Themes

The following themes have been proposed by the client which may be considered within the design of the underwater museum at Killala Bay:

3.1.3.1 Shipwrecks

Shipwrecks are a common part of Irish maritime history, some famous examples which could explored within the content of the museum are as follows:

- La Concorde, the French naval vessel that General Humbert sailed into Kilcummin on
- Viking boats that raided Irish monasteries
- Vessels from The Spanish Armada
- “Coffin Ships” from the time of The Irish Famine
- A replica of the bridge, or other famous artifacts, from the Titanic .

3.1.3.2 Irish Mythology

It is important that the underwater museum is Irish in its content and representative of the local culture, heritage and storytelling. The client has proposed several potential themes around Irish mythology, including:

- Mac Lir
- Children of Lir
- Cu Chulainn fighting Ferdia or dying standing upright
- The Flight of the Earls
- Fionn mac Cumhaill creating the Giant’s Causeway, burning his hand on the Salmon of Knowledge or with the horse that brought him to Tir na nÓg
- Queen Maeve
- St. Patrick's slave ship travelling to the Wood of Fochill
- Pirate queen Grace O’Malley.

3.1.3.3 Topical Statement Themes

In addition to the heritage themes around maritime and mythology, there is an option to provide a topical element to the museum in a bid to highlight a particular cause through artistic means. Examples of such provided by the client are included below:

- Marine mammals versus plastic pollution
- Farmers versus rising water from global warming.

3.1.4 Onshore Design

3.1.4.1 Parking Availability

The site is remote and currently has available space for parking on a side street beside the port. While this is sufficient for initial numbers of visitors at site it is recommended to develop this area into a dedicated parking area to support greater numbers. This would also provide dedicated parking for visitors with boat trailers, these spaces would also function as two regular car spots if the other spots are full.

Satellite imagery indicates that the side street is fully hard standing, therefore only lines for parking spaces are required. However, a site investigation would be necessary to ensure that no landscaping is required.

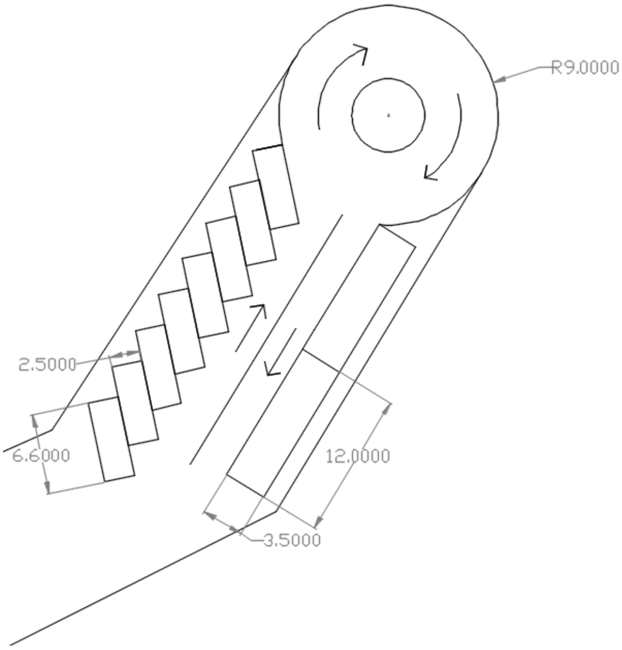

Figure 3-2: Conceptual Car Parking Arrangement with 8 45° Angled Regular Spaces and 2 Dedicated Trailer Spaces

3.1.4.2 Future Growth

As the site is intended to increase traffic through Kilcummin area, the site should have capacity to expand as numbers rise over time. The parking arrangement could be expanded through negotiations with the neighbouring fields to increase available area. Additionally, an onshore structure to provide an onshore liaison point could be considered.

As diving is typically seasonal, with fewer visitors expected in winter months, a permanent structure may not be economically viable. However, a mobile coffee shop, such as a retrofitted van, has high potential in the summer months. The provision of warm coffee would be welcome to any divers emerging from the cold water. This coffee van would also function as a small visitor centre with information brochures about the site. The available area is quite large and would accommodate several picnic tables and chairs.

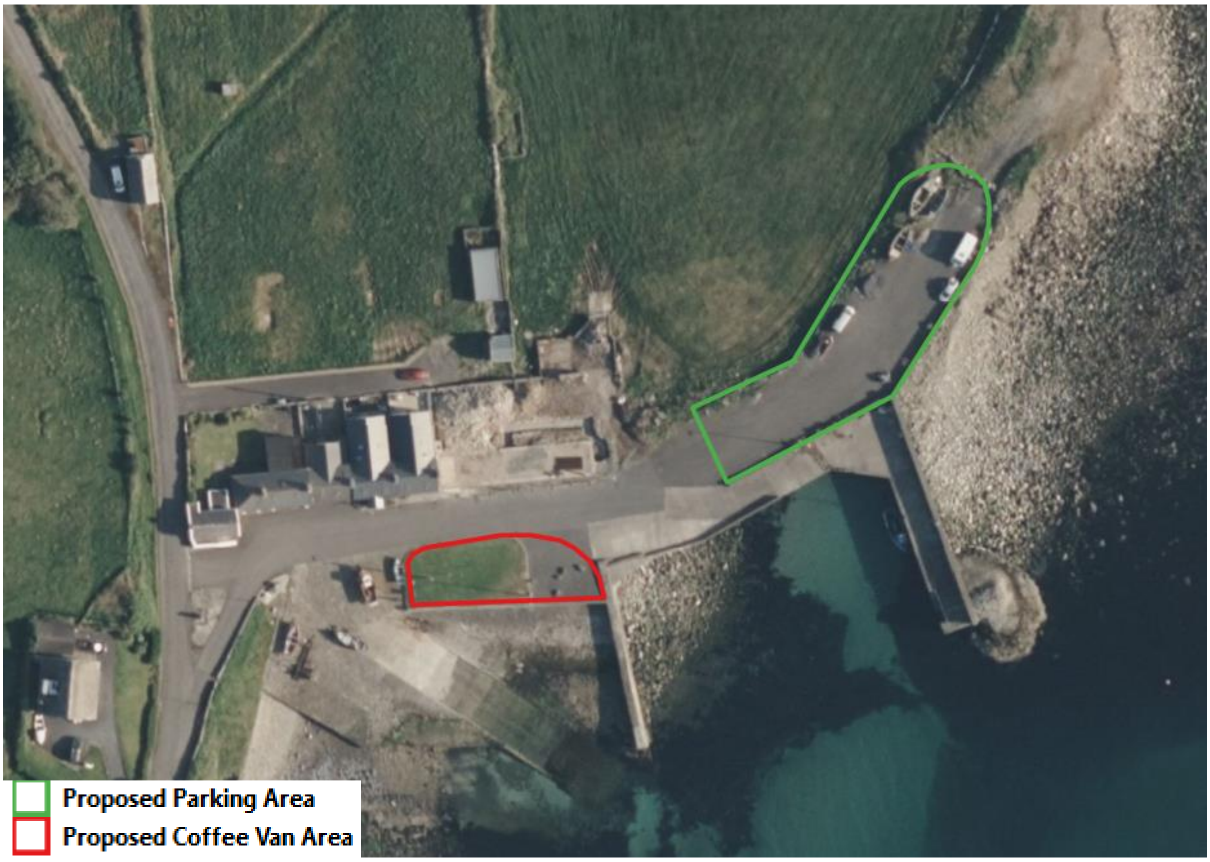

Figure 3-3: Proposed Onshore Development Locations

Figure 3-4: Streetview of Proposed Coffee Van Area

3.2 Underwater Museum Materials

It is anticipated that the underwater museum will comprise a number of materials to enhance the visual experience, reflect light and provide variety.

As a minimum the following are anticipated, however it is noted that additional materials proposed by suppliers or contractors may be considered by the client provided they meet the durability requirements and can demonstrate the required biodiversity criteria. Where proposed, additional or alternative material specifications should be submitted to the client team for approval.

- Timber (potentially for sunken shipwrecks, signposting or other features) - Dense varieties, such as Green heart, typical of what would be used for marine applications.
- Marine grade stainless steel (for signposts, structures or frames)
- Concrete (specialist mix and grading to ensure durability within marine environment and also with properties which are favourable to local biodiversity).
- Bronze (will patina to a blue/green finish over time, not anticipated to encourage the same level of biodiversity but can be visually very effective).

Note, the above applies to the sculptures and artist elements only. A separate section is provided detailing the basis of design pontoon elements.

3.2.1 Durability and Maintenance

Whilst ageing of any proposed sculptures will be allowed, the structure should be of suitable composition to meet the following design life criteria. It is noted that given the majority of structures will be at least partially submerged, maintenance should be kept to a minimum.

Table 3-1: Durability and Maintenance Requirements (Sculptures)

Material	Design Life	Period to First Maintenance	Minimum Allowable Maintenance	Unacceptable Repair and/or Replacement within Design Working Life
Concrete Elements	50	15	Visual Inspection, Cleaning of any elements as deemed required, Repair to any items as deemed required.	Replacement of entire sculptures/elements.
Timer Elements	25	5	Visual Inspection, Cleaning of any elements as deemed required, Repair to any items as deemed required.	Any removal / replacement of component parts.
Steel Elements	50	15	Visual inspection.	Replacement of corroded steelwork or fixings.

3.2.2 Stainless Steel

All elements proposed as steel, must be marine grade stainless steel - SAE 316.

3.2.3 Concrete

3.2.3.1 General

The use of ECOncrete or similar products is encouraged (https://econcretetech.com/).

The proposed mix for any concrete sculptures must promote the growth of organisms like oysters, corals, or barnacles, which act as biological glue, enhancing the strength and durability of structures, and adding to their stability and longevity.

Surfaces must be textured to create homes, breeding areas and protective spaces for marine life.

Figure 3-5: Example of Concrete with Biologically Sensitive Admixtures and Surface Complexity (ECOncrete, 2023)

3.2.3.2 Mix Specification

To meet the required design life, the following must be met as a minimum:

The specified concrete is C40/50, type IIIA with 36% GGBS and minimum 380kg/m^3 cement content with a 50-year design life.

Biologically enhancing admixture shall be included at a weight equivalent to 10% of the weight of the cementitious material in the mix. The accepted products shall demonstrate scientifically-proven enhanced ecological performance compared to standard Portland cement products including significant reduction in dominance of invasive species. Accepted products shall also have a track record in demonstrating biological and structural performance over time through demonstrated and recorded monitoring and analysis in peer-reviewed publications and reports, and shall comply with ASTM C494 / C494M – 17.

Concrete elements proposed for placement within the underwater museum are anticipated to be precast. Consequently, the tolerance for reinforcement placement can be controlled through quality assurance procedures. The cover to the reinforcement within the precast shall be 55mm (50mm + Δc) as recommended by BS 6349-1-4:2013 Table 2 for 50-year design life under XS2/3 exposure.

The concrete design shall be in accordance with BS EN 6349-1-4, Table 2.

Exposed concrete will adopt an exposure class as appropriate:

XS2/3 – frequently wetted (e.g. mid and lower tidal zone)

XS3 - infrequently wetter (e.g. upper tidal, splash/spray, “dry” internal faces of submerged structures).

3.2.3.3 SURFACE FINISH SPECIFICATION

Surface finishes shall be required to be textured to promote the growth of organisms on the face of any concrete elements. The textured finish shall be obtained using a formliner, the formliner pattern can be proposed to the client for approval.

The use of the textured formliner will require the concrete cover to be increased to account for any indentations, the degree to which adjustment will be required will depend upon the final choice of formliner and depth of any indentations.

3.2.4 BIODIVERSITY

Materials proposed for any sculptures or structures placed within the underwater museum must be pH neutral, environmentally sensitive materials to instigate natural growth or local biodiversity.

Figure 3-6: Example of Concrete with Biologically Sensitive Admixtures and Surface Complexity (ECOncrete, 2023)

3.3 Pontoon Specification

The following sets out the minimum requirements for the design of the pontoon elements proposed within the underwater museum.

The pontoon system including, hinges and fixings shall be designed by specialist pontoon contractor or supplier.

The contractor, in his role as pontoon designer, shall comply with the Safety, Health and Welfare at Work (Construction) Regulations 2013.

The pontoon system shall be designed in accordance with BS6349 and all other appropriate standards. It is a requirement that fatigue loading shall be considered in the design. All design to be agreed with Engineer prior to fabrication.

3.3.1 Durability & Maintenance

Table 3-2: Durability and Maintenance Requirements (Pontoon)

Material	Design Life	Period to First Maintenance	Minimum Allowable Maintenance	Unacceptable Repair and/or Replacement within Design Working Life
Pontoon System	50	15	Visual Inspection, Cleaning of any elements as deemed required, Repair to any items as deemed required, replacement of brackets and chains as necessary.	Replacement of entire pontoon.

3.3.2 Materials

The pontoon frames shall be designed to carry imposed working loads from the deck and boats as well as the local stresses at the various fixing points, including fender fixings, and shall perform within the specification and tolerances. The pontoon shall also have sufficient longitudinal stiffness to prevent flexing greater than 1/400 (ratio of deflection/span) under design dynamic loading and the overall pontoon frame/structure shall have torsional rigidity to the satisfaction of the Engineer.

Pontoon Flotation – The internal flotation shall be made from high impact strength Styrofoam of minimum 65N/mm^2 and shall be resistant to or protected from chemical and petro-chemical attack. All flotation shall be designed so that it is inherently within the concrete structure of the pontoon and may be positively retained under all loading circumstances.

Pontoon Fendering – All exposed sides of the pontoon walkway shall have either hardwood fenders of at least 45mm thick x 145mm deep or pressure treated pine of at least 95mm thick and 145mm depth. They shall be fixed in such a way to eliminate warping of the timber longitudinally and laterally. End joints between adjacent timber fenders shall be connected or chamfered to provide a smooth berthing line without snags.

Pontoon Connections – There shall be flexible connections between each individual pontoon unit with one connection at each side of the pontoon. Each connection shall be capable of accommodating at least 5 degrees of vertical movement between the pontoons and of transmitting working loads of at least 300kN at each side of the pontoon.

The connections shall be such that the pontoons will not work loose due to vibration, ongoing flexing movements from boats, waves, currents or other causes. The supplier shall ensure that the deck of adjacent pontoons is level and that no tilting of the pontoon occurs as a result of their connections.

3.3.3 Design Environmental Conditions

The pontoon shall be designed to accommodate the environmental conditions outlined in Section 3.5.

3.3.4 Mooring Chains & Anchor System

To ensure the pontoon can withstand the anticipated conditions year-round at Killala Bay, heavy duty mooring chains and anchors are proposed for securing any pontoon system installed as part of the museum installation.

The mooring chain system should ensure the pontoon is robustly restrained to avoid routine removal when conditions become harsh.

The mooring system design will be designed by the specialist pontoon contractor or supplier to suit the environmental conditions shown Section 3.5. The mooring system design shall be compliant with BS6349:Part 6.

3.3.5 Emergency SOS Bollard

Any pontoon provided as part of the museum must provide an emergency SOS bollard, the bollard is to be provided as a red pillar bollard with the following:

- 1 x 2kg dry powder extinguisher
- 1 x first aid kit
- 1 x life buoy and 10m of floating throwing rope (throw line)

3.3.6 Access

Four number ladders shall be provided at the quarter points of pontoons. Ladder details are to be in accordance with BS 6349-2:2010. Hot dip galvanizing shall be in accordance with BS EN ISO 14713-2:2009.

3.3.7 Navigation Light

A green SABIK LED 160 navigation light shall be installed centrally on any pontoon provided as part of the underwater museum. The navigation light shall be installed at a height of +10mCD. The column supporting the navigation light shall be marine grade stainless steel with a 50-year design life.

The column supporting the navigation light shall be provided with an access ladder mounted to the column to allow for maintenance, also to be marine grade stainless steel with a 50-year design life.

3.3.8 Warranty

The supplier shall fully guarantee the equipment and the Warranty shall provide for:

- The equipment shall conform to and perform its function in accordance with the Specification as stated or as implied by the supplier.
- Any part of the equipment which is or becomes defective during warranty shall be removed and replaced to the satisfaction of the Engineer without cost to the Client.

The Warranty shall remain in force for a period not less than 12 months following substantial completion on site.

3.4 Health and Safety

3.4.1 Delineation of Museum Area

To protect divers, swimmers, snorkelers from recreation vessels which may utilise the adjacent harbour, floating buoys should be provided to delineate the underwater museum area from the rest of the Bay.

Floating buoys must be Platform A-Series and provided in orange to ensure visibility.


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Figure 3-7: Floating Buoy System

3.4.2 Access and Egress

Access to the site will be primarily from the slipway at Kilcummin Harbour. Any of the three zones can be reached from the harbour. However, experienced diving groups might prefer to travel by boat out to the advanced zone to conserve oxygen and physical energy. To support this, dedicated parking spaces for personal vessels are included in the parking area.

3.4.3 Identification of Route

Signposts and other means of demonstrating the proposed route must be clearly visible, potentially making use of bright colours/materials to ensure even in turbid waters that divers cannot become lost.

3.4.4 Snags

Any sculptures, shipwrecks, signposting or other elements placed within the underwater museum must not allow for divers to swim underneath the element. This is to avoid a diver snagging their tank or other equipment and becoming caught.

3.4.5 Reflective Surface

At least one of the sculptures provided within the museum should have an upright mirror to allow a diver to see himself and check his trim and tilt.

3.4.6 Water Temperature

A gauge must be provided to measure water temperature as the museum is proposed for year-round use. This will determine the suitability for snorkelers or swimmers and the requirement for wetsuits.

The gauge should be clearly visible at the start of the museum route, and relayed to screens within landside facilities.

3.5 Metocean Criteria

The structures proposed to be installed must be design and placed to withstand the anticipated environmental loading at the museum location. It is noted this criteria is applicable for both the museum sculptures/elements and the pontoons proposed within the masterplan.

The following outline preliminary environmental data which the structures must accommodate. It is noted this is preliminary data only and further detailed site analysis will be required to inform detailed design.

3.5.1 Wind Data

As some elements will be placed on the shore and the intertidal zone, they will be subject to wind loading year-round. The following are provided as design criteria for the stability of any element placed above water, or in the intertidal zone.

The ECMWF ERA5 climate reanalysis model provides numerical datasets for wind and wave variables on a global level. ERA5 is the fifth-generation current atmospheric reanalysis model produced by Copernicus Climate Change Service (C3S) at the European Centre for Medium-Range Weather Forecasts (ECMWF) and is based on the 2016 version of the integrated forecasting system (C3S, 2017). It produces data from 1940 to 2023. Its outputs include atmospheric, ocean wave and land surface data. The reanalysis combines model data with observations from across the world into a globally complete and consistent dataset. The horizontal resolution of the model is 0.25° x 0.25° (atmosphere variables) and 0.5° x 0.5° (ocean waves variables).

The closest ERA5 wind grid point to the proposed site is located at 54.25 °, -9.25°. To examine the wind characteristics of the proposed site the details of the data used are provided in the bullet points below:

- Dataset used: ECMWF ERA5 Climate reanalysis dataset[1]
- Variables download: Wind u and v velocity @ 10m above sea level
- Timeframe: 2001 to 2021 (inclusive)
- Spatial resolution: 0.25° x 0.25°
- Temporal Resolution: 1 hour

From this 21-year timeseries, a wind rose is presented in Figure 3-8 alongside summary statistics in Table 3-3.

[1] https://www.ecmwf.int/en/forecasts/datasets/reanalysis-datasets/era5

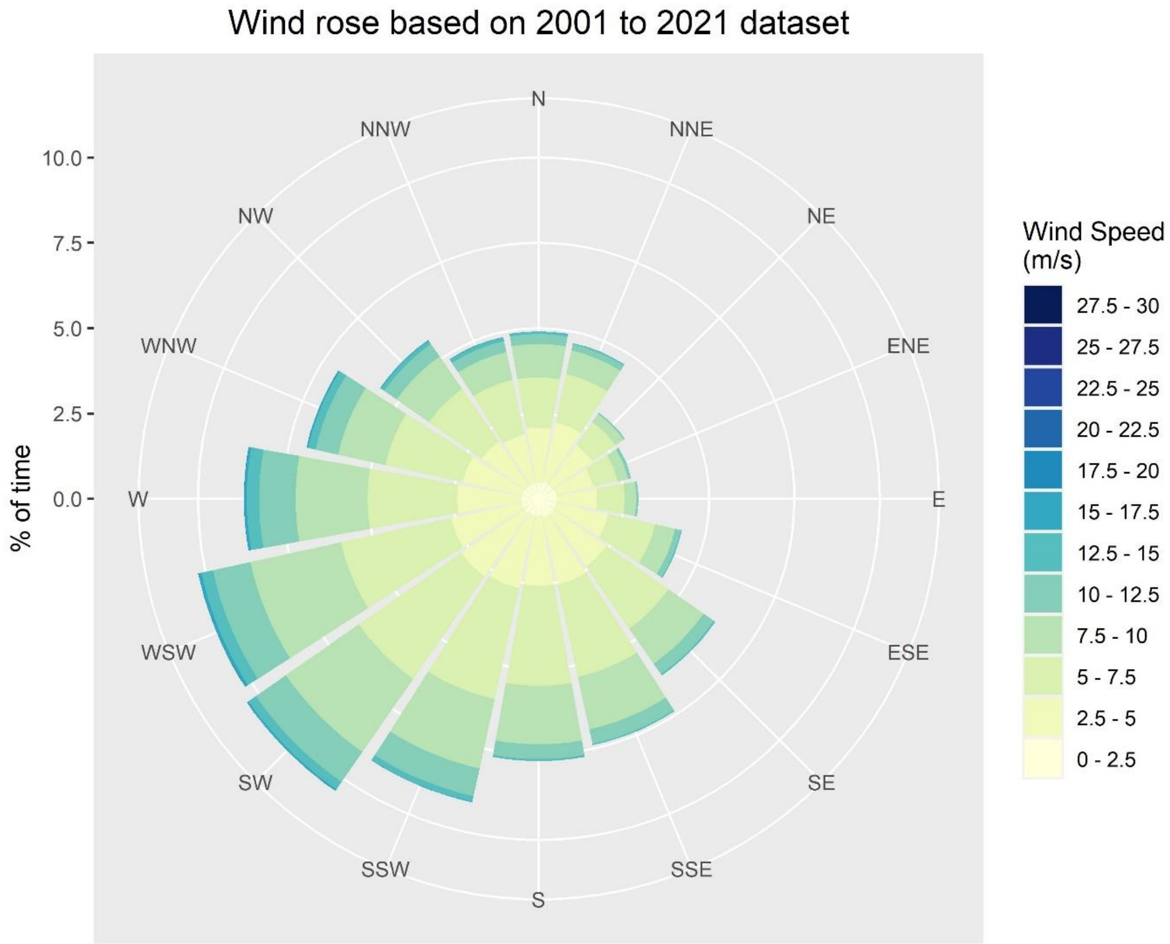


Figure 3-8 Wind rose plot of 1-hour averaged wind speeds at 10 m above sea level

Table 3-3 Monthly and overall statistics of 1-hour wind speeds at 10 m above sea level in Killala Bay

	Wind speed (m/s)			Wind direction (°)
	mean	**max**	**min**	**mean**
January	7.37	18.97	0.09	226.03
February	7.01	18.85	0.12	217.75
March	6.53	19.34	0.02	223.90
April	5.69	16.60	0.07	237.04
May	5.68	18.35	0.03	251.68
June	5.36	15.82	0.06	264.91
July	5.07	14.64	0.01	263.48
August	5.41	15.12	0.09	251.05
September	5.96	17.56	0.06	233.96
October	6.46	16.99	0.13	213.76
November	6.91	19.09	0.27	239.41
December	7.25	20.98	0.01	226.21
Overall	6.22	20.98	0.01	234.41

For this study, a generalised extreme value (GEV) methodology was chosen as the best-fitting analysis to calculate the extreme values for wind speed at this location. Due to the adequate length of the wind dataset, the block maxima (annual maxima) approach was chosen to extract extreme events over the 21-year time period as input into the general extreme value analysis.

The GEV methodology has been developed by Jenkins (1995) as a combination of Gumbel, Frechet and Weibull models. The GEV distribution is a family of continuous probability distributions developed within extreme value theory. Extreme value theory provides the statistical framework to make inferences about the probability of very rare or extreme events. The GEV distribution unites the Gumbel, Fréchet and Weibull distributions into a single-family to allow a continuous range of possible shapes. These three distributions are also known as type I, II and III extreme value distributions. The GEV distribution is parameterized with a shape parameter, location parameter and scale parameter. The GEV Is equivalent to the type I, II and III, respectively when a shape parameter is equal to 0, greater than 0, and lower than 0. Based on the extreme value theorem the GEV distribution is the limit distribution of properly normalized maxima of a sequence of independent and identically distributed random variables. Thus, the GEV distribution is used as an approximation to model the maxima of long (finite) sequences of random variables.

Equation: The cumulative distribution function (CDF) of the GEV distribution is

$$\mathrm{F}(x;\mu,\sigma,\xi) = exp\left\{-\left[1+\xi\left(\frac{x-\mu}{\sigma}\right)\right]^{-1/\xi}\right\} \qquad \text{Eq. (1)}$$

where the three parameters, ξ, μ and σ represents a shape, location, and scale of the distribution function, respectively. Note that σ and $1+\xi(x-\mu)/\sigma$ must be greater than zero. The shape and location parameter can take on any real value.

The resulting probability distribution function (PDF) for two categories of shape parameter (i.e., whether it is equal to zero or not) is

$$\frac{1}{\sigma}t(x)^{\xi+1}e^{-t(x)} \qquad \text{Eq. (2)}$$

Where

$$t(x) = \begin{cases} \left(1+\xi\frac{x-\mu}{\sigma}\right)^{-1/\xi} & if\ \xi \neq 0 \\ e^{-(x-\mu)/\sigma} & if\ \xi = 0 \end{cases} \qquad \text{Eq. (3)}$$

In this case, the numerical method used to estimate the parameters of the extreme value distribution is maximum likelihood.

A summary of extreme 1-hour wind speeds at 10 m above sea level based on different return periods are presented in Table 3-4 and Figure 3-9.

Table 3-4 Summary of extreme 1-hour wind speeds at 10 m above sea level based on different return period

Parameter	2-Year	10-Year	20-Year	50-Year	100-Year
Wind speed	18.60	19.53	20.01	20.77	21.45

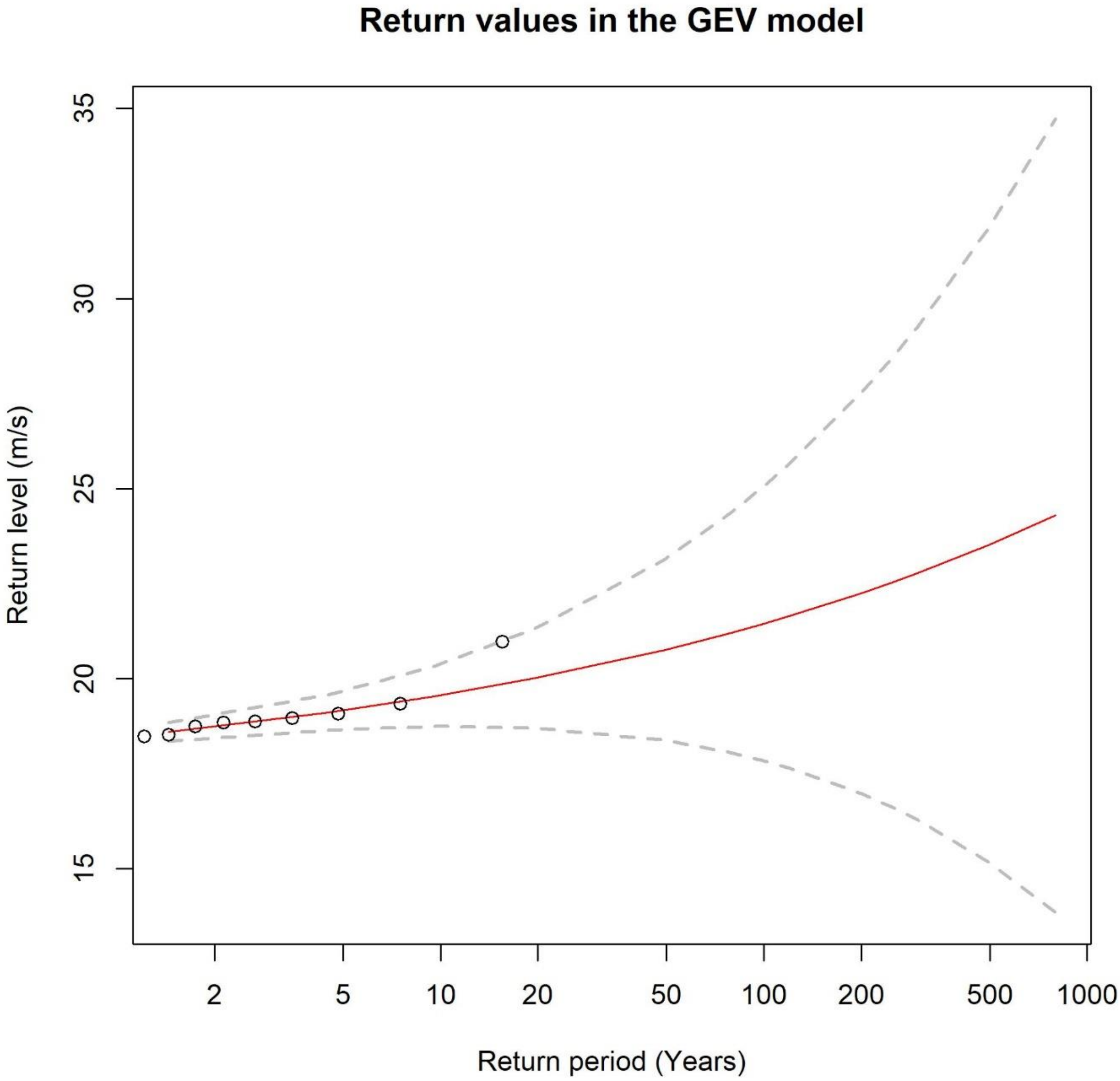


Figure 3-9 Return values in the GEV model (wind speed at 10 m above sea level)

3.5.2 WAVE DATA

Partially submerged elements placed in the intertidal zone will be subject to wind and wave loading and will be subject to such year-round. The following are provided as design criteria for the stability of any element placed within the intertidal zone.

These annual average wave height and wave period parameters for Irish Waters have been created by the Pelamis Wave Model developed by ESB International as part of the Wave Power Atlas project known as the Accessible Wave Energy Atlas Ireland published in December 2005. Data values are represented as lower and upper values according to the Pelamis wave model and can be accessed via the Marine Atlas [5]. The upper and lower value of average annual wave height in Killala Bay is 0.5 to 0.75 m. The upper and lower value of average annual wave period is 7.5 and 7.75 s.

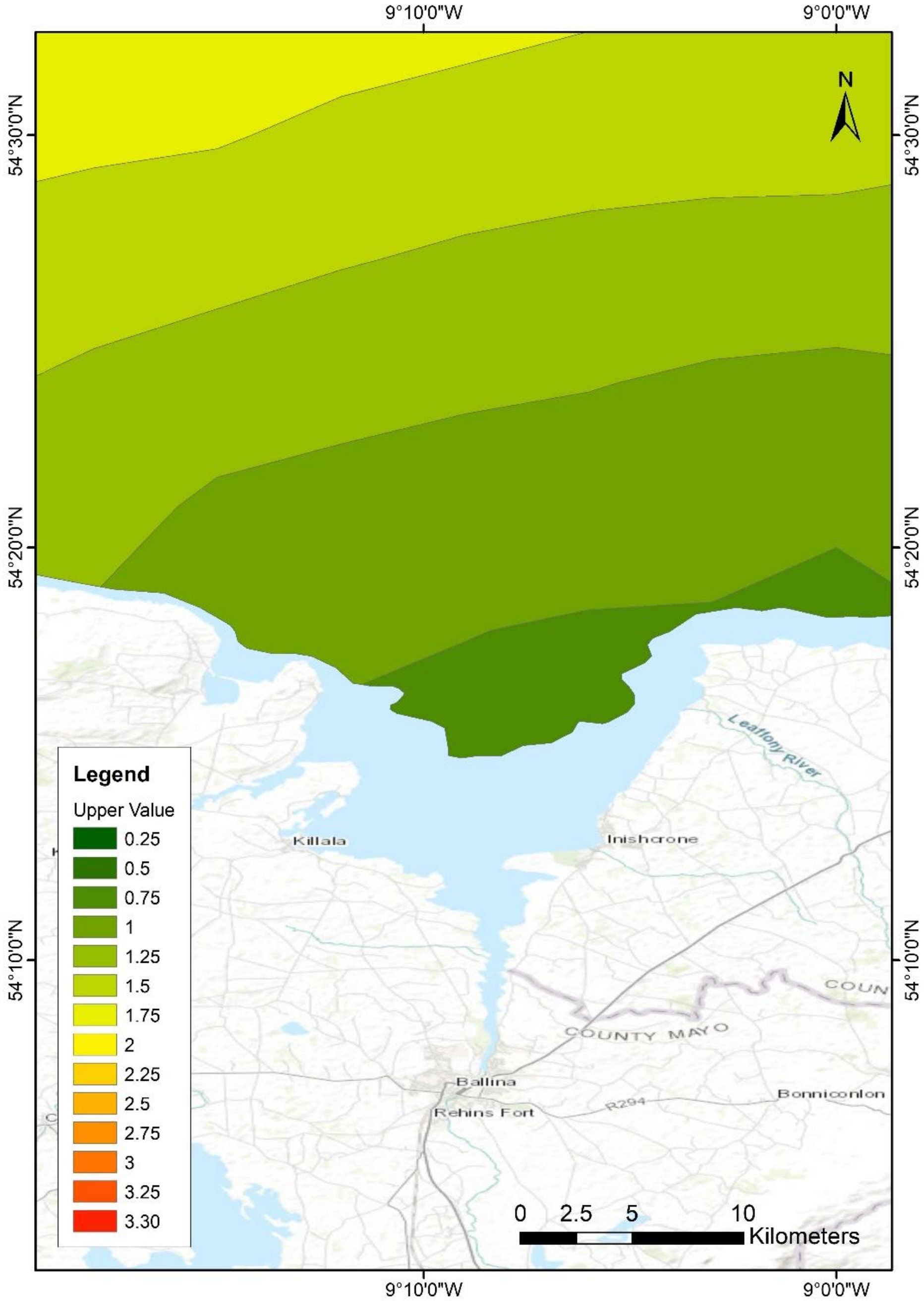


Figure 3-10 Annual average wave height. Source: [5]

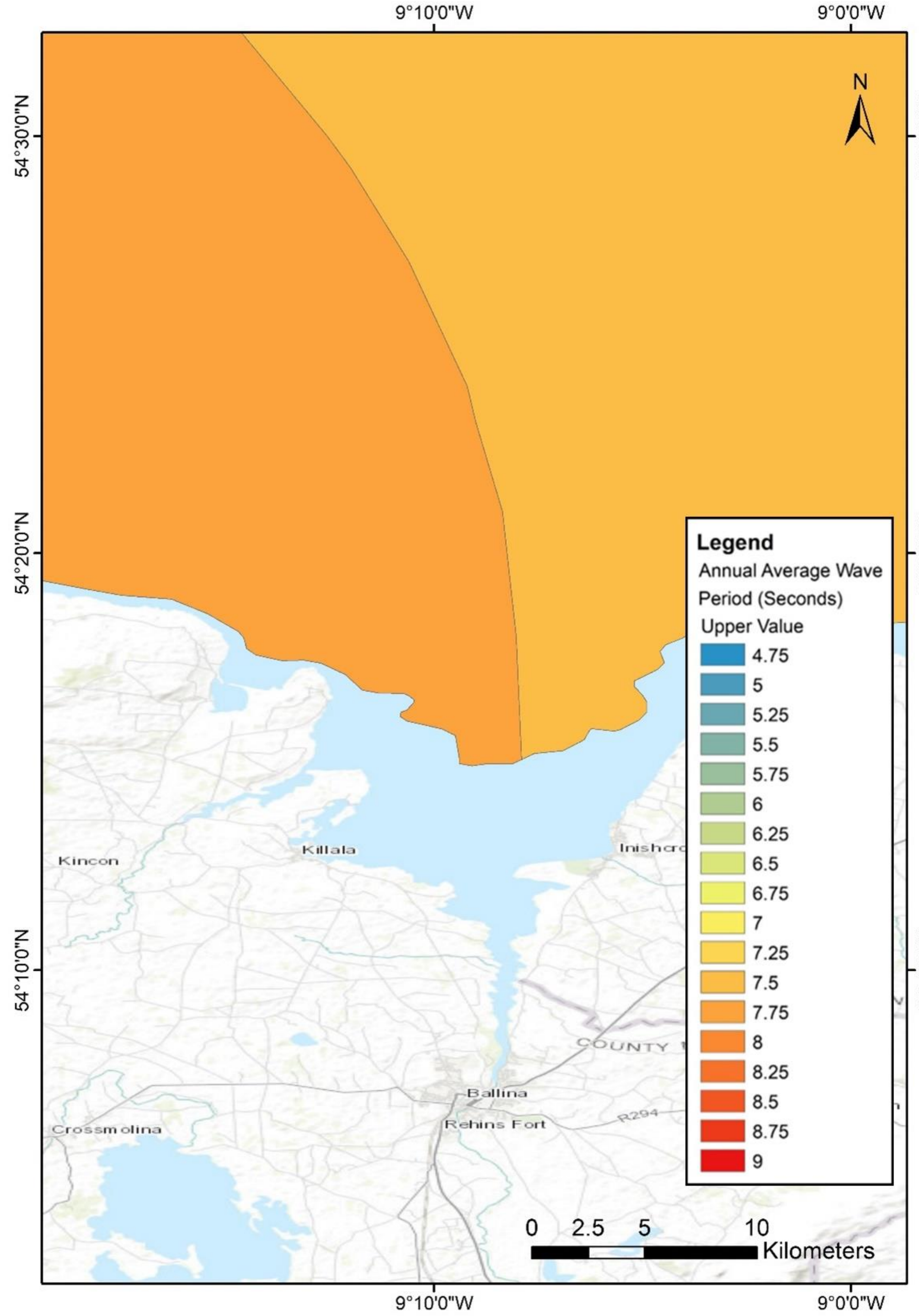


Figure 3-11 Annual average wave period. Source: [5]

No wave buoy datasets or numerical modelled datasets have been identified in Killala Bay that could produce detailed design parameters. The closest ECMWF ERA5 wave grid point is located offshore at 54°, -9° and would not correctly represent wave characteristics translated nearshore into the harbour. It is recommended to obtain in situ observational datasets (wave buoy deployments) that will enable the calibration and validation of site-specific numerical modelling efforts. The outputs of these numerical modelling efforts will inform detailed design.

3.5.3 WATER LEVEL AND CURRENT DATA

Submerged elements will be required to ensure stability year-round. The following are provided as preliminary design criteria for the stability of submerged elements.

A 20-year time series of surface elevation and depth-averaged current speed and direction was predicted using the global tide model for Killala Bay. The Global Tide Model is developed by DTU Space and is available on a 0.125° x 0.125° resolution grid for the major 10 constituent in the tidal spectra. The set-up and validation datasets are outlined in DHI Group [5]. Figure 3-12 displays the validation points of the global tide model against tide gauges in UK and Irish Waters. Monthly rose plots of current speed and direction are provided in Figure 3-13. Summary statistics are outlined in Table 3-5.

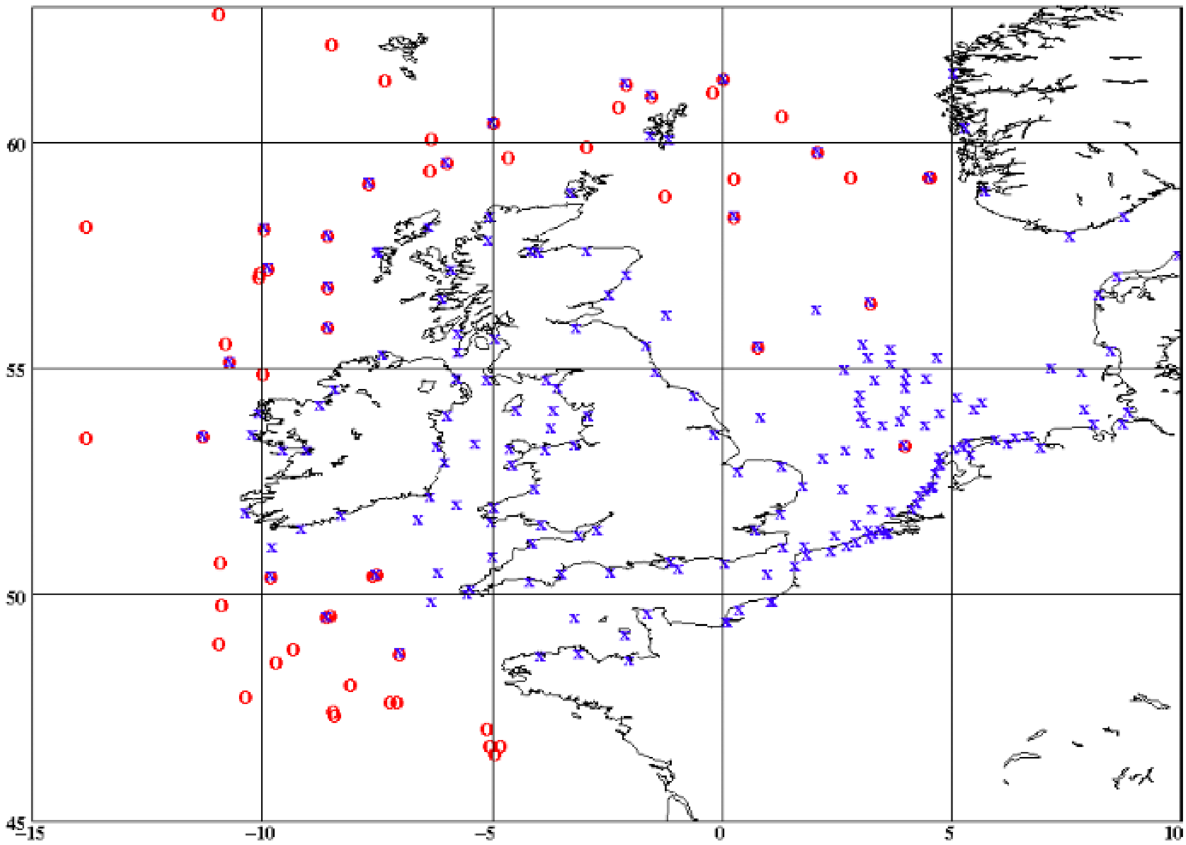


Figure 3-12 Location of Tide Gauges on the NW European shelf. The red circles are high quality pelagic tide gauges stations. The blue crosses are 199 coastal stations gathered from various sources in the region.

The currents are rectilinear in nature with mean directions occurring in the E-ESE and W-WNW sectors. The maximum depth-averaged current over the 20-year timeseries is 0.23 m/s. Meteorological forcing may influence current speeds but is not included in the Global Tide Model. The inclusion of this phenomenon in further hydrodynamic modelling studies is strongly recommended.

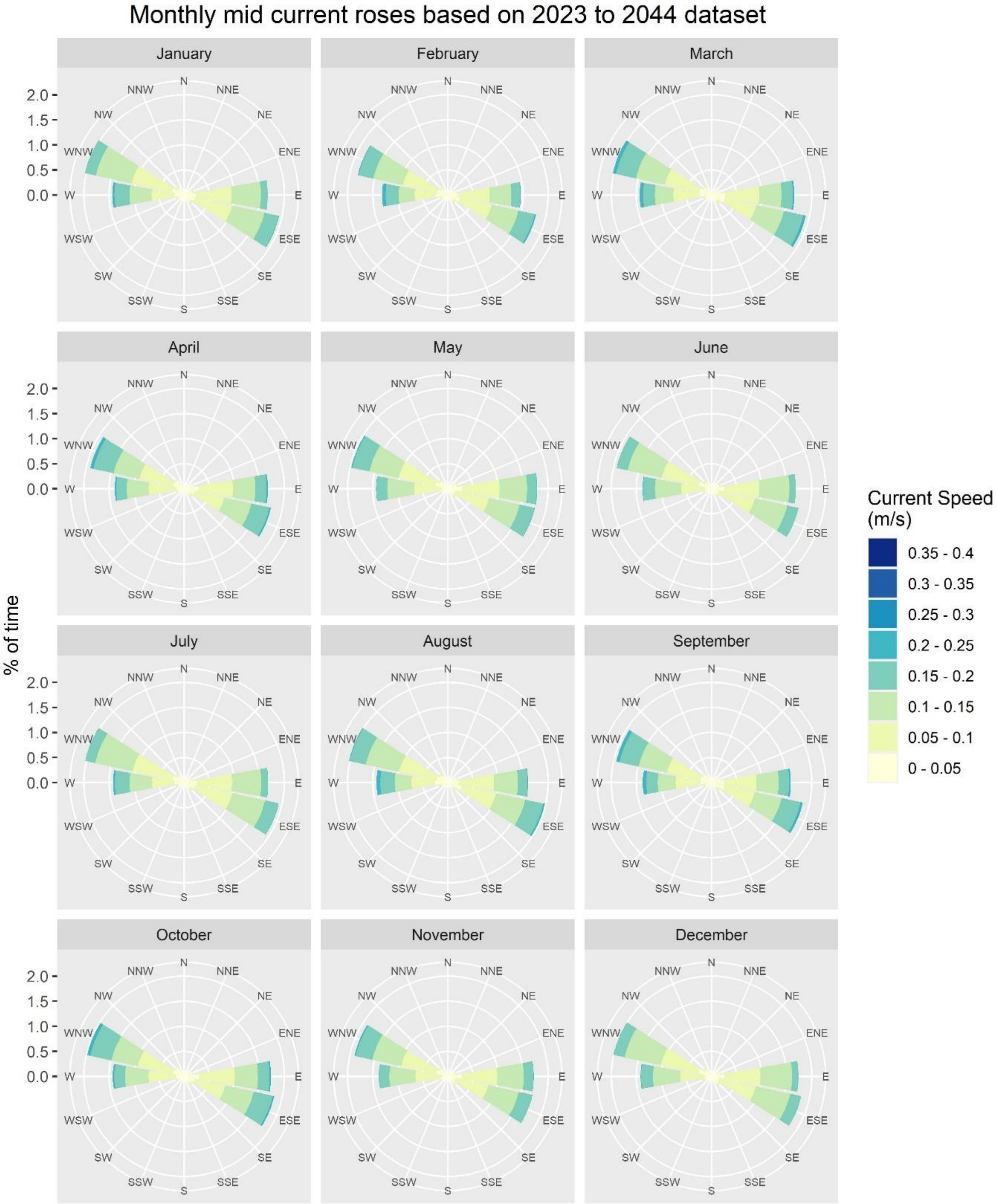


Figure 3-13 Monthly depth-averaged current speed and direction from 30-year time series

Table 3-5 Depth-averaged current speed statistics derived from 30-year time series

	Current speed (m/s)			Current direction (degrees)	
	mean	max	min	mean	mean
January	0.09	0.23	0.00	278.03	103.97
February	0.09	0.23	0.00	278.09	103.91
March	0.09	0.23	0.00	278.13	103.42
April	0.09	0.23	0.00	278.30	103.60
May	0.09	0.22	0.00	277.98	104.22
June	0.09	0.21	0.00	278.24	103.75
July	0.09	0.22	0.00	278.39	103.65
August	0.09	0.23	0.00	278.17	103.62
September	0.09	0.23	0.00	278.54	102.61
October	0.09	0.23	0.00	278.14	103.05
November	0.09	0.22	0.00	278.12	103.05
December	0.09	0.22	0.00	278.20	103.43
Overall	0.09	0.23	0.00	278.19	103.52

A representative spring-neap cycle is presented in Figure 3-14. Long term water level statistics are summarised in Table 3-6 whereby the Highest Astronomical Tide (HAT) and Lowest Astronomical Tide (LAT) relative to Mean Sea Level (MSL) is 2.21 m and -2.10 m respectively. According to Olbert et al [6], 50-year positive storm surge in the bay ranges from 1.3 m to 1.5 m Figure 3-15. Negative surge values in this area are not available.

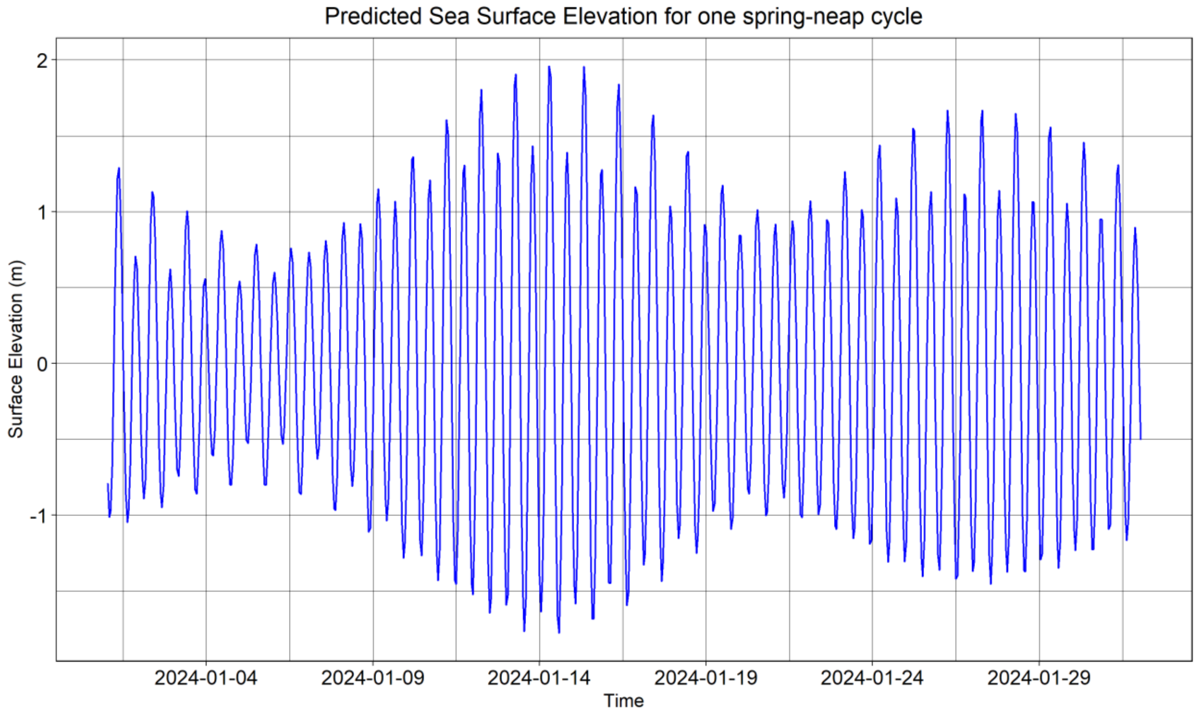


Figure 3-14 One month representation of water levels in Killala Bay under astronomical tide only produced from the Global Tide Model

Table 3-6 Long term water level statistics in Killala Bay derived from the Global Tide Model

	Surface Elevation (m)
HAT	2.21
MHWS	1.66
MHWN	0.75
MSL	0.00
MLWN	-0.75
MLWS	-1.66
LAT	-2.10

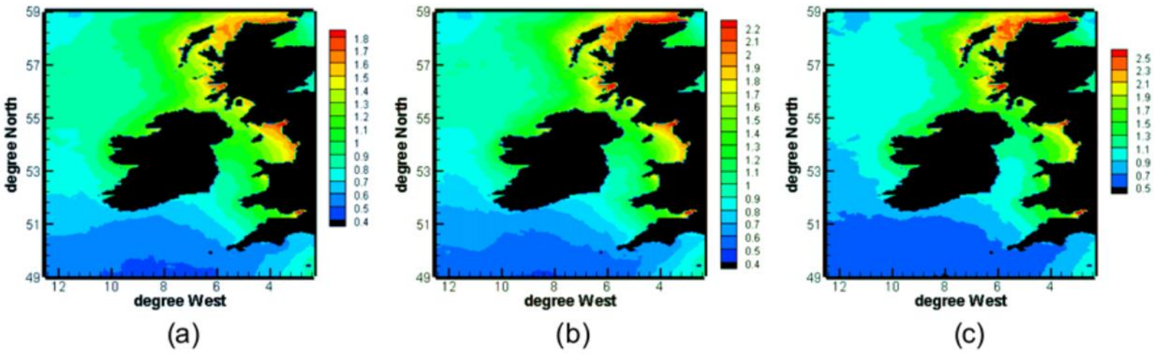


Figure 3-15 Surge residuals values from hybrid GEV-EV1 model for RP of (a) 10 years, (b) 50 years and (c) 200 years. Source: Olbert et al [6]

It is recommended that in situ geophysical data such as high-resolution bathymetry datasets and metocean data such as tidal current and water level information is collected for the site. Tidal current and water level information can be in the form of current meters, Acoustic Doppler Current Profilers (ADCPs), tide gauges or AWAC buoys for example. This will feed into local numerical model development which will in turn provide detailed design information for the site.

4 THEME DEVELOPMENT

Specialist architectural firm Wignall & Moore have provided initial design work and conceptual ideas for the underwater museum. The proposals have followed the themes set out by the client, focusing on Irish mythology and maritime tropes.

In addition to sculptures and ornamental pieces, additional elements which can hance the biodiversity aspect of the museum have been considered.

4.1 SHIPWRECKS

There are a significant number of shipwrecks around the Irish coast. These are typically hot-spots for divers given the historical interest and antiquity.

4.1.1 SS THAMES

Of particular interest to the local area is the SS Thames, which sank within Killala Bay in March of 1893. The vessel was a 295-ton London steamer, heading from London to Sligo with guano when the vessel struck St. Patrick's rock off Kilcummin Head in fog. The wreck was discovered in 1984.

Figure 4-1: SS Thames Steamer (Wignall & Moore Concept Document)

4.1.2 SPANISH ARMADA

The West Coast of Ireland has a significant tie to the exploits of the Spanish Armada, with a large number of wrecks within Irish waters. Wignall & Moore proposed this as another potential shipwreck theme to exploit within the underwater museum.

4.1.3 LA CONCORDE

GDG have also considered relevant local examples, such as the vessel La Concorde which sailed into Kilcummin Harbour directed by General Humbert. Humbert arrived in Killala Bay with 1,100 men and three ships on 22nd of August 1798 with the aim of supporting the Irish patriots in their cause of the Rebellion of 1798.

Whilst the vessel did not sink, and consequently cannot be considered a shipwreck, provision of a replica vessel would be significant in respect of local heritage.

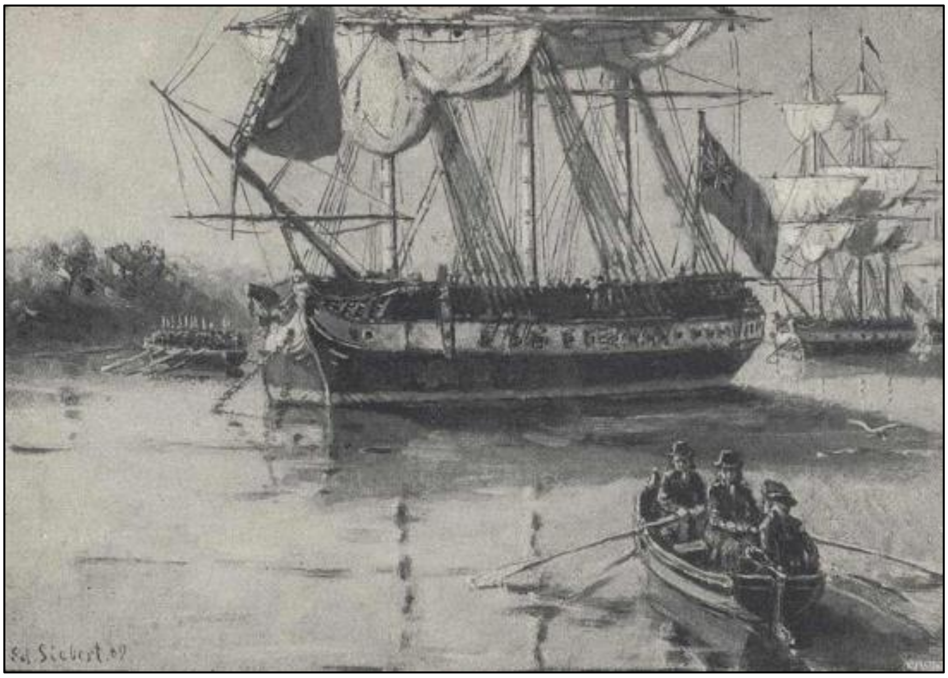


Figure 4-2: SS Thames Steamer (https://www.libraryireland.com/frenchinvasion1798/general-humbert-killala.php)

4.2 Reef Blocks

Reef blocks are an element which could relatively easily be incorporated into the museum design. Arc Marine provide innovative reef blocks typically used for applications within the offshore wind sector as a means of provided scour protection to turbine foundations. Arc Marine have been engaged with as part of the design process.

4.3 Local History and Mythology

Wigall & Moore considered a number of themes considering local history and mythology. These included the following:

Manannán mac Lir (Son of the sea) - warrior and king of the Otherworld in Irish Mythology. He appears in numerous tales and is known to have a horse, Aonbharr, who can travel on both land and sea, and a legendary sword named Fragarach.

Hy-Brasil – the mythical lost island of the Irish west coast. It was said to be clouded in mist except for one day occurring once every seven years at which time it would be visible but still unreachable.

Figure 4-3: Hy-Brasil Location Illustrated on Historic Map (Wignall & Moore Concept Document)

Selkie - Selkie are creatures found commonly in Celtic Folklore. In water they take the form of seals but they are able to shed their seal skins and become human on land.

5 PROPOSED CONCEPT

GDG and Wignall & Moore have proposed the following as the concept for the underwater museum, this has considered the themes proposed by the client and developed the key ideas proposed in Section 4. This is a short overview of the conceptual work completed by Wignall & Moore, and further detail is included within the document 'Underwater Museum – Initial Thoughts & Concepts – Wignall & Moore'.

It is noted that whilst the following is proposed as a concept for the underwater museum, the client encourages further development of ideas, particularly those around local mythological and maritime themes.

The final proposal for the underwater museum route, theme and aesthetic must consider how to make best use *of light, sound* and *buoyancy* to create a memorable and artistically rich experience.

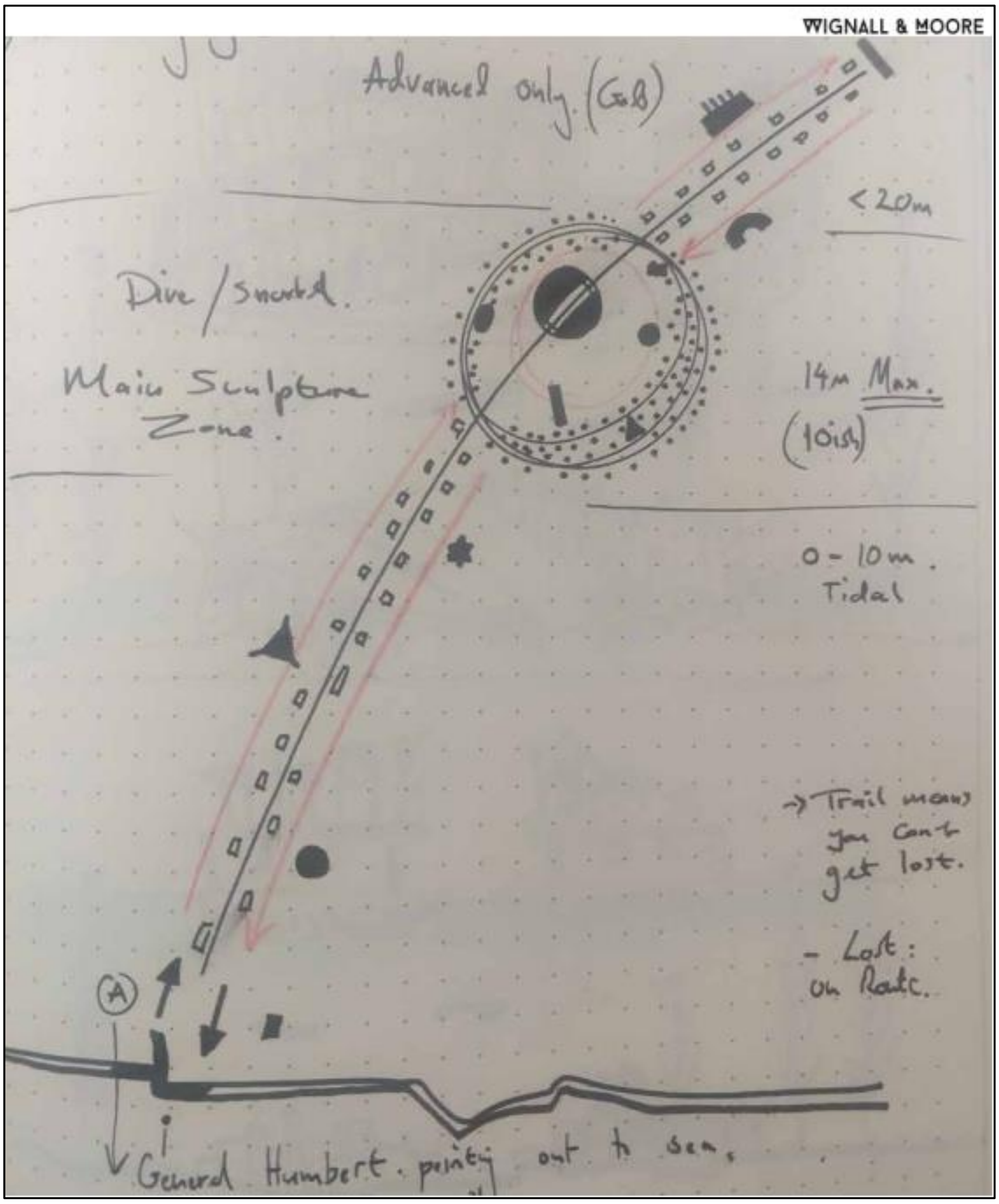


Figure 5-1: Proposed Concept Layout by Wignall & Moore (Wignall & Moore Concept Document)

5.1 The Quest for Hy- Brasil

Hy-Brasil was first shown on sea charts in 1325 to the west of Ireland, described as a small round island veiled in fog only appearing for one day every seven years. The legend says a single lone sorcerer resides on the island, shrouded in mystery and uncertainty the quest for the phantom Island has never had a conclusion; until now. Follow the exhibition to discover the mystical world of Hy- Brasil.

The museum is separated into three principal zones, following a diving route which is linked by a central curved spine and a main sculptural zone. The variation in depth is proposed to cater for swimmers and snorkelers in addition to divers, thus increasing the potential attraction to the facility.

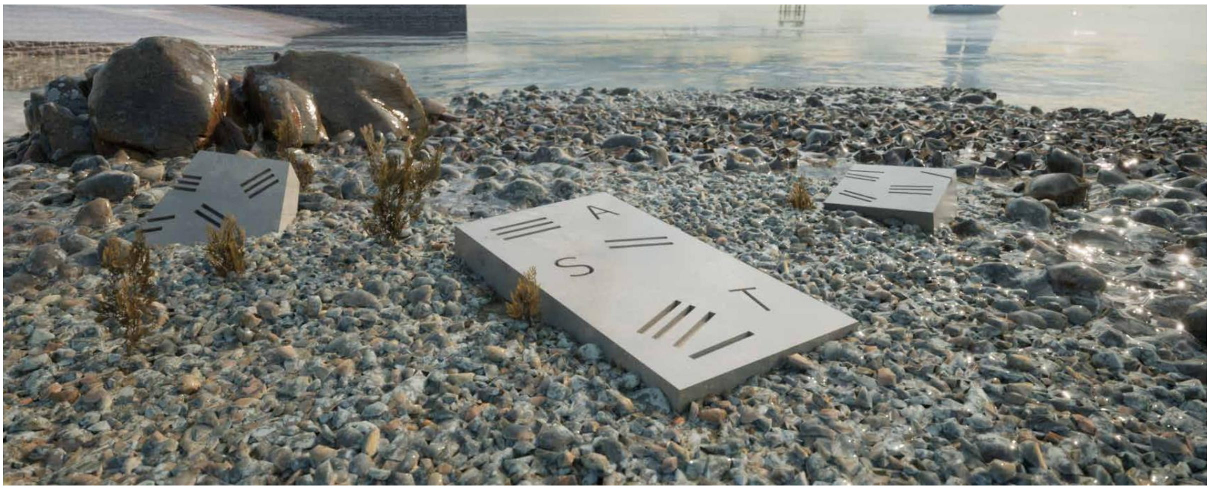


Figure 5-2: Quest to Hy-Brasil Quest/Tidal Zone Ideas (Wignall & Moore Concept Document)

5.1.1 Quest / Tidal Zone

The starting route for the underwater museum beginning on the shore is proposed as the Quest Zone. It is intended that this will include elements which are visible on the landside to appeal to those which may not be entering the water, and also encompass a number of elements which will be tidally visible.

This zone would allow for anyone walking along the shore to appreciate the museum elements and will cater for swimmers and snorkelers in addition to facilitating the route for divers out to the deeper areas. The proposed depth will vary from 1-8m depending on the exact bathymetry at the final location and will be tidally dependant. Ideas proposed for the Quest Zone include the following:

- Lost Irish Language, Ogham and Irish sea words.
- Symbols and directions point the direction of the route.
- Lost Ships, maybe searching for Hy Brazil but also famous ships of Ireland (Spanish Armada, 'Coffin Ships' or SS Thames options to include).
- Loss Ecology.
- The Ogham Dictionary.
- General Humbert Pointing out to sea.

5.1.2 Hy-Brasil / Main Sculpture Zone /

After exiting the intertidal Quest Zone, the next 'zone' is proposed as the 'Hy-Brasil' main feature area. The proposed depth is to be 10-14m and will cater for snorkelers and divers.

Given snorkelers won't be able to reach depths on par with divers, some of the elements should be readily visible to those at shallower depths. Ideas to consider within the Hy-Brasil main zone are:

- Introduction to the Landscape of Hy-Brasil, the forest, the river and the introduction to the sorcerer.
- Loss Ecology.
- The tunnel to the after world
- Local Architecture and heritage.

It is also proposed to provide a feature pontoon 'island' within this zone of the museum. This will provide an above water feature visible from shore and can be utilised by snorkelers, divers and other recreational users of the marine space (paddle boards, kayaks, etc). Given the health and safety implications, no motorised vehicles would be proposed to utilise the pontoon.

Figure 5-3: Hy-Brasil Sculpture Ideas (Wignall & Moore Concept Document)

Figure 5-4: Hy-Brasil Pontoon Island Artists Impression (Wignall & Moore Concept Document)

5.1.3 The Land of the Gods

After transitioning through the Island, visitors will find themselves in the land of the Gods which is the deepest zone of the museum. Here objects can take an even more surreal turn including multi-level structures and perhaps the skeletons of large sea creatures. This area is the deepest section of the museum and is intended as an advanced diving zone with depth in excess of 14m.

Examples of elements which could be included within this zone of the museum include:

- Sea creatures.
- The Sorcerers home.
- Gods /The after world.
- The Standing Stones.

Figure 5-5: Land of the Gods Artists Impression (Wignall & Moore Concept Document)

5.1.4 Puzzle Concept

To increase immersion and provide an engaging experience, creating an interactive component of the museum was proposed. Inspiration was taken from handheld puzzle boxes to create an experience that would allow visitors to be more involved in the museum. A suggested storyline is given below.

"The legends state that in exchange for their immense power, the sorcerer was cursed with a fatal weakness, bound to a single word. Simply speaking this word strips them of their powers, allowing the courageous adventurer to prevail and set foot on Hy-Brasil. To hide this secret the sorcerer has sunk many past explorers in the waters around the mystical island. Perhaps some of them discovered a clue to this mysterious word?"

To lean into the culture of the area, an Irish word would provide a more unique site experience while also providing more publicity for the language. As this language is likely to be foreign to any tourists a key to solve the anagram could be hidden to ensure it can be solved with no prior language knowledge. The correct word would be entered into an online site for a congratulatory message and could also provide a discount code for diving equipment or a free traybake if you buy a coffee at the nearby coffee shop.

Four conceptual methods of hiding these letters are provided below:

5.1.4.1 Concept 1

This concept involves letters strewn about the middle zone. These letters would be heavy enough to not be swept away by currents but light enough to manually moved. This concept can therefore adapt by changing letter locations or simply swapping the letters to form a new word, allowing for a new experience each time while also ensuring the answer isn't leaked to the public as it would change regularly. This letter swapping could potentially be performed by a nearby diving club, providing an interactive 'hide and seek'-esque experience for their frequent dives. A key for the anagram would be hidden in the shallow area to ensure more parts of the museum are involved.

5.1.4.2 Concept 2

The second concept would involve a more interactive element. Instead of the letters being separate to the statues they would be incorporated within them. Some examples are given below.

- Light passing through a letter shaped gap to project a letter on a surface.
- Statues with a hidden letter shape formed of a much different material, such as bronze on a concrete statue.
- Making the letters so large they can only be noticed from a significant distance.
- Carving a letter into a noticeable surface, such as a mirror.

5.1.4.3 Concept 3

A third approach could follow a more abstract interpretation. Instead of physically finding letters, the letters or word could be represented through the names or themes of the statues. For example, the first letter of each statue following a certain theme (e.g. , Aonbharr and Kelpie for an animal theme) or translated Irish words could be provided onshore and the overall theme chosen from the options.

5.1.4.4 Concept 4

A simplistic method would be to hide the complete word within the museum with the storyline of *"a past adventurer already discovered the weakness but their vessel was sunk before having the opportunity to use it"*. The museum would lead towards this hidden word through statues pointing or looking a certain direction. Then in the final location divers would search and interact with the statue to find the word. The final word could also be the name of the statue, such as the SS Thames.

6 SCULPTURE BASE DIMENSIONS

Based on the anticipated wind, wave and current conditions, GDG have completed engineering calculations to determine the anticipated size of sculptures bases.

The minimum dimensions will ensure the proposed museum elements will stable in the anticipated conditions and not subject to sliding, overturning or bearing failure when placed on the seabed.

It is noted that the proposed base sizes are preliminary calculations only, and these will require verification on completion of final design. However, these should allow for the contractor to price elements of the museum and to understand installation method.

Methodology

The preliminary sizing of sculpture bases has been completed as per the following methodology**:**

1. Completion of high-level metocean assessment to determine suitable design criteria for environmental conditions at proposed location.
2. Selection of a number of proposed sizes of sculptures/elements assuming basic dimensions to allow for an understanding of size and weight. Dimensions for both submerged and intertidal zones to consider the practicality of installation, visual impact if in the intertidal zone and also the proposed objectives for the museum.
3. Calculation of environmental loading on proposed sculpture sizes in both the submerged and intertidal zones.
4. Selection of proposed base dimensions for sculptures (as per proposed sculpture/element sizes determined in 2.).
5. Check on the stability of proposed base dimensions considering the environmental loading anticipated (as calculated in 3. for both submerged and intertidal zones).

6.1 SUBMERGED ZONES

For the sculptures located in the submerged zones, the sizing of the concrete bases has considered the design current speed as outlined in Section 3.5.3.

As outlined within the methodology, the following preliminary sculpture/element sizes have been selected for the determination of loading (and subsequent sizing of bases) within the submerged zone. The sizing has been cognisant of the objectives of the deeper areas of the museum, with the intention of providing at least one large sculpture which can be a significant selling point of the museum and elements which are large enough when placed on the seabed to be visible to snorkelers in shallower waters.

Sculpture Height (inc Base)	Estimated Sculpture Dry Weight (tonnes)	Base Length & Breadth (m)	Base Height (m)
1.25	0.54	1	0.5
2	2.22	1.25	0.6
2.5	4.34	1.5	0.7
4	17.78	2	0.8

Table 6-1: Proposed Sizes for Submerged Zone Sculptures/Elements

The calculation of the steady drag forces experienced on the sculpture has been as per the guidance of BS EN 6349-1-2: 2016, E1.

To allow for a degree of conservatism, the dimensionless drag coefficient has assumed that at least some sculptures may be square sided, and therefore has assumed a value of 2.0.

$$F_D = \frac{1}{2}(C_D \rho V^2 A_n)$$

where:

F_D is the steady drag force, in newtons (N);

C_D is the dimensionless time-averaged drag coefficient for steady flow;

ρ is the mass density of the water, in kilograms per cubic metre (kg/m³);

V is the incident current velocity, in metres per second (m/s);

A_n is the area of structural member normal to flow, in square metres (m²).

Figure 6-1: Extract from BS EN 6439-1-2:2016 E1 (Steady Current Drag Force)

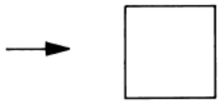
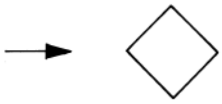
Cross-section type	Attitude to flow or wave direction	Drag force coefficient C_D
Circle	Any	See Figure 19
Square		2.0
		1.6

Figure 6-2: Extract from BS EN 6439-1-2:2003 for Drag Force Coefficient on Square Members

Table 6-2: Partial Factors as per BS 6349-1-2:2016 – Table 1 (1 of 3)

Table 1 **Partial factors for actions** *(1 of 3)*

Action type	Scenario	Item	Symbol (in accordance with BS EN 1990:2002+A1)	EQU (Set A) Unfavourable	EQU (Set A) Favourable	STR/GEO (Set B) Unfavourable	STR/GEO (Set B) Favourable	STR/GEO (Set C) Unfavourable	STR/GEO (Set C) Favourable
Permanent actions [A)]		Steel self-weight	$\gamma_{G,sup}$ $\gamma_{G,inf}$	1.05	0.95	1.20	0.95	1.00	1.00
		Concrete self-weight	$\gamma_{G,sup}$ $\gamma_{G,inf}$	1.05	0.95	1.35	0.95	1.00	1.00
		Weight of soil and other materials	$\gamma_{G,sup}$ $\gamma_{G,inf}$	1.05	0.95	1.35	0.95	1.00	1.00
		Superimposed dead loads [B)]	$\gamma_{G,sup}$ $\gamma_{G,inf}$	1.05	0.95	1.20	0.95	1.00	1.00
		Geotechnical actions	$\gamma_{G,sup}$ $\gamma_{G,inf}$	1.05	0.95	1.35	0.95	1.00	1.00
		Ground water [C)]	$\gamma_{G,sup}$ $\gamma_{G,inf}$	1.05	0.95	1.35	0.95	1.00	1.00
		Uneven settlements	$\gamma_{G,sup}$	—	—	1.20 [D)]	—	1.00	—
		Prestressing	γ_P as defined in the relevant Eurocode or for the individual project						
Variable actions	Road traffic actions	Road vehicles (gr1a)	γ_Q	1.35	—	1.35	—	1.15	—
		Pedestrian loads (gr1a)	γ_Q	1.35	—	1.35	—	1.15	—
		Horizontal forces (gr2)	γ_Q	1.35	—	1.35	—	1.15	—
		Pedestrian loads (gr3)	γ_Q	1.35	—	1.35	—	1.15	—
	Equipment loads [E)]	Gantry crane	γ_Q	1.35	—	1.35	—	1.15	—
		Mobile harbour crane	γ_Q	1.35	—	1.35	—	1.15	—
		Construction crane	γ_Q	1.35	—	1.35	—	1.15	—
		Port vehicles	γ_Q	1.35	—	1.35	—	1.15	—
		Cargo handling equipment	γ_Q	1.35	—	1.35	—	1.15	—
	Cargo loads	Containers	γ_Q	1.50	—	1.50	—	1.15	—
		General cargo	γ_Q	1.50	—	1.50	—	1.15	—
		Bulk cargo	γ_Q	1.50	—	1.50	—	1.15	—
		Liquid products	γ_Q	1.05	—	1.05	—	1.00	—

Table 6-3: Partial Factors as per BS 6349-1-2:2016 – Table 1 (2 of 3)

Table 1 **Partial factors for actions** *(2 of 3)*

Action type	Scenario	Item	Symbol (in accordance with BS EN 1990:2002+A1)	EQU (Set A) Unfavourable	EQU (Set A) Favourable	STR/GEO (Set B) Unfavourable	STR/GEO (Set B) Favourable	STR/GEO (Set C) Unfavourable	STR/GEO (Set C) Favourable
Variable actions	Environmental loads	Wind actions [F)]	γ_Q	1.50	—	1.50	—	1.30	—
		Operational wind (an environmental operating limit as defined in BS 6349-1-1:2013)	γ_Q	1.50	—	1.50	—	1.30	—
		Thermal actions [F)]	γ_Q	1.50	—	1.50	—	1.20	—
		Snow	γ_Q	1.50	—	1.50	—	1.30	—
		Ice	γ_Q	1.50	—	1.50	—	1.30	—
		Water currents	γ_Q	1.50	—	1.50	—	1.30	—
		Wave	γ_Q	1.50	—	1.50	—	1.30	—
		Operational wave (an environmental operating limit as defined in BS 6349-1-1:2013)	γ_Q	1.50	—	1.50	—	1.30	—
		Tidal lag or variable ground water [C)]	γ_Q	1.50	—	1.50	—	1.30	—
	Ship operational loads [G)]	Berthing (from characteristic energy) [H)]	γ_Q	1.35	—	1.35	—	1.15	—
		Berthing (from design energy) [H)]	γ_Q	1.20	—	1.20	—	1.10	—
		Mooring	γ_Q	See Table 8	—	See Table 8	—	See Table 8	—
		Ship ramps	γ_Q	1.50	—	1.50	—	1.30	—
		Ships propulsion	γ_Q	1.50	—	1.50	—	1.30	—
	Construction loads (execution)		γ_Q	1.50	—	1.50	—	1.30	—
	Geotechnical actions [I)]	Earth pressures	γ_Q	—	—	—	—	—	—

Table 6-4: Partial Resistance Factors for Sliding and Bearing Check

Table A.NA.5 **Partial resistance factors (γ_R) for spread footings for the STR and GEO limit states**

Resistance	Symbol	Set R1
Bearing	$\gamma_{R;v}$	1.0
Sliding	$\gamma_{R;h}$	1.0

6.1.1 Sliding Check

On the basis of the current loading, the sliding check on the proposed element dimensions has been completed as per the following equations:

$$R_d = V'_d \tan \delta_d \text{ or } R_d = (V'_d \tan \delta_k) / \gamma_{Rh}$$

Where R_d (sliding resistance) must be greater than the horizontal force generated by the current loading.

For the purposes of the sliding check, and considering the anticipated seabed conditions, a friction angle, $\delta_d = 28°$ has been assumed.

6.1.2 Overturning Check

The overturning check has considered the stabilising moment generated by the submerged weight of the elements (calculated for assumed dimensions) acting vertically through the centre of the base.

The destabilising moment has been calculated as per the current loads calculated for the assumed sculpture dimensions, acting at half the height of the element.

Rotation is assumed about one of the element corners.

6.1.3 Bearing Check

From inspection of the anticipated bearing pressures and the expected ground conditions at bed level, bearing pressures are considered to be adequate to support the museum elements based on the dimensions identified.

6.2 Intertidal Zone Sculptures

Sculptures located within the intertidal zone will be subject to both wave and current action. The design has considered the design wave height, period and current speed as indicated within Section 3.5.2 and 3.5.3.

The hydrodynamic load acting on the piles is a combination of effects from the current and waves, expressed as:

The Morison equation can be expressed as follows:

$$F_W = F_D + F_I$$

where:

F_W is the total wave force normal to the axis of the member, in kilonewtons (kN);

F_D is the steady drag force, in kilonewtons (kN), given by:

$$F_D = \int_0^{L_s} (1/2 C_D \rho W_s |U| U) dL_s$$

F_I is the inertia force component, in kilonewtons (kN), given by:

$$F_I = \int_0^{L_s} \left(C_I \rho A \dot{U} \right) dL_s$$

where:

L_s is the submerged length of the member, of which dL_s is an elemental length, in metres (m);

C_D is the drag force coefficient;

C_I is the inertia force coefficient;

U is the instantaneous water particle velocity normal to the member axis, in metres per second (m/s);

$\dot{U}$ is the instantaneous water particle acceleration normal to the member axis, in metres per second squared (m/s^2);

ρ is the mass density of the water, in tonnes per cubic metre (t/m^3);

A is the cross-sectional area of the member, in square metres (m^2);

Figure 6-3: Extract from BS EN 6439-1-2:2016 E3 (Wave Action on Vertical Structures) – Morrison's Equation

The following expressions for instantaneous water level, particle velocities and acceleration are derived from linear theory and have been utilised within Morrison's Equation.

$$\eta = \frac{H}{2}\cos\left[2\pi\left(\frac{x}{L} - \frac{t}{T}\right)\right]$$

$$u = \frac{\pi H}{T}\frac{\cosh[2\pi(y+d)/L]}{sinh(2\pi d/L)}\cos\left[2\pi\left(\frac{x}{L} - \frac{t}{T}\right)\right]$$

$$v = \frac{\pi H}{T}\frac{\sinh[2\pi(y+d)/L]}{sinh(2\pi d/L)}\sin\left[2\pi\left(\frac{x}{L} - \frac{t}{T}\right)\right]$$

$$\dot{u} = \frac{2\pi^2 H}{T^2}\frac{\cosh[2\pi(y+d)/L]}{sinh(2\pi d/L)}\sin\left[2\pi\left(\frac{x}{L} - \frac{t}{T}\right)\right]$$

$$\dot{v} = \frac{2\pi^2 H}{T^2}\frac{\sinh[2\pi(y+d)/L]}{sinh(2\pi d/L)}\cos\left[2\pi\left(\frac{x}{L} - \frac{t}{T}\right)\right]$$

where:

η is the height of the water surface above still water level, in metres (m);

u is the horizontal component of water particle velocity, in metres per second (m/s);

v is the vertical component of water particle velocity, in metres per second (m/s);

$\dot{u}$ is the horizontal component of water particle acceleration, in metres per second squared (m/s^2);

$\dot{v}$ is the vertical component of water particle acceleration, in metres per second squared (m/s^2);

(all at time t at a distance x from the wave crest and, in the case of velocities and accelerations, at a height y above still water level);

d is the still water depth, in metres (m);

H is the wave height, in metres (m);

L is the wave length, in metres (m);

T is the wave period, in seconds (s).

Figure 6-4: Extract from BS EN 6439-1-2:2016 E3 (Wave Action on Vertical Structures) – Particle Velocity Equations

Sculpture Height (inc Base)	Estimated Sculpture Dry Weight (tonnes)	Base Length & Breadth (m)	Base Height (m)
1.25	0.54	1	0.5
2	2.22	1.25	0.6
2.5	4.34	1.5	0.7

Table 6-5: Proposed Sizes for Intertidal Zone Sculptures/Elements

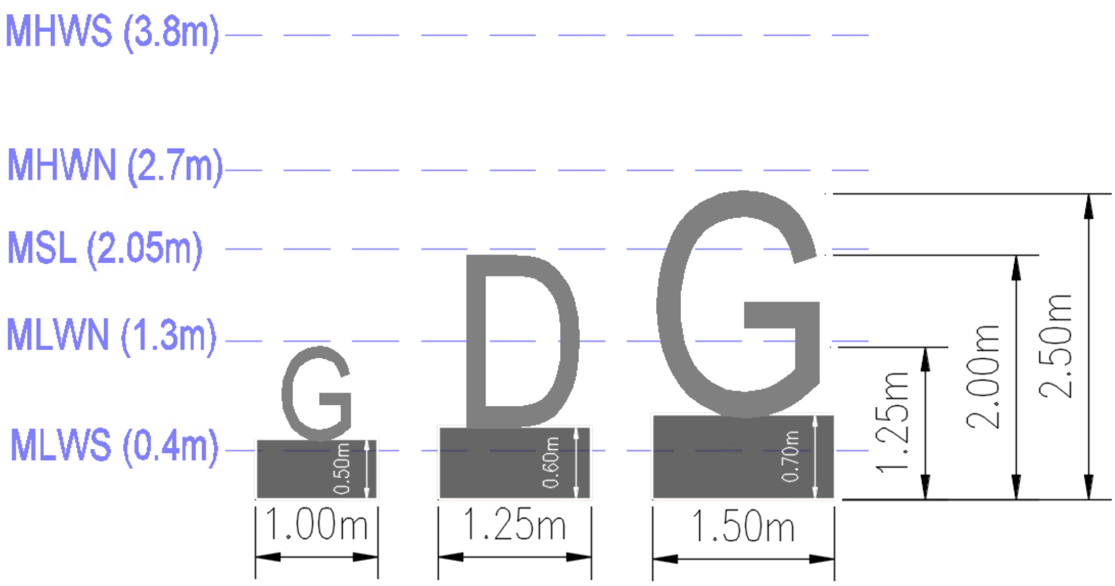


Figure 6-5: Intertidal Zone Sculpture Sizes Sketch

6.3 Additional Information

It is noted that these represent high-level preliminary calculations, and that verification of final designs will be required to ensure stability of sculptures in the long-term condition.

To allow for further detailed assessment and design the following is recommended:

- Collection of site-specific environmental data.
- Completion of detailed bathymetric survey and topographic survey of the proposed museum area.
- Completion of a ground truthing to confirm nature of seabed and collection of a number of grab samples.
- Completion of a number of vibrocores to confirm the anticipated seabed strength profile.

7 PRELIMINARY CONSTRUCTION AND INSTALLATION OVERVIEW

The following is provided as an overview of how the construction and installation of the underwater museum may take place. It is intended as an overview only and will help inform the planning and foreshore consenting process. It will be the responsibility of the appointed contractor to complete detailed method statements and risk assessments in line with the Safety, Health and Welfare at Work (Construction) 2013.

7.1 ANTICIPATED PLANT

Considering the nature of the proposed elements of the underwater museum, the following are anticipated as the likely required plant:

- Multi-cat with mounted cranes (similar to that shown in Figure 7-1).
- Floating barge.
- Excavator capable of being mounted on barge.
- Additional landside excavator(s)
- Landside craneage, Hiab crane potentially depending on final weight of elements, or small mobile crane.
- Safety vessel.

Whilst divers are not considered plant, it would be anticipated that diver work will be required as part of the installation works.

Figure 7-1: Damen Multi Cat 2613 Vessel

Figure 7-2: Floating Barge with Excavator

7.2 ANTICIPATED INSTALLATION METHOD AND SEQUENCE (UNDERWATER MUSEUM ONLY)

The following is considered the likely sequence of installation for the underwater museum, note this does not consider any civil and structural works which may be associated with landside facilities:

1. Setting up of site compound and placement of safety buoys delineating the construction boundary from other marine areas.
2. Site preparation including for excavation works to provide suitable surface for placement of sculptures/elements (likely to include for excavation works on the shoreside and potential levelling of certain zones). Note the requirement for any bed preparation will be informed by detailed bathymetry in addition to in-situ ground investigations.
3. Submerged site bed preparation to provide suitable surfaces for placement of sculptures/elements (likely to include for excavation works on seabed, potential levelling of certain zones or provision of gravel 'bedding'). Note the requirement for any bed preparation will be informed by detailed bathymetry in addition to in-situ ground investigations.
4. Loading of elements destined for deepest zone (+14m depth) onto floating barge or multi-cat from shoreside. Placement of submerged sculptures onto seabed anticipated to be completed with cranes loading element into the water (likely secured with 4-point chains to maintain a level of verticality as best possible). Divers required in the water to guide gradual submerging of sculptures. Divers to release chains on completion of placement on seabed. Vessel to return to shore on completion of deepest zone.
5. Loading of elements destined for 8-14m mid-depth zone onto floating barge or multi-cat from shoreside. Repetition of process outlined above for placement of elements into seabed.
6. Placement of elements within the intertidal zone (1-8m) may be possible from the landside depending upon the reach of the landside crane and location of elements relative to the crane

set-up. Divers or construction operatives will likely be required in the water to assist with the placement of the various elements on the seabed. Depending upon final weights, some smaller items may be suitable for hand placement on the shore or within the intertidal zone.

7. Completion of any additional landside works including provision of access paving and installation of fencing, gates and signage to the facility.

7.3 Potential Restrictions on Construction Period

The following may be considered to restrict or inform the timing of the construction period for the underwater museum:

- Any particular conditions imposed by the Foreshore Consent relating to local protected species (for example certain activities which are considered to emit significant noise may need to be scheduled to avoid impacting breeding birds, migrating fish or other marine wildlife). The imposition of any such restrictions would not be known until after all the relevant consent applications have been submitted and all required environmental assessment completed.
- Weather conditions making marine construction activities unsafe. To reduce the potential weather downtime, it would be proposed to schedule the construction activities for the summer months.

Whilst it is unlikely to restrict or impede construction, the timing of the installation period should be cognisant of the local users of Kilcummin harbour. It would be suggested that the local harbour users are consulted on the works and feedback sought on how best to avoid impacting key stakeholders.

7.4 High Level Programme

The following provides a high-level programme for the installation works. Note this assumes the planning and environmental works are completed over a period of 12 months, including for approval of planning and marine area consent. It also assumes that early works are undertaken in preparation of sculptures, ready for completion and installation in the contract window.

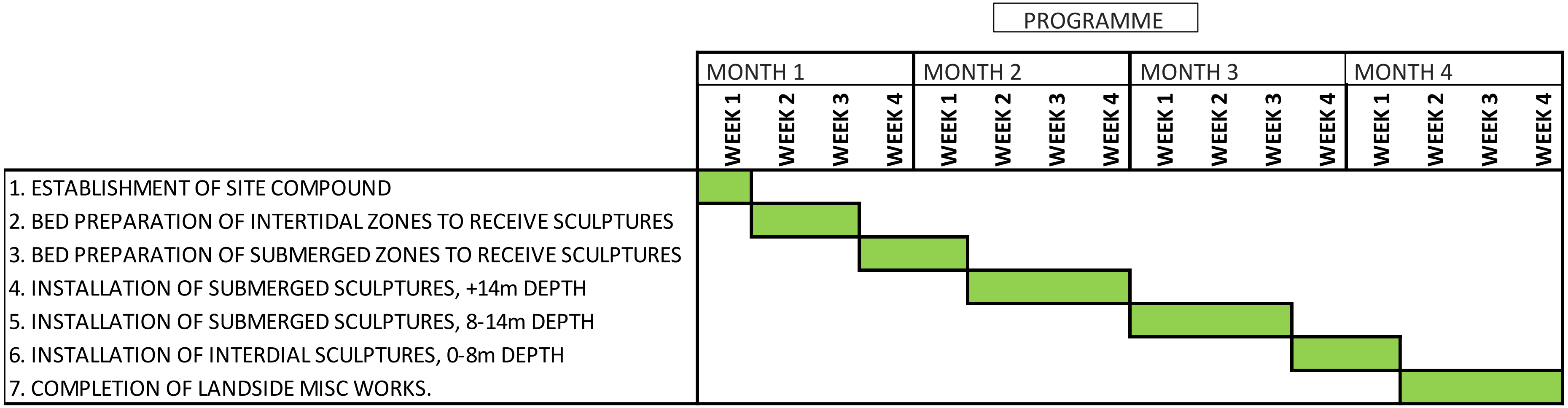


Figure 7-3: High level Indicative Installation Programme

<u>Note this is a high-level consideration of programme. The contractor selected for the works will be expected to provide a detailed programme for the works reflecting his chosen methodology.</u>

8 Cost Estimates for Next Stages

On completion of the concept stage (documented in this report), the following steps are anticipated to take the project through to completion:

Note, given the nature of the scope, it is assumed that the construction works will be procured on a Design and Build basis, allowing for a degree of engagement between the client and contractor during the tender phase and in finalising the contract price. It would be anticipated that the contractor's team would include for a specialist marine civils contractor (as lead partner), with a design consultancy team providing detailed design services in addition to an artist informing the development of the museum theme and final nature of the sculptures.

1. **Development of a business case / financial feasibility study of the project . Estimated at €30,000**
    - Assess the business case and financial feasibility of the proposed project.
    - Bring the proposed project through Decision Gate 1: Strategic Assessment and Preliminary Business Case Stage of the Public Spending Code (as amended by Circular 6/23) and to gain Approval-in-Principle to proceed to and complete Stage 1. Works to include services of a specialist marine civil engineering consultant and a financial services expert.
    - Identify a forecast on expected return of investment.
2. **Investigative Works to Inform Consenting & Design – €60,000 ex VAT, *note assumes the client bears the cost of any surveys/investigations. Assumes separate management/procurement of contractor(s) and supervision of the survey works.***
    - Identification of required surveys and investigations to inform the design and consenting process.
    - Foreshore Licence Application (FLA) – issued by Maritime Area Regulatory Authority (MARA) (issued under the Maritime Area Planning Act) for any proposed site investigation works (as required, will depend on the nature of the investigations/surveys).
    - Procurement of contractor(s) to complete investigation works.
    - Completion of site investigation works (anticipated to include, bathymetric surveys, topographic surveys, grab sampling, and some intrusive ground investigation).
    - Environmental Impact Assessment (EIA) screening for the wider museum project to understand if the project is beyond the threshold criteria (desk-based study). Depending on the project specifics and EIA may be required to inform the marine consents.
3. **Consenting Applications & Decision Period - €60,000 ex VAT (assumes no EIAR required).**
    - Planning application for any works proposed above the mean low water mark.

      This work should include; drawings, planning application forms, Appropriate Assessment by ecological team and stakeholder engagement with interested locals. It is assumed at this stage that an Environmental Impact Assessment Report (EIAR) would not be required. The planning submission would be made to Mayo County Council.

- Maritime Area Consent (MAC) for museum works below the high water mark. This element is necessary under the Maritime Area Planning Acts 2021 and 2022 and is the replacement for the previous 'Foreshore Licence' process. The process requires approval of the financial, administrative and 'occupation of the seabed' aspects of the project under MARA licence, with subsequent application to the local coastal authority (Mayo County Council) for the technical and planning development aspects of the works.
- Liaison with Mayo County Council and MARA throughout Planning and MAC application processes respectively. There would be expected to be some queries arising from the processing of the development applications and an element of cost should be allocated to resolving such queries.
- An initial estimated fee for submission of these two applications has been included in the overall cost estimate noted above.
  - It is understood that a MAC application would cost €1,000 for projects under a capital value of €10m.
  - A planning application is dependent upon the final footprint and category of usage, but is expected to be less than €400 (category expected to be 13. Development not coming within any other foregoing class: €80 or €10 for each 0.1 hectare, whichever is the greater)

4. **Procurement of Contractor - €25,000 ex VAT.**
   - Preparation of tender documentations, to include all relevant drawings, specification and licence conditions as informed by 2.
   - Input into tendering process.
   - Tender assessment of contractor proposals.
   - Liaison with contractor alongside the client prior to appointment, finalising museum themes and proposed content.
5. **Construction Phase and Handover - €30,000 ex VAT (note this assumes 6-month construction period, with no site supervision provided by GDG).**
   - Project management of the construction phase on behalf of the client.
   - Responding to contractor requests for information.
   - Completion of construction and handover of facility to the client.

GDG have prepared high-level cost estimates for the completion of items 1-4. Note this assumes GDG acting as the client's engineer and not as detailed design consultant on behalf of the future contractor. These have been provided as an illustration and to allow for client budgeting.

Should GDG be retained for the completion of these activities in the future, we would seek to revisit costs to account for inflation and exchange rates current to the time, and to allow for consideration of a detailed scope.

9 Potential Suppliers and Contractors

Given the bespoke nature of the commission, GDG have assessed potential suppliers and contractors in relative proximity to Co. Mayo which may have an interest in tendering the opportunity.

9.1 Potential Suppliers of Sculptures and Artifacts

9.1.1 Local Artists

The following are identified as local artists which could be engaged as part of the underwater museum project at Killala:

- Bettina Seitz – responsible for 'Underwave'- an underwater exhibition in Sligo Bay of 11 sculptures, representing successive arrivals to our shores from Sligo's earliest settlers to people contributing to our modern multi-cultural society.
- Noah Rose – responsible for 'The Museum of Interconnected Events', that took the form of a small museum comprising a series of sculptural cabinets sited outdoors in County Mayo, Northamptonshire, England and Girona, Catalunya.
- Gareth Kennedy – Irish artist Kennedy has presented work in numerous key galleries and museums such as the LAB, Dublin. Gareth Kennedy was one of several artists selected to contribute to the North Mayo Sculpture Trail.

9.1.2 Precast Concrete – Sculptures

- ARC Marine (Torquay, UK) – Project partner with experience of reef cubes and other structures that enhance biodiversity.
- Moore Concrete (Ballymena, Antrim) – Have been involved with precast concrete sculptures previously in NI, not specifically marine.

GDG engaged directly with ECOncrete in regard to the project during the completion of the initial concept design phase. ECOncrete produce an admixture and liner system which promotes the growth of biodiversity on the surface of concrete elements. They indicated they work with Moore Concrete as a supplier in (Northern) Ireland.

9.2 Potential Installation Contractors

9.2.1 Specialist Dive Contractors

Given the nature of the proposed museum installation works, it is likely that this would suit a specialist marine contractor with dive expertise (may be in-house or subcontracted out). The following are identified as potential marine contractors based in Ireland:

- Irish Sea Contractors (Fearns, Wexford)
- Subsea Marine (Dundalk, Louth)
- Marine Specialists (Larkins Cross, Wexford)
- Ward & Burke Construction (Kilcolgan, Co. Galway).

9.3 Potential Project Manager for Management of Construction Phase of Works

The following are identified as potentially suitable parties for the management of the construction stage of the works:

- Gavin & Doherty Geosolutions (Presence across Ireland, including - Dublin, Cork, Belfast, Galway).
- Langan Consulting Engineers (Westport, Mayo)
- Malachy Walsh and Partners (Blackrock, Cork)
- Malone O'Regan (Clonskeagh, Dublin).

It is noted that given GDG's involvement in the early stages of the project, it would provide greater continuity and project efficiencies if we were retained for the management of the construction phase.

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