Updated Requirements Formulation

D10.5

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Executive Summary

The Space@Sea floating island contains various different applications, i.e. Energyhub@Sea (WP6), Living@Sea(WP7), Farming@Sea (WP8) and Transport&Logistics@Sea (WP9), see Figure 1-1. Each has specific (operational) requirements. In order to design a modular island, that serves different purposes and is not limiting, it is necessary to respect all these requirements at an early stage. At the beginning of the Space@Sea project, a catalogue of requirements was formulated in D10.1 [1]. However, at the start of the project some requirements could not be known, changed, or were not identified yet. Therefore, it was decided to keep the definition of requirements open to all applications in order to update changes that became necessary by knowledge gained. Regularly, a questionnaire was sent to all partners to gather the information and to provide a data base with the updated requirements and boundary conditions [2]. One result of this report is the definite requirement of rigid connectors between the modules, as applications require more undisturbed deck space than the given module size. Some requirements and limiting criteria could not be evaluated within the scope of the project, however this report gives an overview of the final information and serves as a base for future development work.

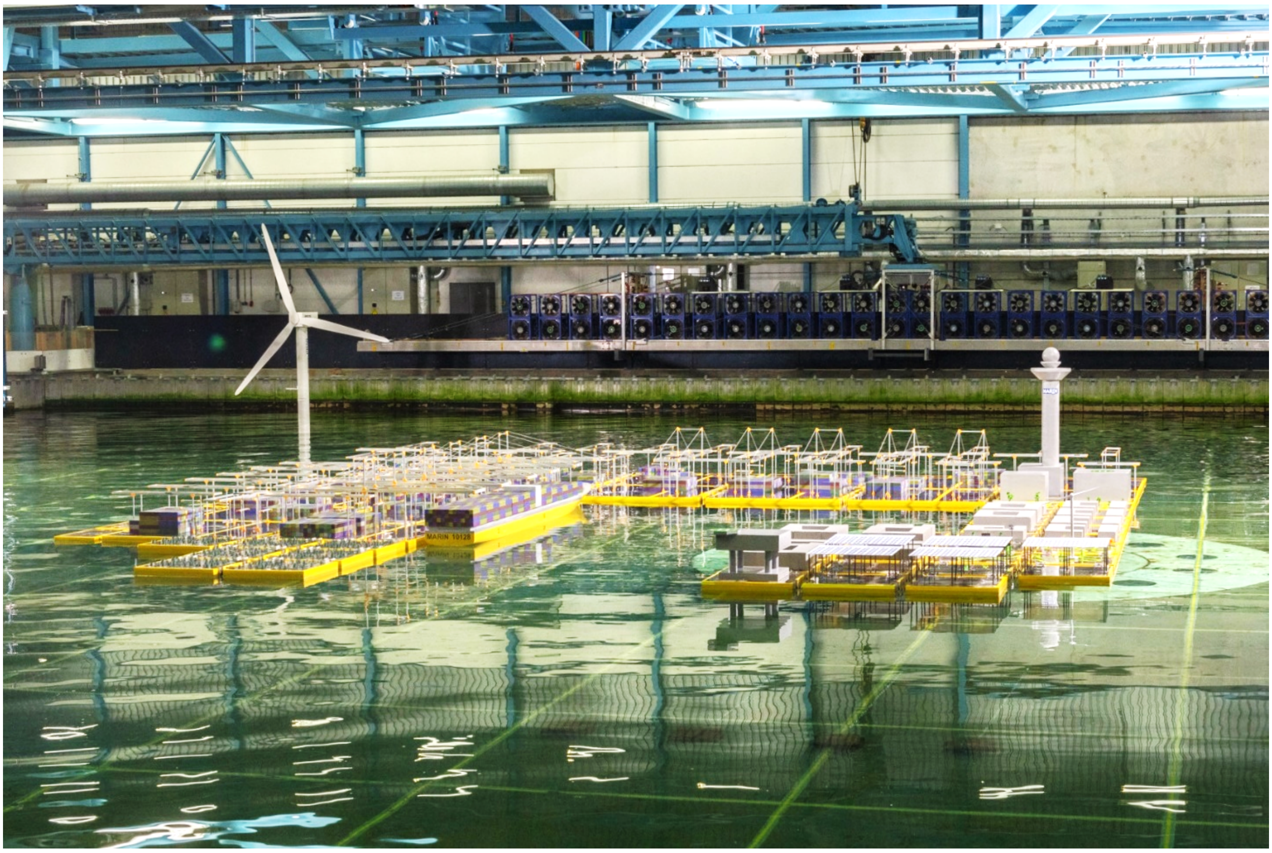

Figure 1-1: Scaled model of Space@Sea island demonstrated in MARIN's Offshore Basin [3]

1. Introduction

1.1 Background

The aim of the Space@Sea Project is to develop floating multipurpose space that is "sustainable and affordable […] by developing a standardized and cost-efficient modular island with low ecological impact." Within the project, the four use-cases "Aquafarming, energy production and distribution, transport and logistics and living" were assessed [4]. Each application has different technical and operational requirements that have been collected at the beginning of the project in Task 10.2 of work package (WP) 10, called "Integration and Demonstration". In this document, the final requirements are gathered.

1.2 Objectives

In this report, following technical information is presented:

- Fixed parameters and boundary conditions of modules, connectors and mooring
- Known properties and requirements of applications (space, number of modules, etc.)
- Limiting criteria per application

2. Fixed Parameters and Boundary Conditions

All requirements presented in this document are based on the following fixed parameters and boundary conditions, unless stated differently.

2.1 Floater Design

After the initial requirements of all applications were formulated in [1], it became clear that some pre-assumptions on the floater design were not applicable. Especially the shape of the floaters that was at first supposed to be triangular, changed towards a square shape.

- Shape: square
- Side length; 45m & 95m
- Height: different standard heights, e.g. 6m and 11m
- Floater type: barge
- Gap width: 5m
- Draught single floater: dependent on Height → 3m or 8m
- Freeboard: 3m

It was decided to have two standardized module sizes: 45m x 45m and 95 x 95m. The requirements in this document are all based on 45m side length modules, unless stated different.

2.2 Connectors

The connectors shall link the modules and preferably reduce their relative motions. However, the more degrees of freedom (DOF) are restricted, the higher the loads become, the connector needs to cope with. This makes the development of a technically and economically feasible connector design very challenging. As a compromise between module displacement and connector loads and as announced in [1] already, two concepts were studied:
1. a more rigid double-hinge-design,
2. a more flexible design using pretensioned cables and fenders.

The connector designs and arrangement at the modules are described in [5]. Tank tests and simulations showed that the second design is more promising for unsheltered installation sites with large storm sea states. Its main properties are:

- 12 or 24 fenders per 45m-module
- diameter of fender: 3.15 m
- combined stiffness of 12 fenders: 117,216 kN/m
- three cables per 45m-gap
- pretension per cable: 10 MN
- stiffness per cable: 6,503 kN/m
- length per rope in example-design: 145 m
- nominal diameter of rope: 184 mm.

2.3 Mooring

An extensive mooring study was performed within the Space@Sea project and is presented in [6]. The following table shows the parameters for a full chain catenary mooring solution for an island setup consisting of 78 standard modules in the Mediterranean Sea.

Parameter	**Unit**	**Value**
Type	[-]	Studless
Grade	[-]	R3S
Length	[m]	600
Nominal Diameter	[mm]	157
Minimum Breaking Load	[kN]	19260
Minimum Breaking (incl. 20mm Corrosion Abrasion Allowance)	[kN]	15442
Mass	[kg/m]	493.0
Submerged Weight	[N/m]	4203.2
Axial Stiffness (EA)	[N]	1.848E9

Table 1: Mooring parameters - chain properties

Parameter	**Unit**	**Value**
Number of Legs	[-]	71
Catenary Depth	[m]	91
Legs Type I		
Pretension	[kN]	995
Pretension Angle (with horizontal)	[deg]	52
Anchoring Radius	[m]	569
Legs Type II		
Pretension	[kN]	1112
Pretension Angle (with horizontal)	[deg]	49
Anchoring Radius	[m]	571
Note: Pretension angle is defined relative to horizontal		

Table 2: Mooring parameters - leg configuration

3. Properties, Requirements and Limiting Criteria of Applications

3.1 Energyhub@Sea (WP6)

The Energyhub developed in WP 6 has the purpose to generate and distribute electric energy throughout the island configuration. Therefor it includes photovoltaic modules and a wind turbine, see Figure 3-1. The energy conversion from relative motion is moved to the outer modules of an island configuration, hence they're not visible in Figure 3-1. Additionally, the Energyhub includes a storage and maintenance hub for offshore wind installations.

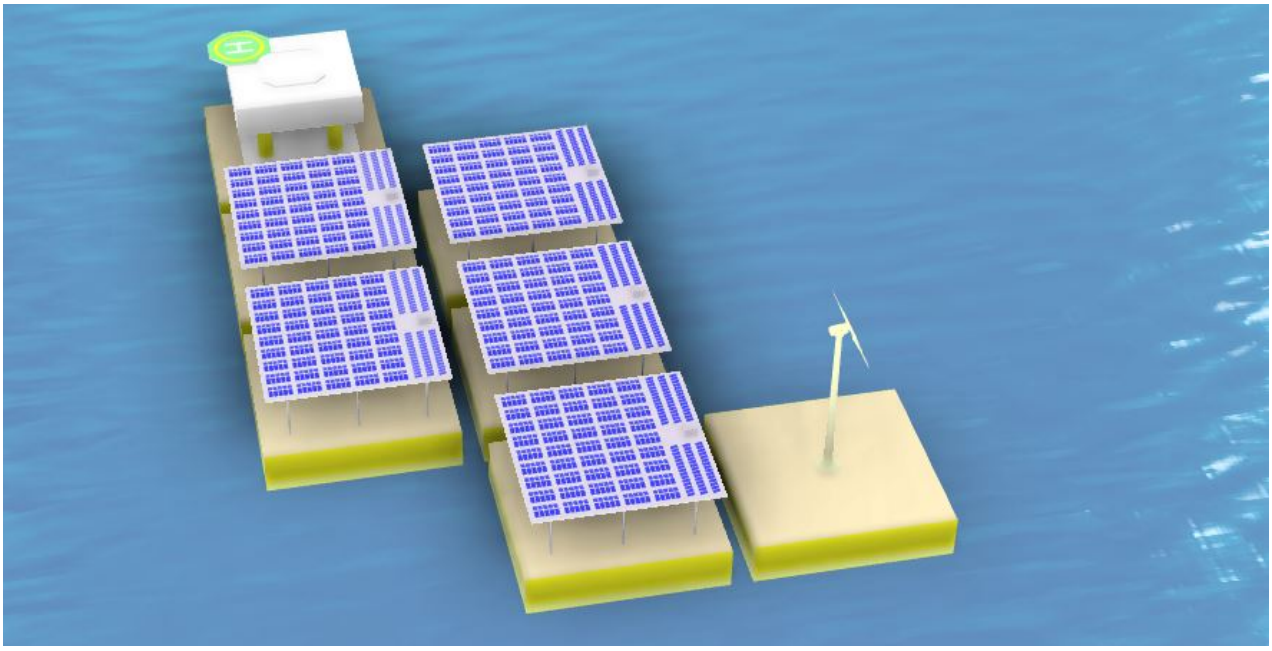

Figure 3-1: Visualisation of Energy@Sea hub [7]

3.1.1 Requirements

Weight [t] and distribution (45m)	superstructures O&M-hub 2,950tons
Deck loading [ton/m^2]	in average 3.25to/m² (loads are transmitted via outer and inner walls of the storage hall – average for the wall footprint 42.5 to/m²) wind turbine weight 32to, max. thrust 200KN, max. bending moment on tower base 7,689KNm (acc. to IEC 61400-2)
Centre of gravity [m, m, m]	[0,0,9.6] deck centre, 9,6m above deck area
# of (45m) floaters	1 - 3
Formation of floaters	single or in a row
Rigid connections needed [yes/no]	yes
Height of objects and locations [m]	top of glass dome 25m above deck area
Energy consumption	460.043 kWh
Energy generation	1.419.497 kWh
# of untrained inhabitants	0
# of trained inhabitants	per living block ~ 32
Transport of people and goods between floaters needed? [yes/no]	not significant only for O&M of the energy supply devices
Minimum required area per user [m^2]	12m² for the living module

Moored vessels length [m], beam [m], height about MSL [m], max draught [m], mass [t], location on island where moored, vessel routes around the island	CTV: 28.5m length, beam 7.5m, height 9m above MSL (radar mast), draught 1.2m, mass 127to mooring at the crane quay
Quay side length required [m]	40

3.1.2 Limiting Criteria

Max overall inclination [deg]	2 (living module) / 7 energy module
Max inclination angle between modules [deg]	2
Max draught difference between neighbouring modules [m]	-
Max acceleration in 6 degrees of freedom [m/s^2]	0.15m/s^2 (living module) / 2m/s^2 (energy module)
Max metres of green water on deck [m]	-

3.2 Living@Sea (WP7)

The Living@Sea application deals with all aspects of living on bord of a Space@Sea island configuration. The vision is to create a sustainable and safe city on water, considering the demands of the inhabitants and the environmental conditions. The superstructures of this applications consist of complete living quarters with trees, parks and sports grounds integrated as visualized in Figure 3-2.

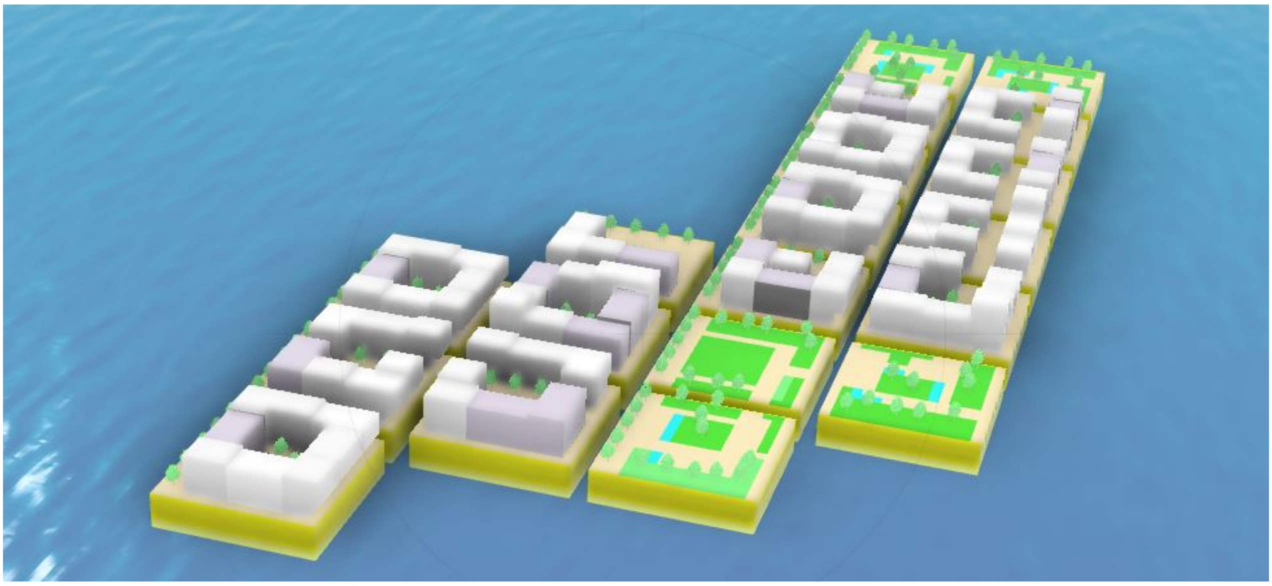

Figure 3-2: Visualisation of Living@Sea hub [7]

3.2.1 Requirements

Weight [t] and distribution (45m)	Depends on: - Built-up area on the platform - Nr of storeys - Type of functions - What variable loads are considered (and what safety margins applied) - Building materials and acoustic requirements Assuming 1) the space within the hull is excluded, 2) only quasi-permanent variable loads are taken into account and 3) at a space ratio of 1 (i.e. net internal floor area of all the storeys is equal to the gross area of the platform), the average weight will be 1.5 t/m² of deck space. If larger urban density would be allowed, this could go up to 2.5 t/ m² deck space Distribution: these loads will be focussed at the perimeter of the buildings. Local line loads can be 25 t/m Variable loads of people, water storage, goods, waste, systems, vehicles, snow, wind.
Deck loading [ton/m^2]	In addition to the above, maximum load from people is 5 kN/m² ≈ 0.5 t/m² (and a full car park weighs a lot less). Axle load of heavy vehicles < 20 t (10 t per wheel)
Centre of gravity [m, m, m]	Building can be designed to distribute weight relatively equally, but in vertical terms the centre of gravity will be about halfway the height of buildings (5 to 12 m above the deck)
# of (45m) floaters	1 to 1000
Formation of floaters	Large number of possibilities
Rigid connections needed [yes/no]	Yes, but depends on size of development and chosen mobility systems (can be No for certain parts).
Height of objects and locations [m]	Buildings: Max height = 24 m (6 storeys) Typical height: 16 m
Energy consumption	1600 kWh electricity and 600 m3 natural gas per person per year (or energy equivalent in electricity)
Energy generation	Heat production from people and appliances. Solar PV/thermal can be installed on roofs.
# of untrained inhabitants	100%
# of trained inhabitants	0%
Transport of people and goods between floaters needed? [yes/no]	Yes
Minimum required area per user [m^2]	Minimum residential: 25 m2 NIA (net internal area), but ideally 45 m2 NIA. Other functions (offices, retail, etc) would probably add 20% to 50% to the available residential space.
Moored vessels length [m], beam [m], height about MSL [m], max draught [m], mass [t], location on island where moored, vessel routes around the island	Passenger ships, large enough to navigate marine conditions For larger projects possibly a cruise ship?
Quay side length required [m]	50-100 m

3.2.2 Limiting Criteria

Max overall inclination [deg]	Intact stability criteria global inclinations: Formula max. inclination for floating residential areas: Max inclination $= \text{atan}(2* \frac{\text{freeboard}}{\text{platform length}})$ Most of the year a max. inclination for floating residential areas (floating city and workers living quarters) of 1 degree should not be exceeded for the serviceability limit state. (99% of the time (1% exceedance = 3.65 days per year)) Based on typical platform dimensions (freeboard<platform length/25), and in order to prevent deck wetness ('shipping green water'), a max of 5 degrees should rarely be exceeded. (e.g. 1/1000y exceedance) N.b. 5 degrees are also the limit for furniture toppling over and endangering disabled people (e.g. wheelchairs).
Max inclination angle between modules [deg]	Max vertical height difference between module edges: ideally only 10 mm. Larger vertical height differences can be accommodated by placing something over the gap (length can be chosen to keep inclination below 1 degree). Max size of this bridging element is ≈ 10 m. Assuming a max inclination of 1:20, this bridge could cope with height differences of up to 0.5 m
Max draught difference between neighbouring modules [m]	See previous item
Max acceleration in 6 degrees of freedom [m/s^2]	Vertical accelerations/heave motion (most important indicator for human comfort) Floating city Most of the year a max. RMS vertical acceleration of 0.15 m/s^2 in each octave band should not be exceeded for the serviceability limit state (99% of the time (1% exceedance = 3.65 days per year)) Workers island living area Most of the year a max. RMS vertical acceleration of 0.2 m/s^2 in each octave band should not be exceeded for the serviceability limit state (99% of the time (1% exceedance = 3.65 days per year source: *DS01) Horizontal accelerations/lateral motions (less relevant in terms of motion sickness, but important because of safety. Sources: ITTC, 1999; NORDFORSK, 1987) Floating city max. RMS horizontal acceleration: 0.03 g and 0.03 g/s (= 0.3 m/s2 and 0.3 m/s)

	(99% will keep balance without holding) Workers island living area max. RMS horizontal acceleration: 0.07 g (= 0.7 m/s2) (99% will keep balance without holding) Bridging element between platforms must withstand the vertical and lateral accelerations in the serviceability limit state.
Max metres of green water on deck [m]	0 m. In areas where it is anticipated it could be up to 1m as long as safety of people is ensured. A 1m water mass could easily knock someone over.

3.3 Farming@Sea (WP8)

The workpackage on Farming@Sea explores the options of aquaculture that benefit from a modular floating island. It considers the cultivation of fish, mussels seaweeds and microalgae in different types of culture systems. In Figure 3-3 below, an exemplary setup of microalgae reactors installed on the floating modules can be seen.

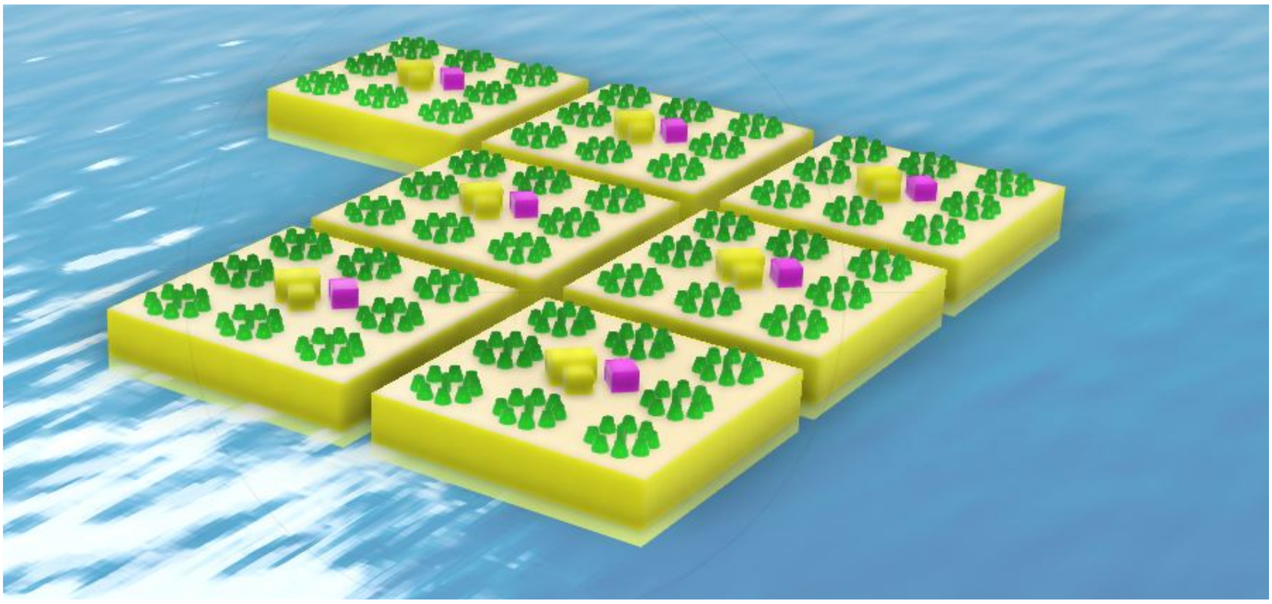

Figure 3-3: Visualisation of Farming@Sea hub [7]

3.3.1 Requirements

Weight [t] and distribution (45m)	Different for each module, depending on specific application
Deck loading [ton/m^2]	< 2
Centre of gravity [m, m, m]	
# of (45m) floaters	5-8
Formation of floaters	Outer borders, preferably in sheltered part
Rigid connections needed [yes/no]	Not necessarily
Height of objects and locations [m]	Less than 5 m
Energy consumption	Not clear yet, energy may be needed for pumping (water), water clearing, storage (freezing)
Energy generation	No

# of untrained inhabitants	0%
# of trained inhabitants	Not clear yet. Probably 5-20
Transport of people and goods between floaters needed? [yes/no]	Yes, also connections of pipelines and cables
Minimum required area per user [m^2]	Not clear
Moored vessels length [m], beam [m], height about MSL [m], max draught [m], mass [t], location on island where moored, vessel routes around the island	Relatively small vessels Mooring preferably at other modules (risk of entanglement with submerged aquaculture systems) Vessel routes away from aquaculture sites
Quay side length required [m]	Not important. 50 m is sufficient

3.3.2 Limiting Criteria

Max overall inclination [deg]	Unknown, but need to be kept low to avoid sloshing
Max inclination angle between modules [deg]	Unknown
Max draught difference between neighbouring modules [m]	1 m
Max acceleration in 6 degrees of freedom [m/s^2]	Unknown, but important to minimize sloshing
Max metres of green water on deck [m]	0

3.4 Transport&Logistics@Sea (WP9)

The goal of WP 9 was to demonstrate the feasibility of an offshore floating container transhipment terminal. An overview of the resulting Transport&Logistics Hub which contains a complete container terminal is provided below in Figure 3-4.

Figure 3-4: Visualisation of Transport&Logistics@Sea hub [7]

3.4.1 Requirements

Weight [t] and distribution (45m)	Unevenly and varying over time; Container storage module Type C features the highest loads: Total load per module Type C: 5035t (Maximum expectable for Port of Antwerps and largest capacity module Type C)
Deck loading [ton/m^2]	~5
Centre of gravity [m, m, m]	Varying, for quay modules the information
# of (45m) floaters	~200
Formation of floaters	See MEMO 12dec'19 send to WP3 and WP4
Rigid connections needed [yes/no]	Yes for quay side definitely, Preferred for storage modules (current design is accounting for flexible ones)
Height of objects and locations [m]	Storage modules: With wind barriers, 5 containers high =13m Without, 3 containers high = 8 m Cranes: RMG Type 5 (A): 10.2m RMG Type 8 (D): 23.7m STS Type 3 (J): 49.5m
Energy consumption	Unknown depends on operational profile
Energy generation	No
# of untrained inhabitants	0
# of trained inhabitants	100%
Transport of people and goods between floaters needed? [yes/no]	Yes Transport of containers between storage floaters = automated
Minimum required area per user [m^2]	Not significant
Moored vessels length [m], beam [m], height about MSL [m], max draught [m], mass [t], location on island where moored, vessel routes around the island	For UCLV Class vessels: up to 400m length, 60m beam, 12m draught. See mooring location below
Quay side length required [m]	895 m Ocean quay for up to 2 ultra large container-carrier vessels (ULCV) and a 645 m Inland quay reserved for several hinterland connection vessels

3.4.2 Limiting Criteria

Max overall inclination [deg]	1 deg (due to dynamic motion= 0.5 deg up or down) Extra Static inclination of 1 deg is acceptable
Max inclination angle between modules [deg]	2 deg
Max draught difference between neighbouring modules [m]	1 m
Max acceleration in 6 degrees of freedom [m/s^2]	For Ship to Shore (STS) cranes: Maximum operation limit 1 m/s^2 at trolley height in trolley ride direction. Perpendicular to the trolley ride direction 0.5 m/s^2.
Max metres of green water on deck [m]	0

4. Conclusion

At the beginning of the Space@Sea project, requirements of the four application WPs 6-9 (Energy@Sea, Living@Sea, Farming@Sea and Transport&Logistics@Sea) have been gathered [1]. At that stage, the degrees of freedom were still extensive, such as the module shape has not been defined. The formulation of requirements was a valuable tool to iterate which parameters are of importance for which application. After certain parameters such as shape, size, connection and mooring have been fixed, it became necessary to reassess the applications' requirements. These were updated and new requirements were added and recorded in a living document [2]. This report contains the final information and can function as a basis for future development work. The table below provides an overview of selected requirements that can be concluded from the input gathered from all the applications. One valuable result of this report is, that the deckload of all applications is around 1.5 t/m², however if feasible 2.5 t/m² are desired by some applications. Another outcome is the definite requirement for rigid connectors between the modules – an issue that has been thoroughly addressed in other work packages. The required quay length is in the same magnitude as the module side length except for the Transport&Logistics application, which needs to moor large container vessels and therefor absolutely requires the rigid connectors.

Weight / Deckload	1.5 - 2.5 t/m²	On average; line loads from buildings or cranes can be higher
Center of gravity above deck	5 - 12 m	
# of floaters per application	-	heavily dependent on scope of each application
Formation of floaters	-	heavily dependent on scope of each application
Requirement for rigid connectors	Yes	
Max. height of superstructures	49.5 m / 25 m	Highest point of crane / max. height of buildings
# of untrained inhabitants	0 - 100%	all inhabitants of the living application are considered untrained; all other applications have only trained personnel
Transport between modules required	yes	
Min. required area per inhabitant	12 - 45 m²	12 m² for professional personnel; 25-45 m² for living inhabitants
Moored vessel length	28.5 m / 400 m	CTV vessels / UCLV; Passenger ships and cruise ships somewhere in between
Required quay length	50 m / 450 m (895 m)	Energyhub; Living; Farming / Transport&Logistics (895 m desired for two ULCV)

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