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D.6.1

Technology Roadmap of the GROOM RI

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Deliverable abstract & Executive Summary

The RI landscape and the world have dramatically changed in the last five years; nowadays, the EU is pushing to consolidate RIs, and there is a significant trend to decarbonise those research infrastructures. The technology framework for the future GROOM RI has been developed during this constant change. Being at the Design Study stage means that the GROOM RI framework will evolve in the next phases of the implementation, with the refinement of the developed design and adaptation to the evolving landscape. The GROOM RI Technology Framework has been designed with all these subtleties in mind, offering a fit-to-purpose yet generic framework for Ocean Observing RIs. This framework provides a clear path into the future that justifies the existence of GROOM RI. It is modular and constructed piece by piece by the future GROOM RI in close collaboration with the rest of the Ocean Observing RIs.

The framework clearly articulates four pillars (programme management, data management, operations at base and operations at sea) and two horizontal workstreams (best practices and cyberinfrastructure) that apply to all the current RIs doing ocean observing (Euro-Argo, EMSO, EMBRC or ICOS) or to RI-type organisations (EuroFleets, WMO or Jerico). The technical framework contains parts currently at different maturity levels; part of the data management and operations at base and sea are partly mature, and most effort around them must be focused in the horizontal workstreams, particularly in generating solid and FAIR best practices. However, the programme management and the piloting component of the operations at sea are still in their infancy; they will require significant effort and investment in creating agreed specifications and cyberinfrastructure to fulfil the vision.

Nowadays, it is clear that adopting Maritime Autonomous Systems at scale to do Ocean Observing is not a discussion but a matter of when it will happen. To allow this transition, a solid framework is required to coordinate, operate and produce high-quality data with those platforms, complementing and amplifying current, more traditional approaches. This document describes:

- A framework is to be developed by the GROOM RI to facilitate and unify MAS operations across the entire Ocean Observing RI landscape.
- The different tasks done in WP6 that have led to the development of the Framework.
- How the future GROOM RI framework interacts with some of the key marine observing RIs.

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Argo	Scientific international programme for ocean observation using a fleet of robots
ASV	Autonomous Surface Vehicle
AUV	Autonomous Underwater Vehicle
EC	European Commission
EECP	European Cluster Collaboration Platform
EMBRC	European Marine Biological Resource Centre
EMODnet	European Marine Observation and Data Network
EMSO	European Multidisciplinary Seafloor and water column Observatory
EOOS	European Ocean Observing System
EuroArgo	European contribution to the Argo Programme
GERI	Glider European Research Infrastructure
GOOS	Global Ocean Observing System
IOC	Intergovernmental Oceanographic Commission
IMOS	Integrated Marine Observing System
IOOS	Integrated Ocean Observing System
JCOMM	Joint Technical Commission for Oceanography and Marine Meteorology
JERICO	Joint European Research Infrastructure of Coastal Observatories: Science, Service, Sustainability
MRI	Marine Research Institute
MS	Member States
OCG	Observations Coordination Group
R&D	Research & Development
SME	Small and Medium Enterprise
WP	Work Package

1. Background and context

Oceanographic organisations require considerable engineering know-how, physical facilities and cyberinfrastructure to deploy and operate gliders and other MAS. Developing and maintaining such facilities and capacities requires significant funding and stability to retain personnel. There are good European examples of facilities that have accomplished a stable status and are operating MAS consistently. Still, for each one of those success stories, there is at least one, if not many, other facility that has yet to achieve such status, just operating gliders sporadically and not having a core stable group of dedicated personnel, while the activities of some groups simply collapsed because of lack of funding or personnel issues. A European research infrastructure aspiring to improve this situation must provide a well-thought-out and consistent technical framework to enable operators of gliders and other MAS to improve operations.

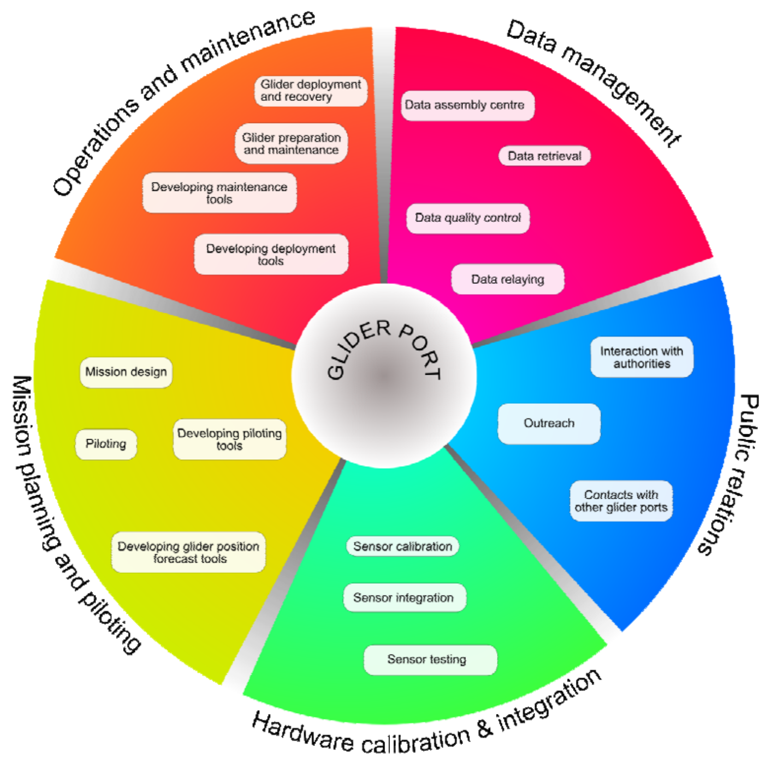


Figure 1 - FP7 GROOM Gliderport concept

Conceptually, the ground facilities can have five different areas ("operations and maintenance", "data management, "public relations", "hardware calibration & integration", and "mission planning and piloting"), this is a mixture of physical facilities, cyber infrastructure and services that a Gliderport can offer, but each Gliderport has different levels of completeness.

The FP7 GROOM project grouped and detailed technical activities and facilities under deliverable 5.1, coming up with the concept of Gliderport (Figure 1); a Gliderport was considered a network node that could host any of the technical parts described in the diagram. It was envisioned that Gliderports would be of multiple sizes and include different capabilities, but it wasn't the intention to imply the Gliderport would have all the capabilities. The concept of the Gliderport was also closely tied to physical infrastructure, which is understandable considering that at that moment, multiple glider facilities were being created in Europe, with intense activity on procuring hardware and building physical spaces to prepare and operate gliders, the GROOM FP7 described the observing components of those facilities. GROOM II faces an entirely different landscape; many facilities have reached good levels of maturity, like SOCIB and PLOCAN in Spain, the University of Bergen in Norway, the Voice of the Ocean Swedish charity or the UK National Marine Facilities working with multiple UK mature facilities (the Scottish Association of Marine Sciences, the University of East Anglia and the British Antarctic Survey among others). Still, we have even seen the most prominent facility at the time of the FP7, the French Parc Nationale de Gliders based at DT-INSU, cease activities, with France returning to a smaller facilities approach. The Gliderport concept is still valid today, but times have changed, and the GROOM II design study must propose a technical framework to complement the Gliderport concept and give operational cohesion between the different infrastructure nodes[1].

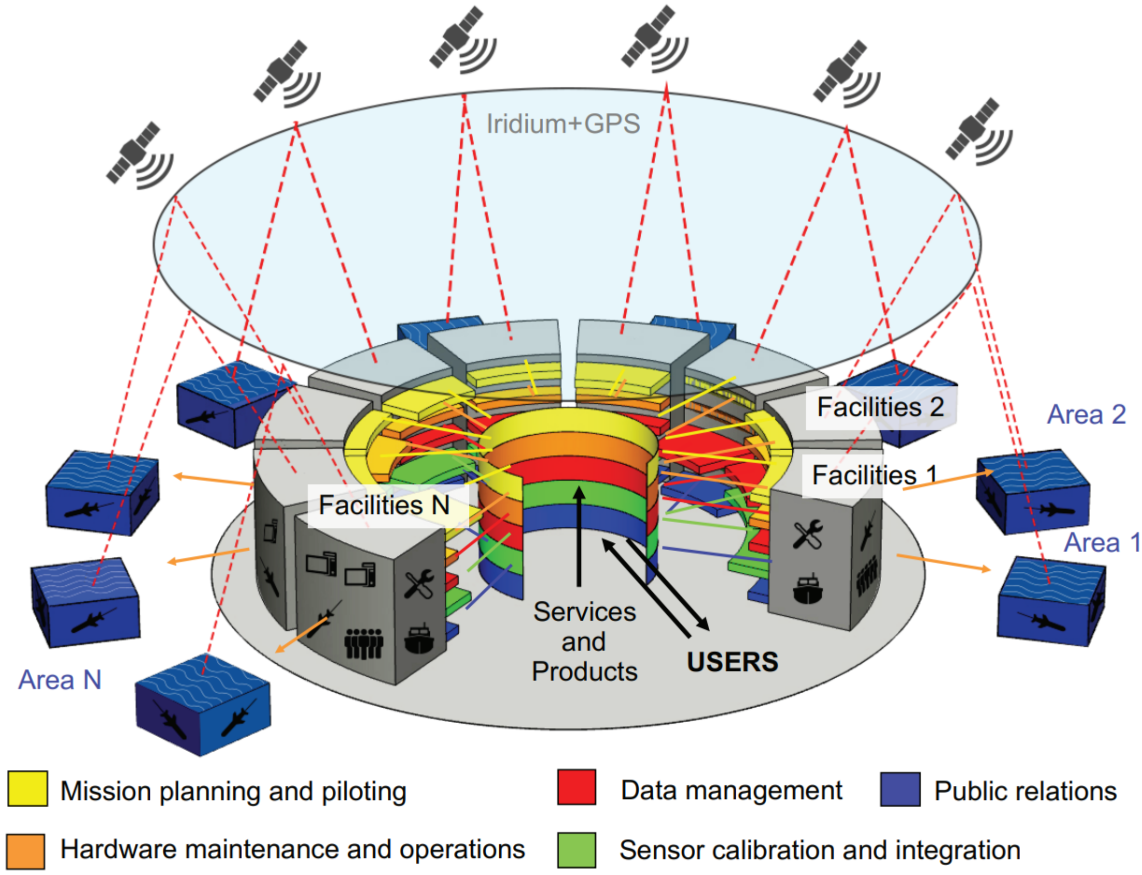


Figure 2 - FP7 GROOM Concept of a distributed RI. This concept serves as the design's starting point

ESFRI defines a distributed RI as consisting of a Central Hub and interlinked National Nodes[2]. Still, ESFRI does not define in much detail the technical attributions of that type of RI beyond a "*high level of integration of the National Nodes*". It was clear by the time of the FP7 that a future GROOM RI must be distributed as it would be politically very complex to have a central facility buying and operating gliders for all the nodes. This distributed nature is one of GROOM RI's most significant challenges as it is complex to integrate nodes of different sizes and levels of maturity, but at the same time, it is a strength that will build resilience and a very big spatial coverage. The future GROOM RI will provide digital and physical infrastructure services to the RI partners and external users. The *nodes* will provide services requiring physical infrastructure. To add value, a

[1] From here on, we will refer to the different facilities in the future GROOM RI as nodes and not Gliderports as we believe this terminology is more inclusive as there can be nodes that are not gliderports as they won't host any gliders or other MAS. Examples of this are the data assembly centers like Coriolis.
[2] https://www.esfri.eu/sites/default/files/ESFRI_Roadmap2021_Public_Guide_Public.pdf

central HUB (Figure 3) will develop and host digital infrastructure to provide coordination services, allow for interoperability within the partners, and facilitate a rapid, "no fuss" flow of operations among organisations within and across operations and projects. The central HUB must coordinate these activities as most individual nodes don't have the size required to develop extensive software infrastructure.

GROOM RI aspires to reduce friction points in designing, planning, and executing data collection operations with MAS, as well as data storage, standardisation, and analytics. This encompasses the following:

1. Increase the visibility and availability of autonomous assets and the human resources to perform activities with those assets across Europe.
2. Allow mission planning that is easy to share and interpret by all partners involved in operations and during all phases of those operations (project proposal, …)
3. Enable shared execution of operations through the usage of common best practices.
4. Facilitate the seamless data flow from the robotic assets to the consumers, helping to integrate new data sources (sensors) into the well-established European data infrastructures.
5. Coordinate & develop digital services to provide the previous activities while maintaining the supporting cyberinfrastructure.

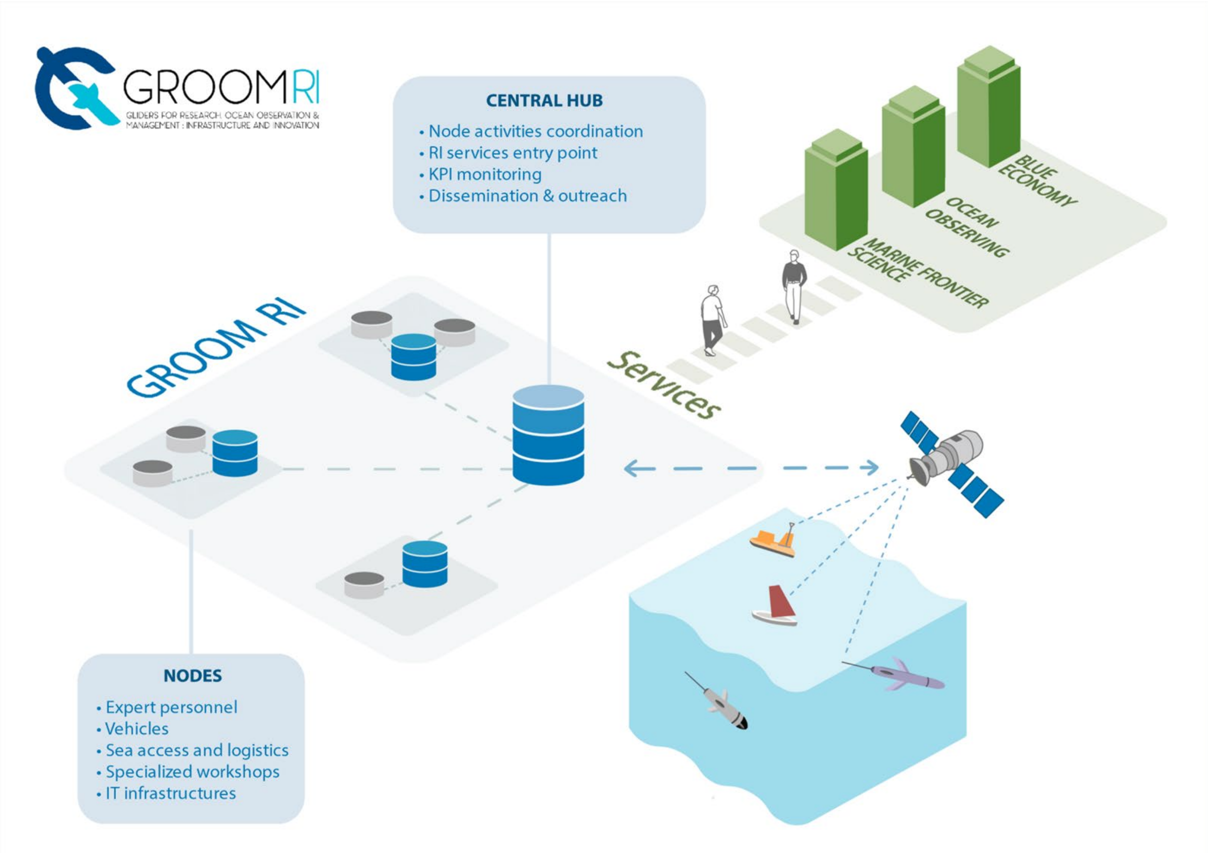
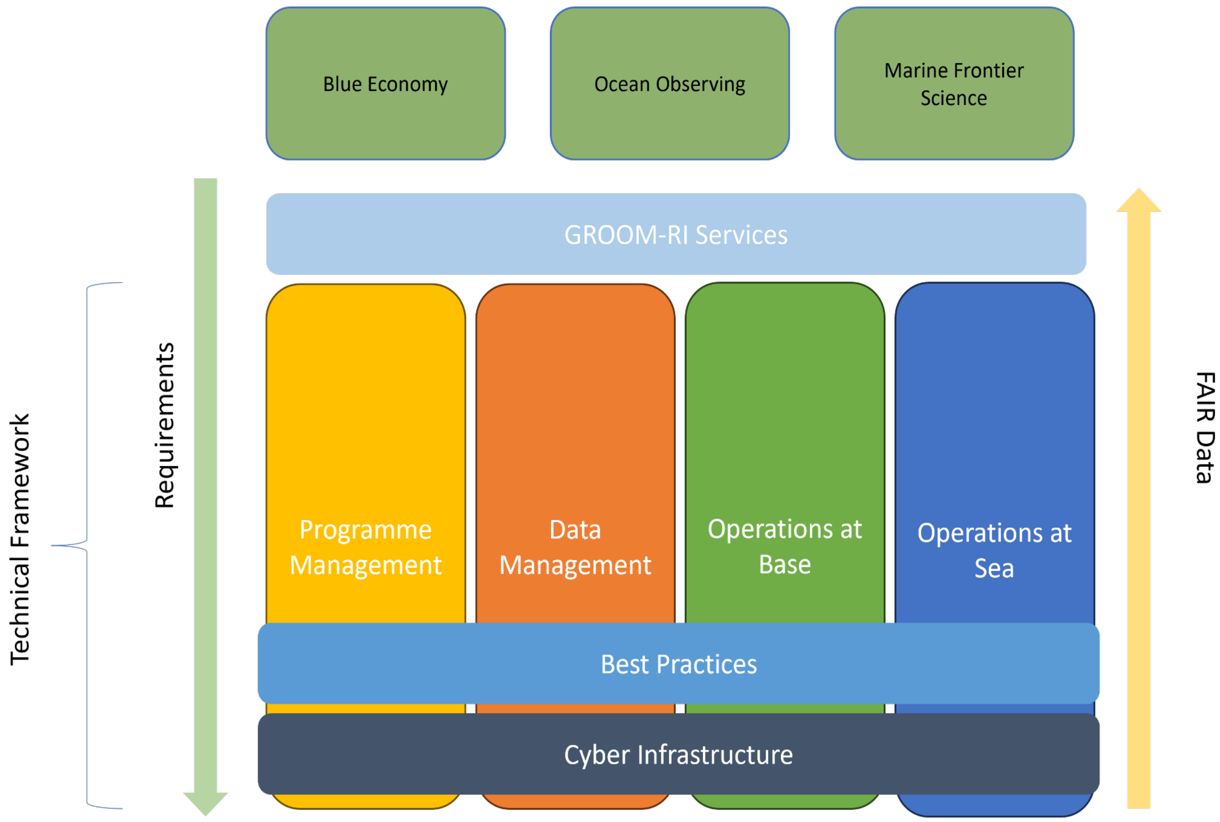


Figure 3 - GROOM II Distributed design

The future GROOM RI will be a federation of facilities or nodes with a central HUB that provides centralised services to the nodes and external users. The central HUB serves as a layer that provides consistency to external users.

2. The Technical Framework

The objective of GROOM II WP6 is to design tools that will give the future GROOM RI the capabilities to deliver its ambitious mission and vision through several services to several stakeholders. The framework comprises four pillars: programme management, data management, operations at base and operations at sea, and two horizontal workstreams: best practices and cyber infrastructure.



The GROOM RI technical framework is built with four pillars mapping to key activities for the lifecycle of MAS operations and two horizontal cross-cutting workstreams, cyberinfrastructure and best practices to bring coherence to those activities. The GROOM RI services will be built on top of this technical structure, taking user requirements and generating FAIR data. The framework modularity should help to distribute activities across different nodes and facilities.

The GROOM RI will provide services that consider the stakeholders' requirements and provide FAIR data. The technical framework will drive this process.

To bring cohesion across the four pillars, the technical framework has two horizontal workstreams:

- Cyberinfrastructure (D6.2 and D6.4). Automating and creating software and cyberinfrastructure to formalise all the activities will be essential for GROOM RI's operation. GROOM RI will not receive requests using Word documents through emails but offers interactive portals and tools. These could be developed for the RI or as part of emerging operation planning platforms.
- Best practices (D6.3). A GROOM RI endorsement process will ensure the use of best practices to deliver all the activities, services and data in a reproducible way. GROOM RI will not do this in isolation. Still, it will work and coordinate with other European Infrastructure initiatives and

Figure 4 - The GROOM RI technical framework

international coordination initiatives, such as the IOC-Ocean Best Practices System (IOC-OBPS) project and the global underwater glider coordination group OceanGliders. GitHub and other community-driven tools will also be considered to avoid work replication. GROOM RI will contribute to all these communities by endorsing existing practices or creating new best practices, such as the practices in the GROOM toolbox that all the GROOM RI partners will follow to deliver GROOM RI services.

While the two horizontal workstreams will provide common tools, the four pillars are the activities that will use those tools to deliver the service.

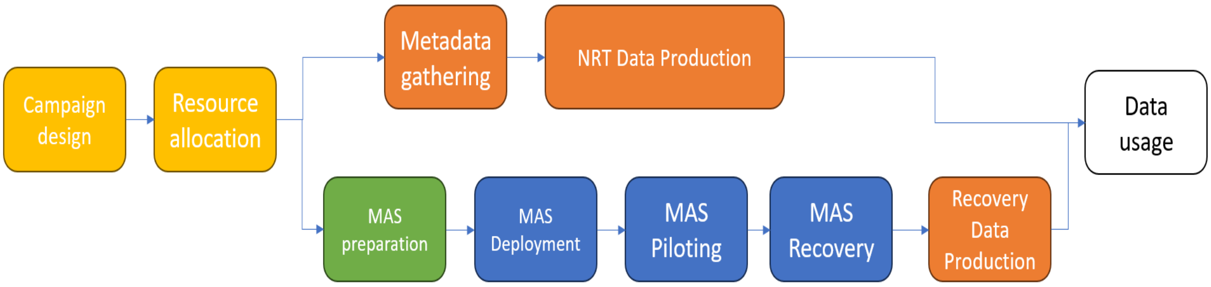


Figure 5 - The MAS Workflow

The activities needed around MAS operations match the framework pillars

In parallel and complementing the framework, an operation MAS-Workflow has been modelled (Figure 5); this workflow captures the MAS operations lifecycle and matches each step with the pillars through the colours used in Figure 4. This is important as it showcases the activities the technical framework will focus on. Any operation starts with the campaign design and allocation of resources. These activities are **programme management**, and having a GROOM RI coordinating resources across the RI will allow better utilisation of resources, coordinating the nodes to enable them to share underutilised resources. The activities that involve hardware; preparation, deployment, piloting, and recovery are pretty mature, with multiple operators having considerable expertise within the boundaries of a future GROOM RI. There are already some initiatives around best practices that involve numerous operators, but there is still plenty to do. A future GROOM RI with dedicated resources and a focus on the nodes to adopt and use best practices in all these areas will be a transformative effort across Europe. These activities map with the **operations at base and at sea.** Finally, in parallel to many of these activities are the **data management** activities; these activities are the more mature and formalised of the entire framework as they have been performed and developed for years in multiple European projects, but even with this in mind, a future RI will enable those activities to thrive.

The GROOM RI is highly modular, allowing the distribution of the different components in the nodes at different maturity levels. Figure 6 shows a hypothetical GROOM RI distributed among the partners within the GROOM II project. The RI will provide unified services, as shown in Figure 2, but in this case, those services are underpinned by the different nodes; there is a central node with a larger orange block representing the project management; this is to aggregate the different resources and services declared by individual nodes and provide coordination and access to users of the infrastructure. Then, the different nodes show bars with the same colours as Figure 2 but different sizes, aiming to represent each node's different levels of maturity or development. This diagram does not seek to describe the current capabilities fully but to showcase how the system will work once implemented, being inclusive and not forcing any node to develop or implement the framework, allowing nodes of different sizes to work together. The diagram even represents specialist nodes that will not implement or adopt many technical framework components. The example we show here is Coriolis which is the GDAC for underwater gliders; Coriolis will always just provide data management services to other nodes and users. Adopting common best practices and cyberinfrastructure will allow the different nodes to implement the four pillars and provide consistency as a unified RI.

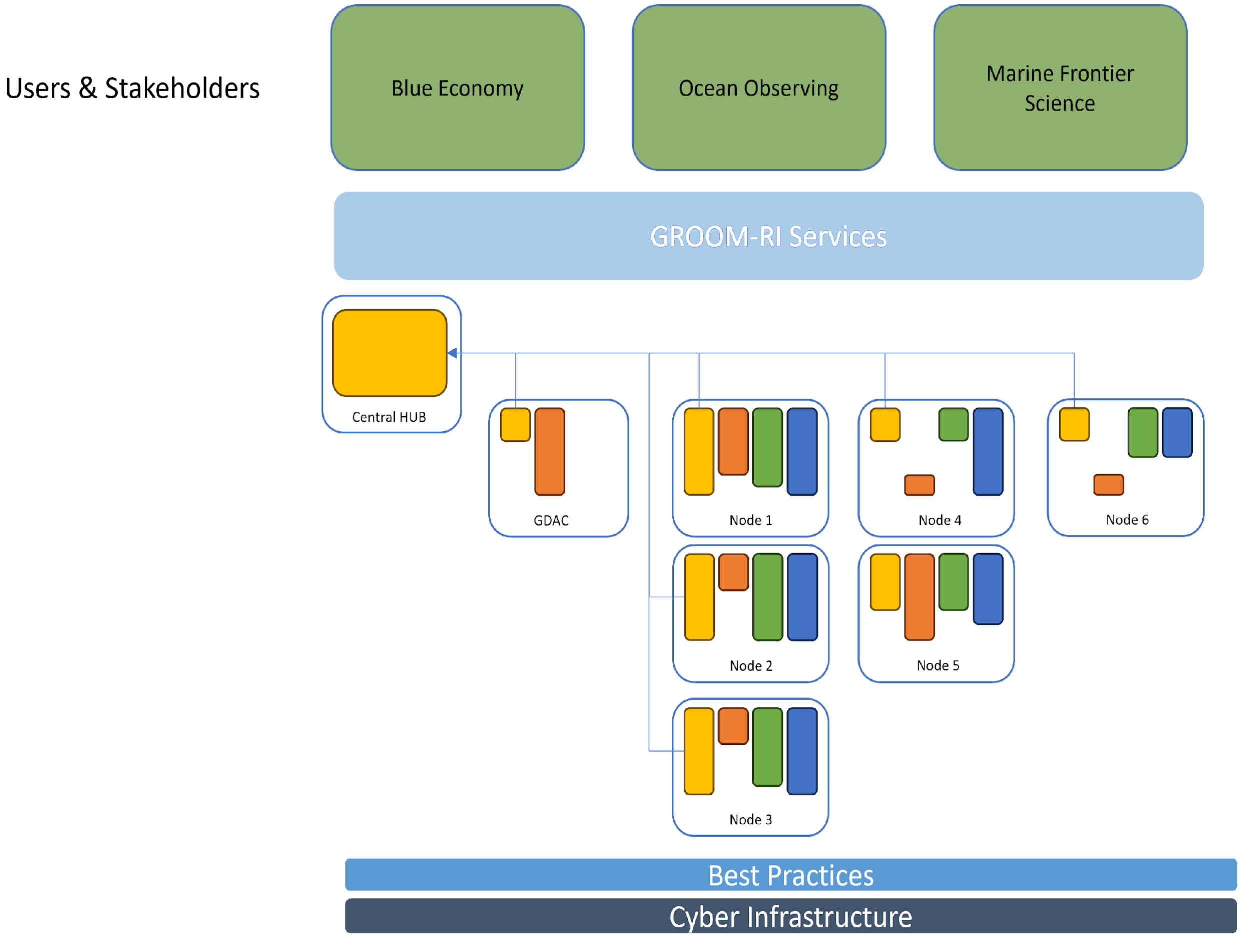


Figure 6 - Technical framework assembly

The design considers the future GROOM RI distributed nature. Hence, it has been designed to allow the partial implementation of the framework by the nodes. Here, we are trying to convey that delivering the GROOM RI services will be done through the aggregated capabilities of the different nodes; some of the nodes will be more developed in some pillars than others, with some even becoming specialists (the central HUB or data management node). The horizontal workstreams will be provided across all nodes, bringing consistency, with most of the activity happening in the central box as the catalyst and coordinator of those workstreams.

3. Programme management

3.1. THE GROOM RI DIGITAL ECOSYSTEM

The GROOM access policy (D2.1) highlights the role of the future GROOM RI in coordinating MAS operations. While this is something that other marine RIs try to do, the GROOM RI approach is much more technological, recommending the deployment of online tools to allow GROOM RI partners to declare resources and the GROOM RI central node to visualise and coordinate those resources. Please refer to D2.1 to go into the recommendations. The tool used by GROOM RI (potentially the MFP) will allow nodes to register the resources to be shared, including MAS services, physical facilities, physical devices, calibration facilities, data management, sensor integration or sensor calibration.

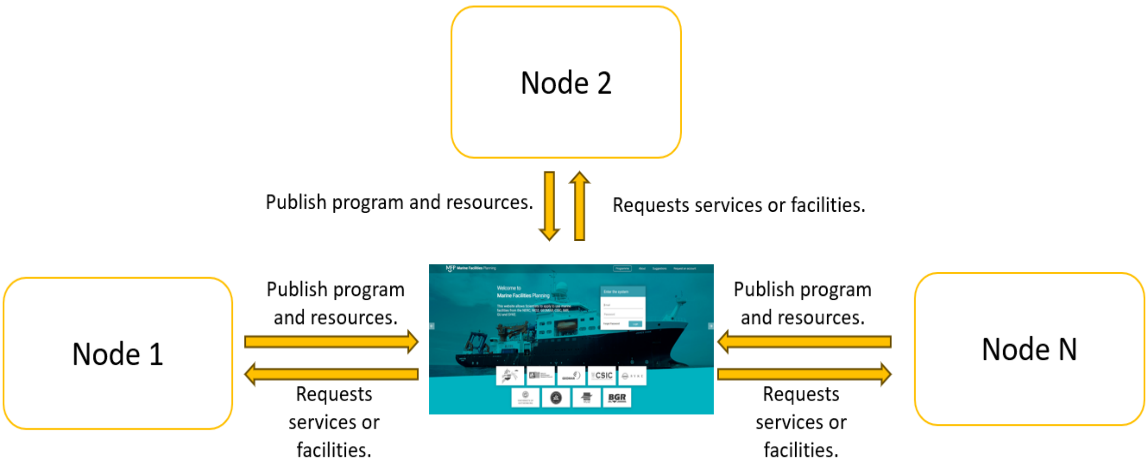


Figure 7 - The GROOM RI Programme management

The nodes publish their programs and available resources to be offered through GROOM into the central HUB. The Central HUB requests the availability of services for users. The nodes shown in the figure are for illustrative purposes. All the nodes will implement this workflow.

The significant improvement that GROOM seeks is to develop a fully interoperable digital ecosystem to enable program management at scale, with different RIs and RI nodes sharing their operations and advertising which resources they want to share. This is a revolutionary vision as currently, each RI does planning on isolation, with most needing central tools to understand the availability of resources.

3.2. THE GROOM RI AND PHYSICAL FACILITIES

The FP7 GROOM D5.1 described the physical facilities necessary in a Gliderport, describing in detail the glider maintenance laboratory and the hardware required to run it. The list described in the FP7 deliverable has remained the very constant, with some facilities including Uncrewed Surface Vehicles (USVs); hence, we consider that description quite valuable today. The big difference nowadays is the maturity of the teams running those facilities; most groups have tight procedures to perform refurbishment processes, and while those procedures remain siloed into organisations, there are similarities between them. To bring consistency to the future GROOM RI, the different groups that are part of the RI will need to submit their procedures to be endorsed; some will become part of the Ocean Best Practices endorsed by GROOM RI, and some others will remain just GROOM RI-endorsed practices. In either case, it is expected that when conducting RI operations, the nodes will have to follow or adopt any GROOM RI-endorsed practices, bringing consistency to lab work. This is covered under the green block of the diagrams shown in the previous section (Operations at base).

The shared usage of physical resources is one of GROOM RI's aspirations, allowing partners to be more efficient in sharing resources across the network, but sharing access to physical equipment is not trivial as it requires:

1. A way of advertising the availability of sensors, lab equipment and facilities.
2. A mechanism to book the facility's equipment from different nodes/Gliderports.
3. A way to track where the physical items are.
4. A way to deal with liability and insurance.

We propose to cover this under the umbrella of access (D2.1) and its counterpart in the technical framework and programme management. GROOM will develop tools integrated within the access to enable the nodes/Gliderports to register the sensors, lab equipment, and facilities they want to share, offering a dynamic online catalogue in which to find and book physical resources. GROOM involvement will end when the user or facility asks for equipment or services, and the providers will engage with them; it will be up to the two of them to agree on the lease terms (for physical devices) and organise the logistics.

4. Data management

Data management is a crucial activity of any RI. The GROOM FP7 significantly impacted how Glider data management is done. GROOM RI will consider data management as a critical activity in delivering services. Deliverable 6.2 offers a detailed roadmap for data management. Still, one of the critical things that GROOM RI will push is to increase the sustainability of data management activities, factor the costs into GROOM RI activities, and take a very technological approach to deploy effective workflows using best practices.

GROOM II has a dedicated task around data management and we have a data management deliverable (D6.2) describing the current state of Glider and other MAS data management. Moreover, we propose a Data management Roadmap for the next ten years (see Figure 8).

Roadmap — GROOM II — CHECK OUR DETAILED ROADMAP HERE

Research Infrastructure data management	1-2 years	5 years	10 years
Infrastructure	• Proposed structure for future developement (cloud-native services & open-source community development) • International agreement • Define the data portal's scope	• Operational exemplars of DAC & GDAC managed whith open-source community & deployed in EOSC • Tools and services aligned with international policies • Operational data portal	• Open source solutions for DAC & GDAC management (OceanGliders community) • Unambiguous and seamless data flows
Tools and services	• Scoping of FAIR data • Meeting with OceanGliders 1.0 format • Data visualisation requirements • WIS 2.0 - BUFR implementation • RTQC consensus on standard tests • Integration data methodologies into OBS framework	• FAIR data alignment with IOC data policy • Data visualisation and user interface for priority • WIS 2.0 - BUFR implemented • RTQC - standard tools • DMQC - 1-2 EOVs + cloud native tools • Alignment and publication of data methodologies whit OBS framework	• Data visualisation and user interface to meet the diverse range of users • RTQC- Operational BGC RTQC • DMQC - 90% of observed EOVs allowing for new ones to come through + cloud native tools • Sustainable & efficient route for new EOVs
Network management	• Agreement of the scope of MAS • Scope tools to harmonize metadata management & planning tools for EOOS observations	• Sensor and platform metadata integrated into the EOOS • Complete vocabulary collections • Agreement of the scope of MAS • Tools to harmonize metada management & planning tools for observations accross marine RI	• Planning and network management integrated in the EOOS • Globally recognised processes to entrain new sensors and platforms
Network evolution	• New networking groups on emerging sensors and platforms • Scope processes to entrain new sensors and capabilities	• Process to entrain new sensors and capabilities as part of wider OG activity	• Globally recognised processes to entrain new sensors and platforms
Skills and training	• Data skills audit	• Training courses on the gaps in data skills	• Training network and activities
The GROOM RI user community	• Define the user community	• Establish coordination groups and committees	• Sustainable data user community

Figure 8 - The GROOM data management Roadmap for the next ten years

The roadmap is divided into six categories and has been developed as a generic roadmap.

5. Operations at base

Operations at the base are all physical activities around the platforms between deployments. These operations can include vehicle refurbishment, sensor calibration, or sensor integration. All the institutions operating gliders and other MAS traditionally perform these activities. However, consistency across the nodes is challenging to solve from an RI angle.

We can summarise the operations at the base in the following activities:

- MAS refurbishment and preparation involves all activities required to prepare the MAS platforms for an optimal state to be deployed.
- Sensor calibrations, either in-house or sent to a calibration facility
- Sensor integration, if new sensors are required for operations.
- Transports: Sometimes, the platforms must be moved around facilities for refurbishment or calibration or deployed in different parts of the planet.

Each facility currently performs all these activities, and there needs to be more consistency across them; for example, while NOC, GEOMAR or HCMR will all refurbish their gliders and operate them, they are not guaranteed to be prepared for the same specifications. If the GROOM RI wants to provide consistent datasets, all the platforms and sensors must be ready to be equivalent to the accepted levels by all the GROOM RI partners and the user community. This is the role of the GROOM-RI Best Practices described in D6.3. The best practices are a horizontal workstream that brings consistency, and having GROOM RI endorse best practices around the areas of operations at base will provide the needed consistency.

6. Operations at sea

Deploying and operating gliders and other MAS are central activities as they require resources to go to sea and to keep operating the platforms once deployed. There are several areas where the GROOM RI will make significant contributions to improve the current state:

- As in previous points, having endorsed and agreed on best practices for the deployment and operation of MAS will provide consistency in the data delivery and certainty to field and remote operators on what to do at any stage.
- Regarding piloting tools and automation, GROOM II has dedicated two tasks and one deliverable (D6.4) to studying the matter. GROOM II is designing an ambitious open cyberinfrastructure and software ecosystem to improve the current landscape.
- Programme management is the framework's first pillar. It will improve operations at sea, optimise resources within the network, and potentially help with cross-node piloting, as organisations can offer and request those resources. The same can be said about sharing cyber resources like proprietary control stations. We discuss briefly the benefits and issues of central iridium purchasing in D6.4.

7. The Cyber Infrastructure

One of the main novel approaches of the technical framework is the transversal Cyber Infrastructure; other RIs (EMSO, EuroArgo, etc.) or proto RIs (Jerico) have designed cyber infrastructures for data delivery to serve their communities, which is very valuable. While considering these developments and designs, GROOM RI will have to adapt because the Data Management roadmap takes a more distributed angle, working with different actors across the landscape to develop data infrastructure for MAS. The GROOM RI will be crucial in creating data infrastructure and engaging and leveraging multiple EU and international initiatives to advance roadmap development. Second, GROOM RI will focus on cyberinfrastructure that no RI is currently developing: tools to allow program management (like the MFP) and tools to improve the piloting through better user interfaces and automation, as shown in D6.4. Once the digital infrastructure starts to grow, creating a real digital ecosystem, the integration of more and more tools to help with operations at the base can be considered; some of such tools can help to store and report faults across the RI to analyse hardware performance or automation of part of the lab-based diagnostics.

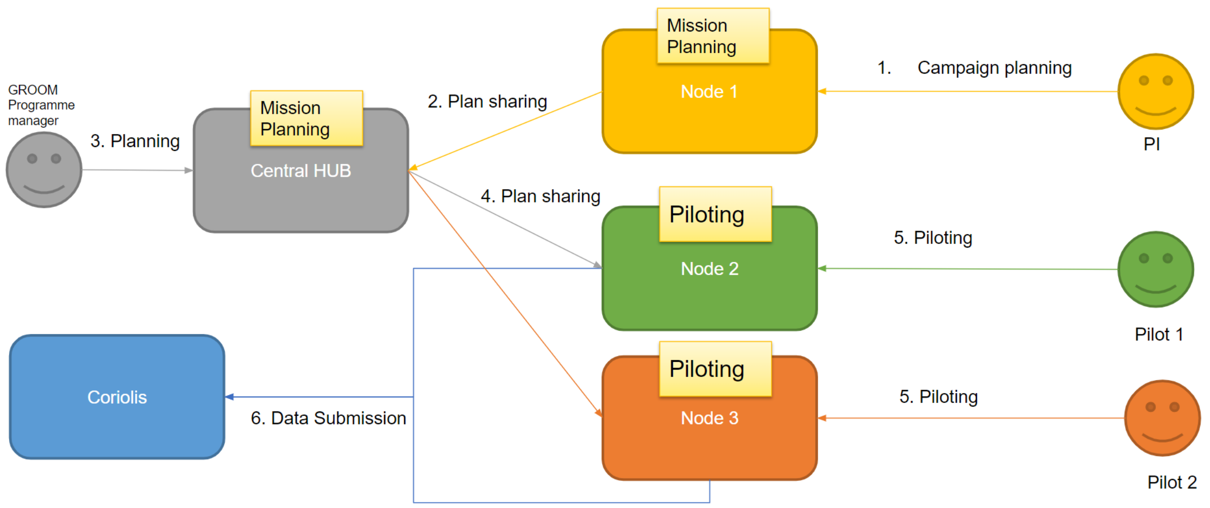


Figure 9 - Example of the type of workflow the GROOM RI Technical Framework and Cyberinfrastructure will enable:

Distributed operations with the planning happening in a node, then the central node will find the partners to operate the MAS and share the plans with them, with the data centre connected to the entire operation. The step change that GROOM RI will provide is the creation of machine-to-machine interfaces in each step, allowing the automation of processes. This example does not include the activities of deploying and refurbishing the MAS and aims just to showcase the conceptual mission planning and operation.

The GROOM RI cyberinfrastructure will build on the software best practices in developing distributed systems and modular, independently deployable, and interoperable systems. GROOM RI may or may not manage some of these systems; for example, all the data-related subsystems can be co-developed with the member's DACs and GDACs. The member's DACs can then deploy them permanently as part of their infrastructure, and GROOM RI may just deploy them ad-hoc based on operations or services. The architecture includes the Autonomy Framework, better described under D6.4, but a key component is the Communications Backbone, which enables standardised communications between the different components in the Cyber Infrastructure. For more details, please read D6.4.

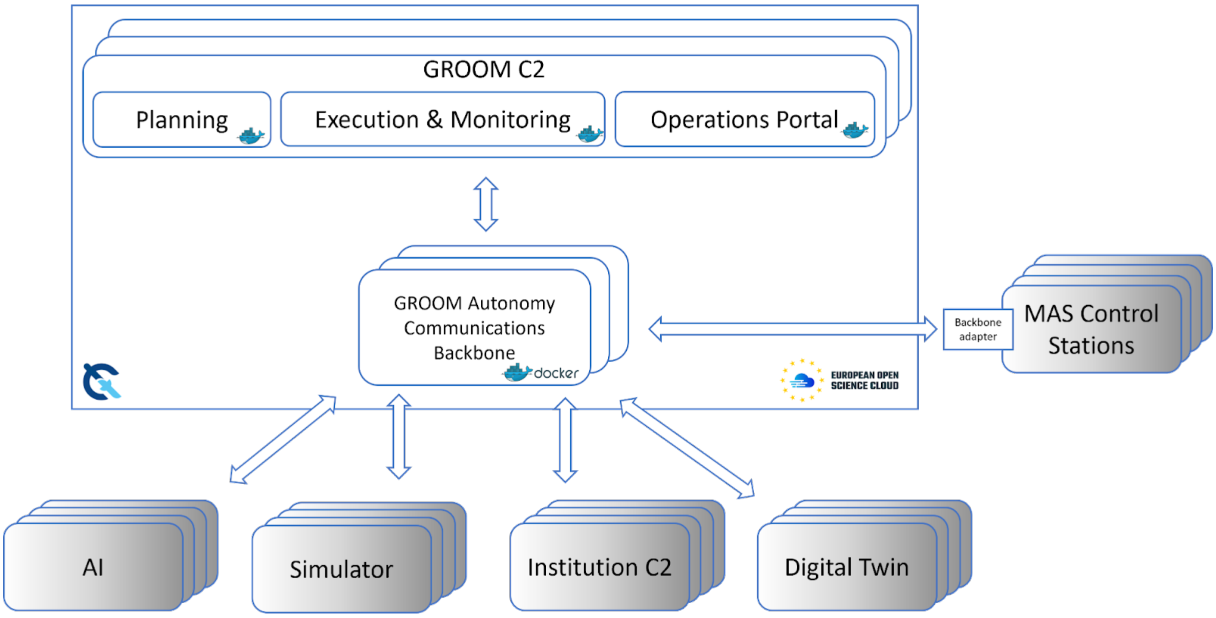


Figure 10 - GROOM RI Autonomy Ecosystem Architecture

It envisions a series of systems (in the middle) developed by the GROOM RI partners, which provide piloting tools and facilitate integration with other systems developed and maintained outside of the RI (grey boxes).

This approach allows us to fulfil the version of the FP7 GROOM design, with the Cyberinfrastructure deployed on any of the nodes or even outside of the GROOM RI. GROOM will significantly contribute to the European and international landscape, filling a void as an infrastructure provider.

The technical framework, particularly the cyberinfrastructure, will complement other RIs (or future RIs). Connections with Copernicus, Eurofleets, EMSO, EuroArgo, and Jerico highlight complementarities and differences.

7.1. Links with Euro-Argo ERIC

EuroArgo is the European contribution to the international ARGO program. ARGO is one of the most successful observing systems, and EuroArgo represents the footprint for marine European RIs. EuroArgo and GROOM are highly complementary; gliders and long-range underwater MAS are ideal for bridging the gap where Argo data becomes complex to obtain, for example, when approaching the shallowing continental margins. There are also operational synergies between ARGO and GROOM that, if capitalised, will bring efficiencies into the system, commonalities in sensor calibration, common usage of vessels for deployments and calibrations, and even joint development of sensors. Examples of those common areas include the implementation of UVP6 and other sensors in both ARGO and gliders. It is common to deploy ARGO and gliders from the same vessels. Still, those collaborations are usually restricted to specific projects with a finite lifespan, are performed by big oceanographic institutions that operate both ARGO and MAS or come from direct PI agreements.

Data workflows between ARGO and gliders are very similar, and this is not surprising, as the original FP7 GROOM created the European glider EGO NetCDF format based on the ARGO and OceanSites specifications. Today, the new global OceaGliders format is the result of the merging of the EGO, IOOS (USA) and IMOS (Australia) format and keeps commonalities with the ARGO format, and the data workflow remains very similar.

Figure 11 shows a hypothetical deployment of the GROOM RI Technical framework in collaboration with Euro-Argo. In this example, the Euro-Argo is treated as a GROOM RI Node; the programme management (yellow boxes) between Euro-Argo and GROOM RI will be shared, enabling high-level planning of resources, allowing, for example, to allocate Gliders and Floats for the same cruise and for similar type of experiments requiring intercallibration. The data-management chain will be developed and deployed using different “modules” in the cloud, and the ownership of those “modules” will be shared between GROOM RI and Euro-Argo. Euro-Argo has already started designing a similar approach for the Argo data management chain, influencing the GROOM Data roadmap. Finally, the blue part will include the monitoring and piloting of both Argo floats, gliders and other MAS working in the same operations. This is a mode of operation that Euro-Argo is considering. While the floats can be remotely operated to change their sampling rates, there are no standard modern tools to do it, and the process of reconfiguring the floats is done by expert operators sending files directly.

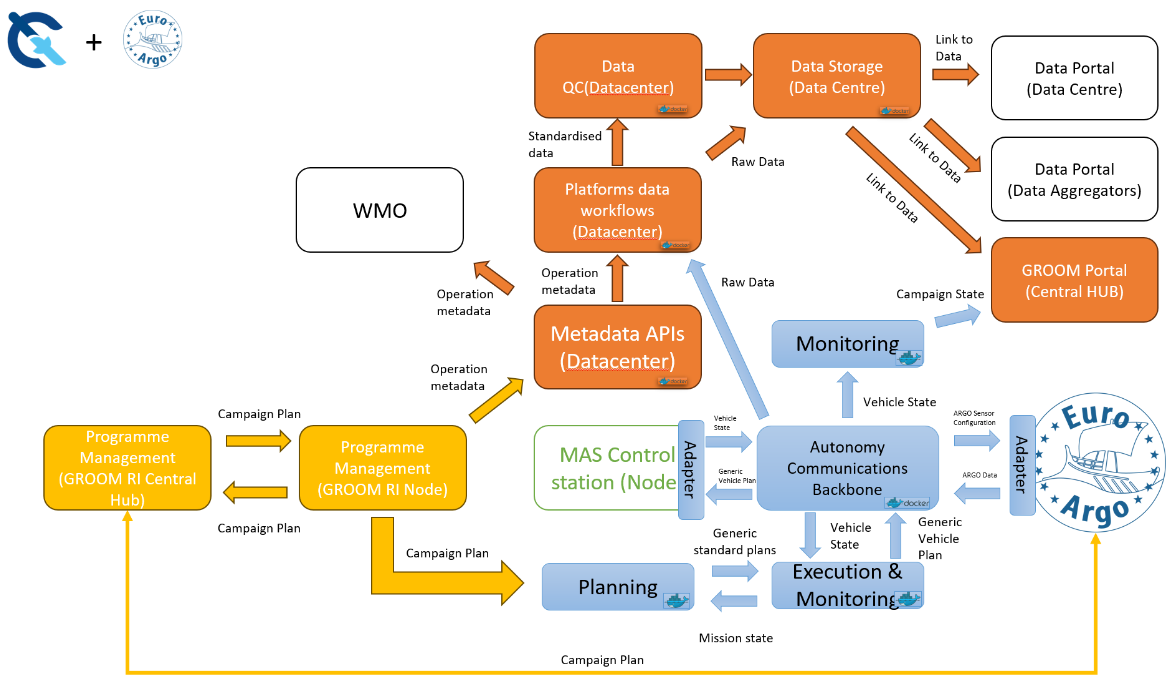


Figure 11 - A hypothetical assembly of the GROOM Technical framework and the distributed Cyberinfrastructure between GROOM RI and Euro-Argo

The example is purely theoretical but shows how the envisioned frameworks are highly inclusive and complementary to current Euro-Argo operations. They would provide coordination and much-needed cyberinfrastructure to the current RI landscape; hence, Euro-Argo and the future GROOM RI must collaborate to develop a proper multiplatform observing system.

7.2. Links with EMSO ERIC

The European Multidisciplinary Seafloor and Water Column Observatory (EMSO), participated by 8 Member States (Italy, Spain, Portugal, France, Ireland, Norway, Greece, and Romania), is a unique marine multidisciplinary, distributed Research Infrastructure to explore, monitor and better understand the phenomena happening within and below the oceans and their critical impact on the Earth. EMSO provides access to fixed observatories, but EMSO partners are currently experimenting with mobile platforms to complement observations, and this happens regularly with gliders in EMSO nodes from Norway, Spain, and Portugal. In this context of mobile platform usage, the complementarity of EMSO and GROOM RI becomes clear. At the same time, we can envision a similar example to the one shown for Euro-ARGO (Figure 11), with the GROOM RI Technical Framework, the framework enabling shared operations, and the GROOM RI providing piloting infrastructure. Still, a joint EMSO-GROOM collaboration can bring even deeper value to the landscape; a clear example of this can be the extension of the Piloting architecture designed in D6.4 to EMSO use cases, enabling complex operations like the one shown in Figure 12.

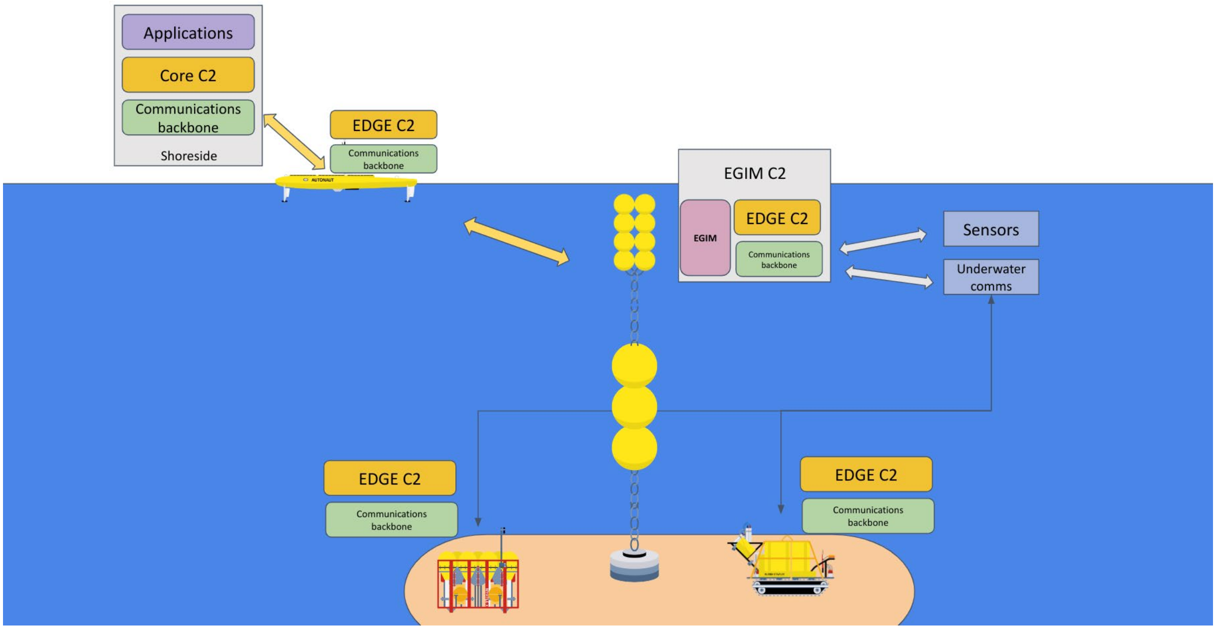


Figure 12 - The piloting architecture expanded to the concept of data mules to hoover data from a moored observatory (in this case, an EMSO observatory)

This high-level design plays with deploying the components designed under D6.4 within the EGIM to enable a rich ecosystem of integration and applications in the context of moored observatories. Parts of the system will also be deployed within autonomous vehicles like USVs or crawlers to create an autonomy ecosystem that will enable complex use cases like the data mule concept.

Moored systems are equipped with sensors collecting data, but that data can't be accessed until the moorings are recovered, except if there is a direct link to land via a surface buoy or a seafloor cable which is pretty rare, and allow very few sensors to report in real time on land. Moorings are usually recovered and redeployed every year or every two years and this requires ship time. The mode of operation is quite inconvenient as no data is received from the mooring until the devices are recovered, and doing those recovering very often is costly. A concept that some EMSO and GROOM partners have hypothesised is the concept of data mules; robotic platforms equipped with acoustic modems could be used to get near the moorings and harvest the data and transport it back to shore either using satellite communications or recover the robotic platform from a more advantageous location than the usually remote positions where moorings are deployed. However, developing such a solution is not trivial, as it requires careful positioning and piloting. There is also a risk of proliferation of non-interoperable solutions to achieve the same results. EMSO has developed the EMSO Generic Module or EGIM, a standard platform to facilitate sensor integration and facilitate telemetry within EMSO moorings and buoys. The EGIM can be considered a type of Edge[3] device that can serve as the tool to synchronise with data mules. To achieve this vision, a software ecosystem is needed, and that is a natural evolution of the design proposed in D6.4; expanding the vision of the autonomy communications backbone, a reference architecture can be developed to be extended to the platforms themselves and moorings as part of the EGIM.

[3] https://en.wikipedia.org/wiki/Edge_computing

Taking this joint technological approach can improve the landscape, with the future GROOM RI pushing the boundaries of what mobile platforms can achieve and EMSO providing solid moored observatory infrastructure.

7.3. LINKS WITH EUROFLEETS

The EuroFleets partnership provides access to ship facilities across Europe. As with the cases of Euro-Argo and EMSO, Eurofleets could benefit from implementing the GROOM technical framework, enabling coordination of resources with other RIs, sharing best practices and using the same Cyberinfrastructure. The usage of cyberinfrastructure is particularly interesting in ships, as they can be considered carriers of different platforms, and a clear expansion of the piloting framework designed in D6.4 to enable distributed local piloting of MAS platforms from ships would be within scope; this would allow de-centralised but synchronised piloting between the vessel and the shore-side.

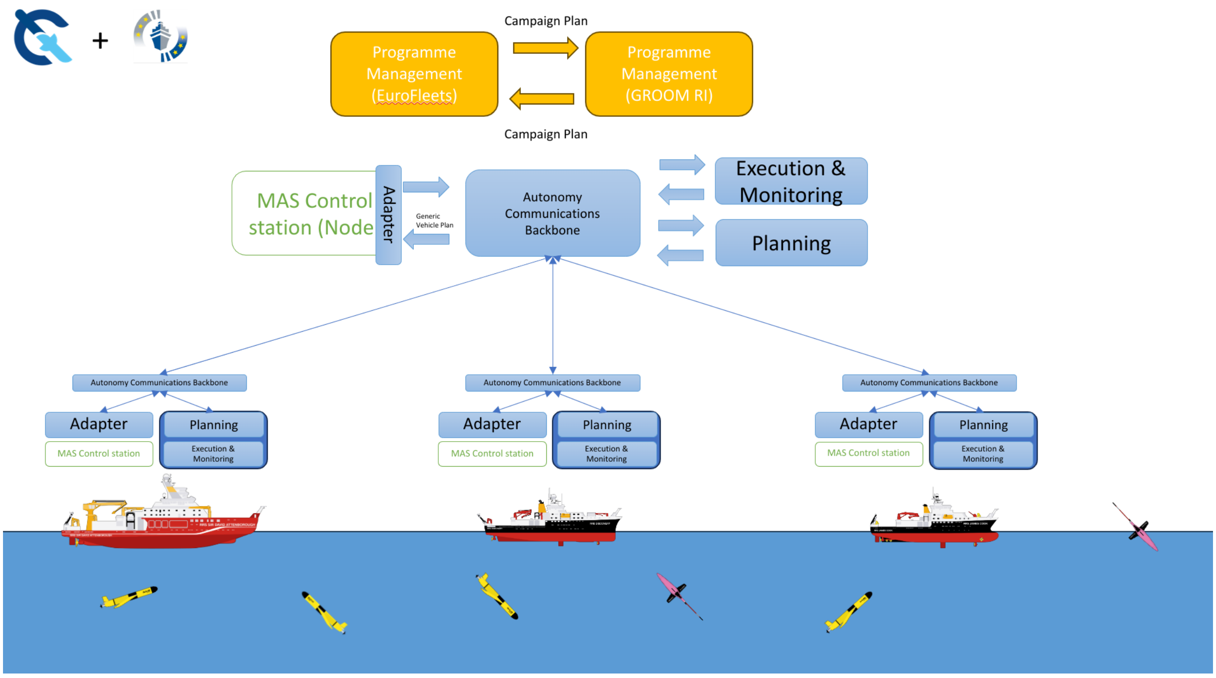


Figure 13 - Showing the GROOM Technical Framework in the context of EuroFleets

There are two clear usages: 1) to do shared planning between the future GROOM RI and EuroFleets using the programme management tools and 2) to use and expand the piloting architecture designed by GROOM II to enable shore-to-ship shared piloting.

8. Conclusion

It takes years from when a proposal is submitted to when a granted project conclusions are written. The GROOM II project is no exception, with the aggravation of a very late start in a world scourge by the COVID-19 pandemic. The RI landscape and the world have dramatically changed in five years; nowadays, the EU is pushing to consolidate RIs, and there is a significant trend to decarbonise those research infrastructures. The development technology framework for the future GROOM RI has been developed during this constant change. Being at the Design Study stage means that the GROOM RI framework will evolve in the subsequent phases of the implementation, with the refinement of the developed design and adaptation to the evolving landscape. The GROOM RI Technology Framework has been designed with all these subtleties in mind, offering a fit-to-purpose but generic framework for Ocean Observing RIs, not just for the future GROOM RI. The framework clearly articulates four pillars (programme management, data management, operations at base and operations at sea) and two horizontal workstreams (best practices and cyberinfrastructure) that apply to all the current RIs doing ocean observing (Euro-Argo, EMSO, EMBRC or ICOS) or to RI-type organisations (EuroFleets, WMO or Jerico). The framework we propose justifies the existence of GROOM RI and provides a clear path into the future. It is modular and can be constructed piece by piece by the current or future RIs. Doing it without the GROOM II partners would certainly delay the process significantly as almost no one else in Europe has the necessary know-how to achieve this task.

The technical framework contains parts that are currently at different maturity levels; the data management and operations at base and sea are (partly) mature, and most effort around them must be focused in the horizontal workstreams, particularly in generating solid and FAIR best practices. However, the programme management and the piloting component of the operations at sea are still in their infancy; they will require significant effort and investment in creating agreed specifications and cyberinfrastructure to fulfil the vision. An important legacy to the innovative design done under the entire WP6 is the funding by the commission of the “Advance Marine Research Infrastructures Together” or AMRIT. The AMRIT proposal took many of the concepts highlighted by the Data Roadmap and included many marine RIs in the proposal. That project will certainly focus on the metadata aspects that are crucial for GROOM RI and the other marine RIs. On top of that, many of the GROOM II consortium members have submitted a second proposal to advance the development of the C2 systems following the design done under deliverable 6.4; that proposal has been called AMRIT-C2, and is still pending evaluation. If these projects will definitely contribute to the set-up of the GROOM RI we envision, they will not provide enough resources to cover all the aspects we considered here and to maintain them on the long term.

Nowadays, it is clear that adopting Maritime Autonomous Systems at scale for Ocean Observing, Frontiers Marine Science and the Blue Economy is not a discussion but a matter of when it will happen depending on the application area and the stakeholders. To allow this transition, a solid framework is required to coordinate, operate and produce high-quality data with those platforms, complementing and amplifying current, more traditional approaches and that is what the framework presented in this document does.