

Underwater Data Centres – Innovative Computing Solutions for Stowing Servers in Ocean Computing Platforms to Reduce Deployment Costs



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ABSTRACT: The siting of data centres comprising multiple server racks in an underwater environment is recognized to reduce cooling costs and improve datacentre performance. However, the siting of data centres in the ocean raises new deployment challenges for cloud service providers. The deployment of large sized datacentres in an underwater environment requires purchasing or hiring large sized high capacity ocean vessels that transport underwater data centres to the designated underwater location before it is dunked into the ocean. The hiring of high capacity ocean vessels with high costs is challenging for cloud service providers with small capital resources. The intended hire might not be challenging for cloud service providers such as Amazon, Google, and Microsoft with significant capital resources. In addition, the use of high capacity ocean vessels increases the visibility of the locations of underwater data centre to other actors leveraging on the ocean's resources for other applications. The use of small capacity ocean vessels reduces the visibility thereby enhancing the security of the underwater data centre. The research being proposed presents a computing based furling and stowing solution. The proposed solution varies the dimensions of server chassis within pre-defined minimum and maximum values. It realizes the goal by incorporating the computing framework and an enabling architecture.

KEYWORDS: Furling Technology, Data Centres, Cloud Computing, Deployment Costs

[Received Jul. 14, 2025; Revised Dec. 14, 2025; Accepted Dec. 14, 2025]

Print ISSN: 0189-9546 | Online ISSN: 2437-2110

I. INTRODUCTION

The penetration of communication technologies (wireless and wired) in the design of embedded systems has helped the concept of smart devices and Internet-of-Things to take significant strides towards a practically achievable level. The idea of embedded systems, which appeared long ago, began to take concrete shape when key breakthroughs in various areas of life began to take advantage of wireless communication technologies through home appliances, power and electronic equipment to mention a few. Today, virtually all areas of life, including agriculture, education, textiles, health, and energy are moving towards fulfilling the sustainable development goals, through the use of smart devices driven by embedded system-enhanced tools and technologies. A very fast developing and exciting technological area is the communication field. Wireless communication has to do with the transmission of data and information from one point to another without using any physical medium such as cables and wires (Teja & Mishra, 2021). Today virtually all areas of life including agriculture, education, textile, health and energy are moving towards fulfilling the sustainable development goals, through the use of smart devices driven by embedded system enhanced tools and technologies (Adetunji et al., 2022). In

general, information transfer from a transmitter to a receiver over a limited distance defines a communication system. Between a few meters, a transmitter and a receiver can be positioned anywhere, just like the remote control of a television set or a few thousand miles, in the case of Satellite Communication.

Data centres play an important role in future technological developments and consume a significant amount of energy due to the necessity of cooling and powering the computing payload. Existing research shows that siting data centres in the ocean and in outer space can reduce the cooling and powering costs while improving the power usage effectiveness. The siting of data centres in the ocean and outer space raises new challenges in the area of deployment. The deployment of data centres in the ocean requires the use of supporting equipment such as vessels and rigs. In the case of space-based data centres, the deployment of data centres requires having access to launch vehicles. In both cases, the mass of the data centre being deployed influences the associated costs. A heavier data centre requires a larger vessel and high-capacity rigs. A heavier data centre has a higher launch mass and costs.

A reduction in the mass of the data centre reduces the deployment costs. This is the challenge being addressed in the presented research. The solution being proposed is that of an

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adjustable volume computing payload for ocean-based data centres. The ocean is a useful resource that is accessible to several potential cloud service providers. The use of the ocean resource to host data centres by cloud service providers is appealing due to the low operational costs associated with cooling (due to abundance of natural coolants) and powering (when marine renewable energy is accessed). However, additional challenges associated with deploying underwater data centres arise and need to be addressed. An important challenge that needs attention in this regard is that of ensuring low-cost deployment of data centres in the ocean while supporting multiple cloud service providers. Though the usefulness of underwater data centres is recognized (Periola, 2019; Periola et al., 2020; Cutler et al., 2017), this challenge needs to be addressed because it is yet to receive sufficient research consideration.

The discussion in (Simon, 2018) notes that Microsoft, the leader in the underwater data centre initiative, has made attempts in the design and realization of an underwater data centre prototype. In this regard, Microsoft has selected the Naval Group to design a prototype (Naval Group, 2020). The Microsoft team has presented Naval Group with information on the general specifications of the underwater datacentre while leaving Naval Group to handle the finer details associated with vessel design and manufacture. The vessel is intended to have the dimensions of a standard cargo container. The areas associated with functioning that has been handled by Naval Group are the heat exchange process and the seawater access system. The data centre utilized in Microsoft's Project Natick is 12.2 m in length and is loaded with 12 server racks hosting 864 servers with associated cooling system infrastructure. The deployed server rack that is deployed in the underwater datacentre developed by Naval Group and deployed in the Microsoft underwater data centre is presented in Figure 1.



Figure 1 Rack Payload comprising servers in the Microsoft Underwater Datacentre developed by Naval Group. Source: (Naval Group, 2020).

The development initiative from the Naval Group does not consider the costs associated with securing the vessel used to host the underwater data centre prior to deployment. A large-sized underwater data centre will require the use of high-capacity sea vessels. The hiring of a high-capacity sea vessel is expected to cost more than that of a small-capacity sea vessel. This is because of the supporting crew size and

resources such as water, food, and additional support required by a larger crew. In addition, the hiring company has to cover the labour costs for crew members. These costs are reduced for a smaller vessel due to the reduced crew size. However, these issues have not received consideration or mention by the Naval Group. These challenges receive attention in the research described in this paper.

Another motivation for the consideration of reducing the size is that it limits the visibility of underwater datacentres, thereby making the knowledge of their locations in the ocean challenging to determine. This is important for the purpose of data centre security. The development of technologies that stow data centres and enable their deployment using low-cost small-sized vessels reduces the visibility of their location to other actors in the maritime domain, especially malicious actors such as pirates. This has the added benefit of enhancing physical level security. The focus of the presented research is the discussion of the systems integration and computing architecture enabling the stowing derivable via deployment size reduction.

The proposed and presented research identifies the realization and execution of unfurling and furling as a key factor in the deployment phase of underwater computing systems and data centers. This focus assumes that the UDC has been deployed successfully and is within the desired ocean depth and location. The concerns about reliability and functionality become important in this case, and after a successful deployment procedure. However, it does not address deployment challenges, the availability of deployment equipment, and deployment cost. These identified factors play a key role in the real-life deployment of UDCs.

The rest of the discussion is structured as follows. Section II discusses the existing and background work. Section III presents the computing payload with adjustable volume; i.e., the proposed volumetric conformal server (VCS). Section IV presents the integration of the proposed VCS in an artificial reef intended for deployment in the ocean. Section V describes the integration of the proposed VCS in a space vehicle. Section VI is the conclusion.

II. BACKGROUND AND EXISTING WORKS

The discussion in this section focusses on the existing and background work in the area of deploying underwater data centers (UDCs).

Abner et al. (2024) identify the increasing research consideration on UDCs with the recognition of the enterprise efforts of Microsoft (Project Natick), Subsea Cloud, and the Highlander UDC initiatives. The research in (Abner et al., 2024) presents and analyses an underwater monitoring and security technologies for UDCs. The presented research also identifies that UDC behaviour and performance are influenced by the host maritime resource. In this case, the Baltic Sea has been considered as the host ocean for the UDC. The Baltic Sea has been identified to be suitable because of its low salinity and temperature variations. This enhances the natural cooling effect, thereby improving UDC service delivery and uptime. The use of remotely operated vehicles is proposed for executing the monitoring of UDCs and their support facilities as deployed in the Baltic Sea. It is also recognized that

autonomous underwater vehicles and smart buoys can be used to execute the surveillance and ensure the security of critical UDC assets. The essential aspect of the contribution by Abner et al. (2024) is designing a system to ensure UDCs have a low exposure to cyber-risks and physical compromise. It has not considered the UDC deployment aspects.

The discussion in (Sheldon et al., 2023) identifies and addresses the challenge arising from the acoustic effect of the underwater environment on the hard disk drives being used in UDCs. The basis of the considered challenge is that underwater acoustic waves and UDC hard disk drives can resonate when their natural frequencies become equal. The observed challenge is quite significant, as acoustic waves are dynamic and can propagate for long distances. The Seagate Barracuda HDD has been selected as the candidate UDC server storage technology. However, additional research is required for other HDD manufacturing specifications and for solid-state drives (SSDs).

Liu et al. (2021) address the UDC challenge from the perspective of the thermal-cooling aspect of its function. The authors proposed the use of the method of the analytic hierarchy process to determine what type of material should be used in the UDC. Essentially, it addresses the problem of UDC thermal design. The candidate materials that have been identified as suitable for UDC design and realization are Aluminium, Copper Alloys, Nickel Alloys, Titanium, and Steel. Additional research is required to consider the use of UDCs with geometrical configurations that are non-cylindrical. This is because a cylindrical UDC has been considered by Liu et al. (2021). The outcome of the research by Liu et al. (2021) is that Nickel Alloy, and Aluminium are most suitable in a non-cost and cost-constrained context, respectively.

Starczewska (2025) identified UDCs as a crucial digital infrastructure that connects remote coastal communities to the network of UDCs thereby enabling content access. The discussion in (Starczewska, 2025) identifies and outlines the challenges associated with the installation of UDCs. This is done by comparing and identifying similarities between UDC and undersea internet cable installation. The challenge of regulatory and ensuring compliance with regulation between UDCs and host nation states is also identified as one that should be addressed. The discussion here does not differentiate between UDC scale and terrestrial data centre scale. This is because it is assumed that the UDC dissipates the same heat as that associated with the conventional terrestrial data centre. However, it is noted that the deployment of a significant number of servers in UDC is required to be capable of increasing the temperature of the Atlantic Ocean by 0.5°C. However, the focus of the discussion in (Starczewska, 2025) is on the legal and sustainable aspects of UDC use and post-deployment phase. The role of deployment technology or the supporting maritime infrastructure has not been considered.

The discussion in (Pasupuleti, 2024) identifies UDCs as an emerging aquatic technology that transforms the scope of the ocean economy. It identifies that the complexity of the underwater environment poses new challenges to the UDC as a new form of ocean asset. The occurrence of underwater earthquake and their high dynamicity is recognized as a

challenge to be addressed by future technology for enabling UDC realization and functioning.

Sobhy (2025) recognize the need to discuss the role of infrastructure behind the artificial intelligence (AI) revolution. The revolution is recognized to identify the role of underwater data centers and their operational benefits such as a low freshwater footprint. The associated challenges are identified as uncertainty in marine ecosystem disruption, enforcing data sovereignty in ocean regions, and addressing geopolitical competition. The outlook of the discussion in (Sobhy, 2025) is that geopolitical concerns should be addressed to ensure the realization of UDC related data sovereignty. The discussion in (Sobhy, 2025) is based on the premise that ongoing research, such as (Hu et al., 2025), has advanced and has led to the recognition of the ocean's suitability for hosting AI revolution supporting infrastructure. The benefits of using UDCs are recognized to be reduced carbon emissions, lower failure rates (in Nitrogen-filled environments) to ensure the realization of UDC structure and ensuring their adaptability to function in the dynamic underwater environment.

III. PROPOSED SOLUTION – UNDERLYING PHYSICAL PRINCIPLES AND TECHNICAL FEASIBILITY

The discussion in this section presents the underlying principles for the proposed stowing technology and approach. In addition, the UDC is deployed in an ocean region with deployed and developed offshore energy resource access, especially with an extensive offshore wind energy farm. The UDC has a Tier 2 rating with a power demand in units up to tens of MW, i.e., 1 MWh – 10 MWh.

The weight of a given object is dependent on the mass, which is in turn determined by the volume and the density of the material used in manufacturing the object. The weight, W is given as the product of the density, ρ , volume v and the acceleration due to gravity g and is given as:

$$W = \rho vg \quad (1)$$

The resulting weight can be reduced by decreasing the value of the density ρ or the volume v but not the acceleration due to gravity being a constant. The density as a parameter can be varied because it is dependent on the type of material used in making an object. The material is not easily varied as it is fixed at the point of manufacture. Another variable parameter is the volume. The volume is influenced by the dimensions of the object. The dimensions of an object are variable and can be adjusted via compression and decompression. The process of compression is akin to deflating an object while decompression is akin to inflating an object.

The variation of the volume can be used to reduce the mass of an object being launched into either the ocean or outer space. Given that the volume v is dynamic, having the value $v(t_y)$ at the epoch $t_y, t_y \in t, t = \{t_1, t_2, \dots, t_Y\}$. The weight of the object is reduced in the transition from epochs t_1 and $t_p, t_p \in t$ if $v(t_p) < v(t_1)$. The incorporation of stowing; i.e., furling technology, can enable the realization of the volume $v(t_p)$ at the epoch t_p . The new weights considering the incorporation

of furling technology are denoted as $W(t_p)$ and $W(t_1)$ at epochs t_1 and t_p respectively. $W(t_p)$ and $W(t_1)$ are given as:

$$W(t_p) = \rho v(t_p)g \quad (2)$$

$$W(t_1) = \rho v(t_1)g \quad (3)$$

The relations between $W(t_p)$ and $W(t_1)$ is given as $W(t_p) < W(t_1)$. The technology being proposed aims to achieve the condition described in the expression $W(t_p) < W(t_1)$. The transportation of the heavier weight $W(t_1)$ requires a vehicle with higher capacity in comparison to the transportation of the weight $W(t_p)$ when the smaller weight is significantly less than the heavier weight i.e. $W(t_p) \ll W(t_1)$. In the case where the condition $W(t_p) \ll W(t_1)$ holds true, the vehicle required to handle the smaller weight $W(t_p)$ is of a lower capacity and also has a reduced cost in comparison to that of the larger weight $W(t_1)$.

The realization of the volume reduction between the epochs t_1 and t_p requires the design of a suitable furling technology. The stowable technology being proposed incorporates the use of supporting sub-systems with a considered weight denoted as $\mathcal{L}$. The total weight of the stowed object, considering the supporting sub-system, is $(W(t_p) + \mathcal{L})$ such that $(W(t_p) + \mathcal{L}) < W(t_1)$, $\mathcal{L} < W(t_p)$. The furling and stowing technology being proposed has the benefit of reducing the mass of an object, thereby enabling the use of a low-cost vehicle for handling and transportation. A furlable technology that achieves this goal is described in the proposed research.

The discussion leading to the relations in Eq. (1), (2), and (3) assumes that the entire structure to be deployed is stowed or furled. However, this is challenging to realize in the context of the proposed UDC. The UDC being proposed has an exterior and an interior. The exterior has a structure made of corrosion-resistant metal such as Nickel-Alloy. This exterior has high dimensions and is not stowed. The interior hosts a finite number of servers, which are protected from the surrounding ocean environment by the exterior. The servers constitute crucial components in the interior and are furled or stowed. Hence, the proposed UDC system has a partial stowing strategy. The execution of the proposed partial stowing has the following benefits of reducing the rotational inertia via the lowering of the centre of mass.

The center of mass has a position vector denoted α_{COM} and UDC total mass, M is given as:

$$\alpha_{COM} = \frac{1}{M} \left(m_{ext} r_{ext} + \sum_{i=1}^I m_{int}^i r_{int}^i \right) \quad (4)$$

m_{ext} is the mass of the UDC exterior.

r_{ext} is the position vector of the UDC exterior and its associated mass.

m_{int}^i is the mass of the i^{th} server (internal component) of the UDC interior.

r_{int}^i is the position vector of the i^{th} server (internal component) of the UDC interior and its associated mass.

The execution of a stowing of the internal components leads to a shift in r_{int}^i thereby lowering the centre of mass, now denoted α'_{COM} and the position vector shift, $r'_{int,i}$ leading to:

$$\alpha'_{COM} = \frac{1}{M} \left(m_{ext} r_{ext} + \sum_{i=1}^I m_{int}^i (r'_{int,i} - r_{int}^i) \right) \quad (5)$$

The transition from Eq. (4) to (5) leads to a reduction in the center of mass thereby leading to torque reduction since the moment is decreased. The moment, i.e., force exertion effect about the centre of mass prior to and after internal component stowing is denoted γ_1 , and γ_2 , respectively; and given as:

$$\gamma_1 = F_1 \times \left(\sum_{i=1}^I r_{int}^i \right) \quad (6)$$

$$\gamma_2 = F_1 \times \left(\sum_{i=1}^I (r'_{int,i} - r_{int}^i) \right) \quad (7)$$

In addition, Eqs. (6) and (7) can be formulated to consider the role of additional components and subsystems. In this case, the additional internal components are designated as the power, cooling, and communication subsystems. A subsystem composition factor denoted as β_{comp} is introduced to describe the proportion of the UDC, which constitutes the computing subsystem. Given that the server payload constitutes the core components of the UDC, it is reasonable to assume the following relation $0.7 \leq \beta_{comp} \leq 0.9$. This implies that servers can constitute at least 70% and up to 90% of the payload on the UDC's interior. A deviation from this assumption implies that considerable maritime launch components are expended on launching the UDC system's overhead. The introduction of the variable β_{comp} leads to a re-formulation and presentation of Eqs. (5), (6), and (7) as Eqs. (8), (9), and (10), respectively ; as:

$$\alpha''_{COM} = \frac{1}{M} \left(m_{ext} r_{ext} + \beta_{comp} \sum_{i=1}^I m_{int}^i (r'_{int,i} - r_{int}^i) \right) \quad (8)$$

$$\gamma'_1 = F_1 \times \left(\beta_{comp} \sum_{i=1}^I r_{int}^i \right) \quad (9)$$

$$\gamma'_2 = F_1 \times \left(\beta_{comp} \sum_{i=1}^I (r'_{int,i} - r_{int}^i) \right) \quad (10)$$

α''_{COM} is the re-computed center of mass considering the subsystem composition factor.

γ'_1 is the re-computed moment prior to the execution of stowing, considering the introduction of the subsystem composition factor.

γ'_2 is the re-computed moment after the execution of stowing, considering the introduction of the subsystem composition factor.

$\gamma_2 < \gamma_1$, as the second term in Eq. (6) is greater than the second term in Eq. (7). Therefore, the torque in Eq. (7) is lower than that in Eq. (6). Hence, a lower rated torque instrument can be used for the case where internal component stowing presented in Eq. (7) than that where no component is stowed as seen in Eq. (6). Though this shift looks insignificant it means that the handling instrument changes. Higher torque-capable instruments, such as those expected to realize the scenario in

Eq. (6), are expected to have higher costs and capital expenditure than lower torque-capable logistic and maritime systems handling instruments required for the scenario in Eq. (7). Higher capital and acquisition costs arise because of the: (i) use of stronger higher stress-bearing materials, (ii) increased gear and transmission complexity (with more complicated components), (iii) inclusion of higher capacity motors, drives and increasingly sophisticated control systems, (iv) increased need for operational and safety certification, and (v) higher labour component and complexity in their manufacturing and assembly.

IV. PROPOSED SOLUTION – VOLUMETRIC CONFORMAL SERVER (VCS)

The proposed Volumetric Conformal Server (VCS) comprises conventional computing components that are present in a server, i.e., storage drives, computing boards hosting memory, network-related hardware, power modules, and additional auxiliary modules. In a terrestrial data centre, these components are manually set up at the designated data centre location and facility. However, this is not feasible for UDCs. Nevertheless, it is important to reduce the mass, the weight, and deployment costs.

A. Proposed VCS – Dimension Variation of Server Chassis and Role of Servomotors

The VCS comprises a chassis that has variable dimensions of breadth, height, and length. The chassis has the minimum dimensions permissible. In addition, the dimensions of the collapsible chassis have pre-specified minimum and maximum dimensions described by the breadth, height, and length. The adjustable dimension is realized via servomotor units that allow the dimensions of the collapsible chassis to be varied after successful deployment. The low-cost servomotors are server chassis specific and derive their power from the power payload of the data centre. In addition, the chassis is collapsible and is able to function, given the occurrence of mechanical stress in the surrounding ocean environment. The chassis is hosted within the UDC interior and has the proximal aspects of the exterior hosting anti-vibration structural elements such as robust dampers. Moreover, the UDC is hosted within the mesopelagic zone with a depth of up to 500 m.

The servomotors are activated at two epochs during the period of data centre use. The first use epoch is after the successful deployment of the data centre comprising multiple servers with each server having side and floor panels having servomotors as described above. The second use epoch applies in the case of UDC facilities. This occurs when UDCs are to be brought to the surface for upgrades and maintenance. The role of servomotors in the server chassis is shown in Figure 2. In Figure 2, the servomotors for ABCD and HEFG have a vertical upward motion and are located mid-way at the paths BC and EF, respectively. There are two servomotors. In addition, each servomotor has a redundant servomotor with a total of two redundant servomotors. The redundant servomotors are located on the floor plane of BC and EF. This serves to enhance reliability. The 2U server rack being considered has a height of 88.9 cm (0.89 m) (approximately

0.9 m) and a weight of 30 kg. Each servomotor is expected to execute unfurling to an altitude of 0.89 m. The required potential energy is given as mgh , with m , g , and h being the mass of the 2U server rack, acceleration due to gravity, and height of the 2U server rack, respectively. There is no rotation involved, hence the torque has not been considered. The potential energy is evaluated as $30 \times 9.81 \times 0.9$. The potential energy is computed as 264.9 J. The computed potential energy of 264.9 J yields a power of 1.77 (J/s), i.e., 1.77 W if the unfurling process takes 2.5 minutes to execute for each furled server. Servomotors with a power rating of 5 W are suitable for executing the required linear vertical motion without the requirement of rotational motion. Therefore, the servomotors to be used have a power rating of 5 W.



Figure 2 Geometry of server chassis showing side panels, upper panel, lower panel, and co-ordinates describing the positioning of low-cost servomotors.

In Figure 2, the motion path, ABCD and HEFG are vertical. This does not require the execution of horizontal motion along the breadth (i.e., x-axis of the components). In this case, the server chassis has a significant height than each server board. This is expected and feasible as the server chassis compartment is greater than the motherboard height. For example, motherboard breadth for the server model Supermicro X10DRI-T4+ (Supermicro.com, 2025), EP2C621D12 WS (ASRock, 2025), and Intel DBS2400EP4 (Intel, 2025) are 33.02 cm (with length 30.48cm), 33cm (with length 30.5 cm), and 26.7 cm (with length 30.48 cm), respectively. The conventional server chassis height for a 2U rack is 88.9 cm. In a three-dimensional orientation, these values correspond to the x-axis and y-axis. However, the motherboard height is significantly smaller and is the thickness of the printed circuit board (in order of units – tens of cm) and is not provided in server data sheets. The movement in the paths ABCD and HEFG occurs along the dimension corresponding to the motherboard height (thickness). The ratio of the 2U server chassis height to the motherboard height can be conservatively estimated as 30. Hence, the movement in the z-axis dimension along the motherboard height (thickness) aspect results in height reduction. The height reduction occurs during stowing and furling. There is no motion regarding furling along the component length and breadth. Hence, existing server motherboard hardware can be used in the proposed solution. In addition, cables are aligned with the server component surface with a full stretching occurring during server chassis unfurling.

B. Proposed VCS - Computing Aspects and Servomotor Functioning

In the considered use context, the servomotors should be able to receive an activation signal for the realization of the desired dimension. The discussion here assumes that each server chassis is loaded with the rated number of computing components that can be supported. Each server chassis hosts an activation module through which the activation command is transmitted to servomotors. The activation module aboard each server is connected to a central servomotor activator in the UDC. The central servomotor activator (CSA) is connected to a computing entity hosting servomotor configuration software. The servomotor configuration software is hosted on a computing entity that is co-located with the data centre crew on the surface of the ocean aboard a vessel. Instructions on the minimum and maximum allowable dimensions of each server chassis are pre-loaded on the CSA, and they can be transmitted to the computing entity with the data centre crew. The CSA's computing aspects are independent of the server's onboard operating system and its directory details. In the proposed solution, servers already have their operating system pre-installed before the furling and unfurling process. Therefore, the computing aspect described does not influence the server operating system functionality.

Furthermore, each server chassis is allocated a server index. Each servomotor associated with the server index denoted as S_IN is further allocated a servomotor identifier described as S_ID . Servomotors are described using the information $\{S_IN, S_ID\}$. The information in $\{S_ID, S_IN\}$ describes the servomotor associated with a given server index. Besides the information on $\{S_ID, S_IN\}$, information on the minimum and maximum allowable values of the height and breadth for the side panel and floor panel is also incorporated. The incorporated information is also known to the CSA being pre-programmed during the data centre design phase. The pre-programmed information is accessed by the servomotor configuration software and used to issue instructions to the servomotor by the engineer who is a member of the data centre crew. The relations between the CSA and server hosting information on the server index S_IN and servomotor identifier S_ID is in Figure 3. The scenario in Figure 3 shows relations between entities in the proposed solution from a computing entity perspective. The execution of the unfurling is the major output of the CSA-driven architecture presented in Figure 3. This is executable in an unmanned fashion within the UDC interior for each server. From the previous analysis that the servomotor can execute the motion within 2.5 minutes with a power rating of 1.77 W, it is conceivable that the motor motion can be timed to stop after 2.7 minutes. An extra 0.2 minutes, i.e., 12 seconds, is allowed to ensure the completion of the linear vertical unfurling motion process. This is programmed on servomotor micro-controller and can be checked by computing the difference between the start time (epoch) and stop time (epoch). Furthermore, CSA function activation occurs after UDC has been deployed successfully. This is ascertained via the detection of non-occurrence of motion by an onboard distance measurement sensor. The UDC hosts the distance measurement sensor. A non-detection of motion by the UDC onboard distance measurement sensor activates communication with the CSA. The CSA is connected to the UDC onboard distance measurement sensor via an interior-

based high-speed copper cable, and not an external connecting cable from the shore.

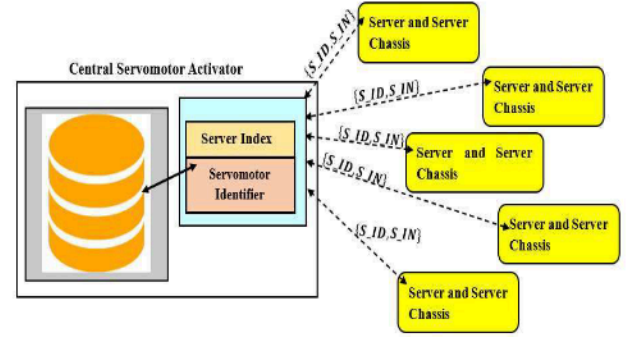


Figure 3 Relations between the central servomotor activator (CSA), servers and server chassis.

An important aspect of the execution of the intended function of the proposed solution is the ability of a stowed server system in the UDC to withstand vibrations during the process of lowering into the ocean. In this case, the UDC with the proposed stowed servers is hosted at an ocean depth of 500 m. The servers are hosted within the physical structure of the UDC. The UDC has embedded anti-vibration structures that shield the internally hosted stowed servers from the vibrations arising from the launch process. In addition, UDC handling is done by high precision maritime logistics equipment that includes viscoelastic dampers as part of its components. This ensures that the UDC being deployed is effectively shielded from vibrations during the launch and deployment process. In the post-deployment phase, the UDC's anti-vibration structures enable shielding of the server being unfurled from vibrations. After the deployment, each server chassis is stable since it has enabling support, such as screws, bolts, nuts, and washers that are pre-embedded. These server chassis stability components become functional after the execution of server chassis unfurling.

In addition, the use of Nickel Alloys as the UDC exterior material ensures successful deployment and protection from the high hydrodynamic pressure at an ocean depth of 500 m. This is because of the high strength of Nickel Alloy as observed in (Sarode et al., 2025).

V. INTEGRATION OF THE PROPOSED VCS IN THE ARTIFICIAL REEF

The proposed VCS can be incorporated aboard an artificial reef that is deployed in an underwater environment. The considered artificial reef can be deployed in any region in the ocean where there are low temperatures, i.e., abundant natural coolants (cold water and ice). The UDC exterior can be realized from Nickel Alloy or Aluminium (Liu et al., 2021). The UDC exterior protects the interior, where servers being stowed and unfurled are located, from having contact with water, thereby preventing corrosion. In addition, the UDC comprises the power subsystem, computing subsystem, stowing subsystem, and the communications subsystem. The power subsystem provides electricity to the components of the UDC aboard the artificial reef. The computing subsystem comprises servers that host the computing components. The

communications sub-system hosts networking components enabling communications between the servers and external networks. The stowing subsystem has close physical relations to the computing sub-system. In the underwater environment, different artificial reef units are used to host the power sub-system and the communications subsystem. A separate artificial reef unit is used to host the computing sub-system and the stowing sub-system. The computing subsystem and the stowing subsystem are closely integrated physically.

The relationships between the power subsystem, communications sub-system, and computing subsystem (integrated with the stowing subsystem) are shown in Figure 4. The scenario shown in Figure 4 considers the case where multiple artificial reefs are used to host the power sub-system, communications sub-system, and the closely integrated computing and stowing subsystems. The computing subsystem and the stowing sub-system shown in Figure 4 are associated with a single service provider. The power subsystem (artificial reef 1) and communications subsystem (artificial reef 2) may or may not be provided by the cloud service providers. The artificial reef 1 and artificial reef 2, and their associated subsystems are provided by an external entity.

The external entity could be an underwater infrastructure services provider or a government municipality. Given the existence of the required infrastructure base, the challenge of stowing the computing subsystem is considered applicable to the cloud services provider. The cloud services provider is a private entity with capital constraints. Nevertheless, the proposed stowing technology can also be applied to the subsystems in artificial reef 1 and artificial reef 2. This requires an adaptive deployment of servomotors considering the components in each subsystem. Figure 4 shows the relations between the individual subsystems in the underwater datacentre comprising multiple artificial reefs. It does not show how the data centre crew interacts with the UDC, comprising multiple artificial reefs. The relations between the datacentre crew and the UDC during the configuration of the stowing subsystem is shown in Figure 5.

The artificial reef has been included to ensure zero or minimal disruption to the marine ecosystem due to the deployment of UDC. Artificial reefs have been identified to be capable of ensuring a non-disruption of marine life when located in the aquatic environment (Riera et al., 2023; Dinu et al., 2025). In addition, UDCs have been recognized to host artificial reefs to further reduce their underwater ecosystem disruption impact. This inclusion can be seen in (Loukoianova, 2024). The unfurling process does not result in the release of any outputs from the UDC into the surrounding ocean environment. Furthermore, the servomotors, being low powered at a rating of 5W and operational for 2.5 minutes (150 seconds), can be reasonably battery operated. In addition, the number of servers hosted by the UDC does not exceed 60. This is done to ensure that there is a reduction in the overhead associated with the unfurling. Instead, multiple pods with a maximum of 60 servers can be launched when needed to provide data storage and processing services. Given that a server can have four 5TB capacity solid state drives, the deployment of 60 servers can yield 1200 TB (1.2 PB). This is a significant capacity. The utilized approach ensures that the

computing service provider does not suffer loss from over-provisioning of computing capacity.

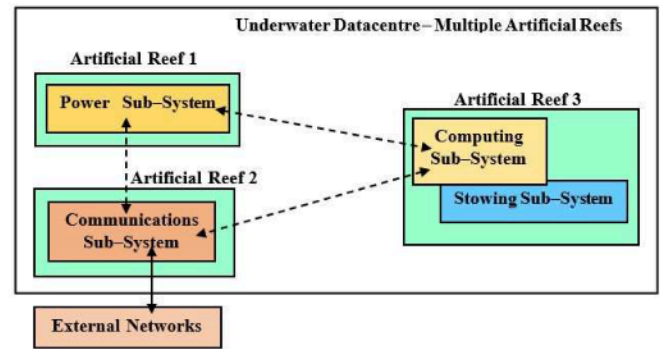


Figure 4 Relations between artificial reefs hosting the power, communications, and closely integrated computing and stowing sub-systems.

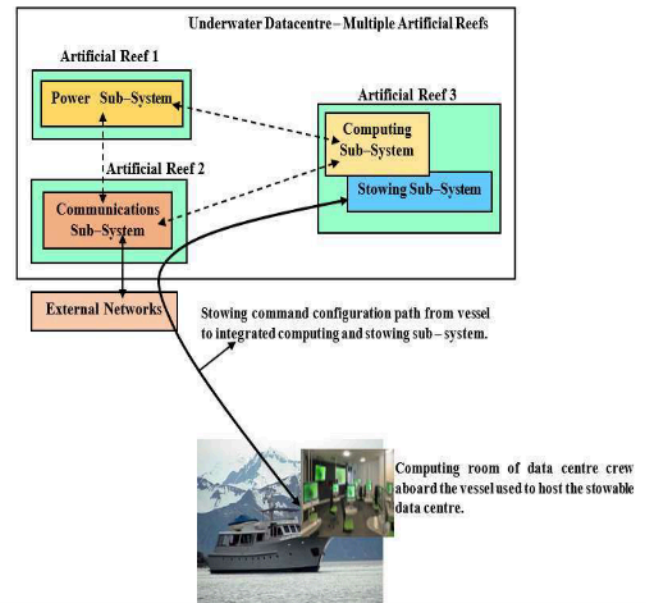


Figure 5 Relations between artificial reefs showing the path between the datacentre crew and stowing command.

The differences between the existing approach and the proposed approach are in the following aspects:

1. Number of Servers – In the proposed approach, the UDC hosts a maximum of 60 servers (less than 100 servers) with computing capacity in the range of 1.2 PB. Existing approach such as Microsoft Natick hosts 864 servers (Roach, 2020) which is more than 500 servers. In addition, an initiative from Subsea cloud deploys UDC capable of hosting 826 servers (Subsea Cloud, 2025). Furthermore, the Chinese initiative by Highlander has a UDC deployment with 400 servers (董志成, 2025), the South Korean initiative aims to host 100,000 servers (Korea JoongAng Daily, 2025).
2. Service Provisioning Paradigm – The hosting of a large number of servers aboard the UDC, as found in existing

deployments from Microsoft, Highlander, Subsea Cloud, and the South Korean initiative, aims to host a large number of servers in the UDC system. This can lead to overprovisioning especially if an aggressive service subscription is not actualized. However, the proposed UDC advocates for a gradual increase in service provisioning. By hosting 60 servers initially in a UDC, the proposed approach aims to ensure a gradual service provisioning with minimized occurrence of overprovisioning.

3. **Reduced Failure Impact** – In the existing approaches, the hosting of a large number of servers has a high failure impact when a non-functioning event occurs. However, the failure impact is significantly reduced in the proposed approach. This is because failure of the entire UDC cluster results only when all deployed UDCs (with each having 60 servers) all fail. The proposed approach employs a modular approach to realizing high-capacity UDC with capacity similar to that found in existing work and approaches.
4. **Deployment Consideration** – The existing approach with initiatives from Microsoft Natick, Subsea Cloud, Highlander, and South Korea focuses on making significant computing capacity available to the end users, clients, and future subscribers. They have not considered the availability of maritime handling equipment for launch execution at the considered locations. Implicitly, they assume that the UDC service provider and operator can afford to execute the launch regardless of the size. This assertion may be true for firms and countries located in the Global North. However, this is not true for firms and countries that are located in the Global South. In the Global South, where capital constraints are significant, the cost of UDC deployment is important and should be considered.

VI. CONCLUSION

The discussion addressed the challenge of reducing the costs associated with deploying UDCs. The paper recognizes that deploying large-sized UDCs requires the use of high-capacity ocean vessels with the associated high costs. It is important to reduce the high costs of deployment. The high costs can be reduced by using small-capacity ocean vessels with lower costs. The lowering of these costs requires reducing the size of data centres. This goal can be achieved via stowing and furling technology. The paper describes the computing framework that enables the variation of the dimensions of the server chassis within a limit, i.e., pre-specified minimum and maximum values. The proposed solution describes how the servomotors are incorporated in the side panels, upper floor panel, and lower floor panel, and activated to extend the concerned dimension. In addition, the discussion here also presents the computing entities associated with dimension variation and describes how they interact in the designed network. Future research will consider the execution of exhaustive structural stability analysis using the finite element analysis (FEA) method, and the inclusion of collaborative level UDC experimentation procedures, with the future use of AI for

adaptive dimensioning recognized as a subject for future work. In addition, the presented research identifies that the proposed partial stowing strategy with its computing framework enables the use of lower-cost maritime underwater payload handling equipment. This is associated with the listing and enumeration of factors that make lower torque-capable payload handling equipment more suitable. However, the derivation of metrics from these listed benefits requires mathematical formulation and simulation in the context of the subject of maritime mechano-economics. Being an emerging area requiring the evolution of standards in the applied maritime research domain, these aspects will be considered as subject of future work.

AUTHOR CONTRIBUTIONS

A. A. Periola: Conceptualization, Software, Validation, Writing – original draft. **A. A. Alonge and K.A. Ogudo:** Conceptualization, Methodology, Supervision. **A.A Alonge and K.A. Ogudo:** Writing – review & editing.

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