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Maritime Computing Transportation, Environment, and Development: Trends of Data Visualization and Computational Methodologies

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Abstract

This research aims to characterize the field of maritime computing (MC) transportation, environment, and development. It is the first report to discover how MC domain configurations support management technologies. An aspect of this research is the creation of drivers of ocean-based businesses. Systematic search and meta-analysis are employed to classify and define the MC domain. MC developments were first identified in the 1990s, representing maritime development for designing sailboats, submarines, and ship hydrodynamics. The maritime environment is simulated to predict emission reductions, coastal waste particles, renewable energy, and engineer robots to observe the ocean ecosystem. Maritime transportation focuses on optimizing ship speed, maneuvering ships, and using liquefied natural gas and submarine pipelines. Data trends with machine learning can be obtained by collecting a big data of similar computational results for implementing artificial intelligence strategies. Research findings show that modeling is an essential skill set in the 21st century.

Keywords: maritime computing, management technology, modeling

1. Introduction

Maritime computing (MC) is an interdisciplinary field comprising economics, geography, transportation, logistics, mechanics, computer science, engineering, and technology [1-3]. It is the application of computing techniques to maritime engineering (ME). Computing techniques are the implemented techniques in computers to solve problems by either step-wise, repeated, or iterative solution methods; also known as in-silico methods. Among these techniques, computational fluid dynamics (CFD) and machine learning (ML) are some of the most widely used techniques. CFD is a branch of fluid mechanics that uses numerical analysis and data structures to analyze and solve problems; its concept is to model the problem using geometric approaches to produce visual results [4-7]. ML is a branch of computer science that uses data and algorithms to mimic the way humans learn; its concept is to develop computers to learn from data and then perform learning [8-11].

ME is referred to the word ocean engineering in certain academic and professional circles as the field of study dealing with the engineering of boats, ships, submarines, and any other marine vessels, as well as other ocean systems and structures. MC will focus on transportation, environment, and development in the ME field. MC transportation is the study of the changes and movement of objects in the sea. MC environment is the study of oceanic issues and environmental simulations. MC development is the study of geometrical simulations and ocean-shaped designs linked to the sea.

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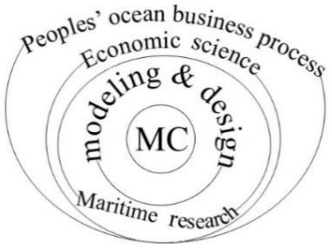
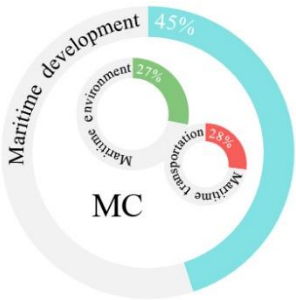
This study is organized as follows. Section 2 describes the proposed method, especially presenting research concepts of literature data describing data. Section 3 illustrates the results obtained from the algorithmic search. Section 4 discusses how the findings will improve future ocean-based businesses. Finally, the last section concludes that MC is important in maritime society to accomplish development goals.

2. Literature review

Instead of being an engineer, MC is more like the computationalist and the socialist which uses computers and technology to assist ocean-based businesses at the microscale and macroscale. MC involves a business process management system. Currently, several crucial maritime studies employ computation and technology. Fig. 1 shows the images of MC and indicates that the relationships between skill sets are mutually linked. The design of numerous ocean-based business processes consists of transportation, logistics, trade, food, environment, data, simulation, and modeling. Transportation, logistics, and computing automation were the core of the maritime business proposed by the World Maritime University [12]. Similarly, bioeconomy involves the conversion of agricultural, organic, and marine resources into materials, energy, fuels, feed, and foods [13-14].



(a) Basic guidance of MC



(b) Relationship of MC domains (c) Conceptual MC domain

Fig. 1 The field of maritime computing (MC)

MC helps bioeconomy to develop in all aspects. Thus, it can provide technological benefits and systems for economic science and bioeconomy [15-16]. Economic science, a smaller area of economics, involves rigorous thinking and mathematical applications. Unlike the political economy, economic science focuses on the production, distribution, and consumption of goods and services [16]. MC supports economic science through a significant aspect of its modeling skill set as shown in Fig. 1(a). It also supports sustainable economic development involved in price fluctuation, banking characteristics, and social development [17-19].

Computing is used to translate information, ideas, and practical and mathematical modeling data into digital data. However, visualization techniques are required to determine computational results and process digital data to interpret and verify the outcomes of these results such that they are applicable in real-world conditions [20-21]. Mathematical modeling alone is inadequate for explaining the computational consequences [20, 22-24]. A computational research of fluids is noteworthy because fluids are present everywhere and are found in numerous computing applications. Therefore, CFD is a preferred concept for ocean-based businesses to classify maritime visualizations and computational methodologies. CFD is an interpreter that provides computational outcomes in terms of data visualizations, including data plots, streamlines, vector changes, contour areas, shading colors, and user-programmable animations [24-26].

In addition, CFD generates computational results, and these data depend on a study design to solve a specific problem statement. Later, visualization methodologies were applied to translate these computational results into graphs, images, and/or animations for understanding the solutions. ML enables computer systems to learn from input data to automatically predict solutions. In this context, the concept of ML and CFDs are possible to build big data of similar study designs as input data for ML to predict the computational outcome.

The use of computing data involves data collection, which is adequate for forecasting the next state of data-driven applications [27]. Massive data collection and automation are usually accomplished through ML. ML can be used to complete routine tasks, simulate virtual contexts, and reduce physical work and manual labor. In the intelligent societies of the 21st century, computing technology has advanced physical labor by inputting human ideas and data into a computer domain. These inputs are then translated into digital data that machines or computers can be used to perform human tasks [28-30]. However, no systematic studies have focused on MC classification. CFD is a key concept in ocean-based businesses that examines maritime visualization and the computational methodologies dedicated to MC transportation, environment, and modeling. The main objective of the present research is to investigate the trends in computer technology and data applications used in MC during the past five decades to help drive and expand ocean studies and support essential skill sets in the 21st century.

3. Proposed Method

MC is generally defined as the analysis of collected material. In this study, a literature review of maritime studies was performed by the preferred reporting items for systematic reviews and meta-analysis (PRISMA) guidelines [31-32]. A comprehensive electronic search of the literature was conducted using the following databases: ScienceDirect, Scopus, the IET Digital Library, IEEE-Xplore, Springer Link, Web of Science, and Google Scholar. The keywords used to perform the search were mainly included in the form of [CFD+(marine_or_maritime)] [33]. Hence, this keyword was preferred.

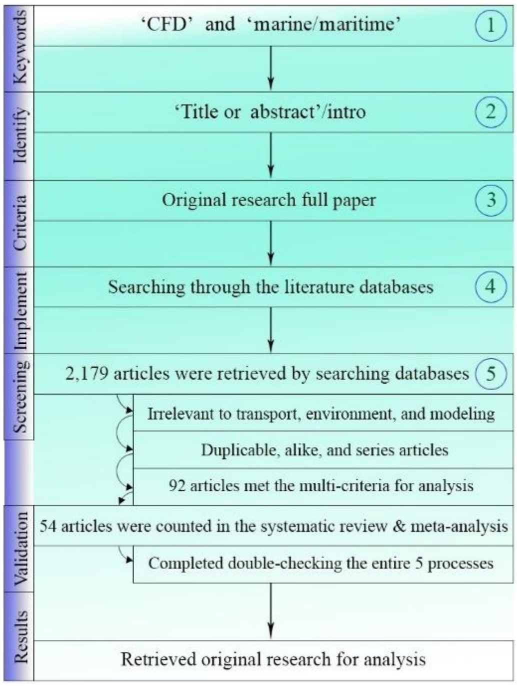


Fig. 2 Protocol representing research concepts of literature data describing data

Maritime studies were searched from the 1960s to 2022 in the aforementioned databases and were eligible for inclusion in the present research. Articles were included if they were peer-reviewed and published in English. The titles of the articles were analyzed using the AND operator in the basic search engine to ensure that the studies met the eligibility criteria before inclusion. In addition, the abstracts of articles were analyzed to determine if the study conditions accurately reflected our study aim and title. The introduction section of each article was scanned for critical thinking. Conference abstracts, review articles, editorial notes, short articles, and other article types were excluded according to the study criteria. Finally, full-text original research papers were included to perform the MC classification. Fig. 2 shows a pictorial representation of the article included in this study.

Computer technology advancements began on a massive scale in the past two decades because of the affordable cost of electronics production, the large-scale design of microelectronics, the availability of computer programs and graphic processing unit (GPU) technology, digital literacy, and computing skills [34]. Thus, few computational applications in maritime studies would have been available during the 20th century. The three significant key areas found in maritime literature are transportation, environment, and development research. Accordingly, keywords, namely “transport,” “environment,” and “modeling,” were used to search for information, along with the aforementioned main keywords (maritime and CFD). These sets of keywords were used to obtain adequate and accurate information to categorize search results into the following phases: the current situation, the prediction of the future situation, and the definition of MC and its basic skillset.

3.1. Data classification and critical evaluation strategies

The data were collected according to the inclusion criteria described in the previous subsection. The last search was completed on October 02, 2022. Each article was manually assessed. An independent assessor (Thanapong Chaichana) classified and tabulated the data in a Microsoft Excel spreadsheet for analysis. The data observer (Thanapong Chaichana) verified the search results of the original MC research, strictly focusing on the algorithmic search for analysis and review. The following characteristics of maritime studies were classified: authorship, year of publication, area of MC research, study design, study purpose, key findings, algorithmic software usage, maritime big-data possibility, artificial intelligence (AI) feasibility, and future direction of research.

3.2. Data validation and double-check of results

After the search was completed, a double-check procedure was performed to verify the results. First, the presence of both keywords (CFD and marine/maritime) in the titles of maritime articles was confirmed. Alternatively, the presence of these keywords was determined in the abstract or introduction section. Second, the key areas of MC were classified. The key research areas and keywords used for classification were transport, environment, and modeling. Subsequently, all the maritime studies were thoroughly read to ensure that they represented the actual research context in the field of MC. Finally, the original research articles were thoroughly evaluated to exclude studies with the same group of authors, the same series of publications, duplicate and similar studies, and articles irrelevant to maritime modeling, environment, and transport research. Accordingly, the entire inclusion process, shown in Fig. 2, was successfully implemented.

4. Results

4.1. Search outcome of the maritime literature

The electronic search yielded 2,179 articles. After applying the search criteria to screen full-text original research articles, 92 of the 2,179 articles were found to be eligible. These articles were then evaluated to determine whether they focused on three research areas: transportation, environment, and development. A total of 62 articles met the criteria and were reviewed; of these 62 articles, 8 were excluded because they were an extension of conference papers (3 articles), focused on aerospace research (1 article), or had the same name as the first author (4 articles). Finally, 54 articles met the research criteria and were included in this meta-analysis.

Fig. 3 shows the characteristics and key research areas of the 54 articles. There are 14 and 15 articles focused on maritime transportation and the environment, respectively. The remaining 25 articles focused on maritime development. The results obtained from the algorithmic search offered unique information and more accurate search results when these results are compared to previous studies [31, 35-37]. Moreover, a bibliometric search algorithm implemented using scientometric software (e.g., BibExcel [38] or CiteSpace [39]) may reduce the time consumption. However, an accurate search result depends on keywords, Boolean conditions, and searching protocol (Fig. 2 offered a newly accurate scientometric algorithm).

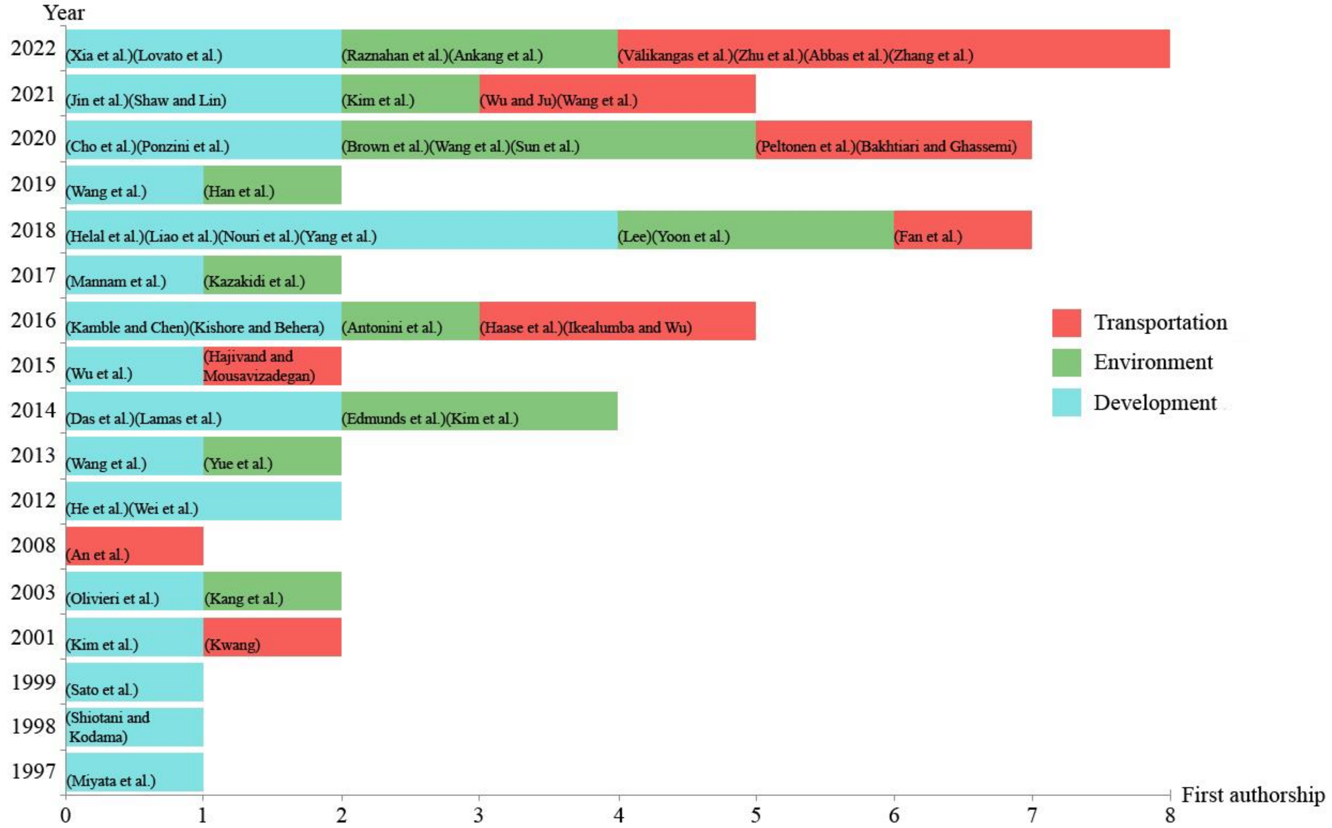


Fig. 3 Studies focusing on MC transportation, environment, and development

4.2. *Maritime computing* (*MC*)

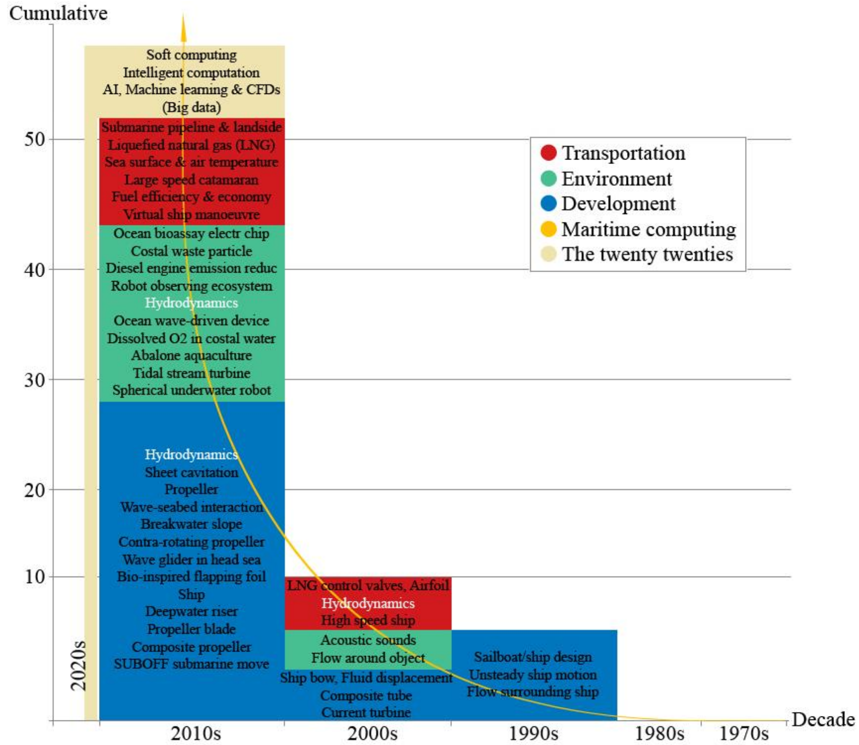


Fig. 4 Data trends of MC methodologies, invention of computers, and computational techniques

In the MC research field, interesting findings were observed in the areas of transportation, environment, and development. Fig. 4 shows an MC chart with details of its development and data reported over the past five decades. In the current decade, computational results visualized using three-dimensional (3D) and multidimensional computing domains have been reported as normal methodologies for MC. In contrast, in the 1970s and 1980s, MC began with one-dimensional (1D) or two-dimensional (2D) mathematical models, drawings, and domain geometries. Technological advancements have led to the visualization and implementation of real-world MC practices.

4.3. MC transportation

MC transportation was developed to research the changes and movement of objects in the sea. Table 1 presents the categorization of MC transportation. The study design began by simulating the ship speeds. Subsequently, a ship maneuvering simulation was performed. Liquefied natural gas (LNG) is widely used in maritime transportation systems. Studies have used LNG fuel in transport to model computer-generated LNG spills and dispersion processes above the sea surface. Studies have also focused on the fuel efficiency and hazard issues of LNG. Submarine pipelines are used for transporting objects, and they cause damage to submarine landslides and the seabed. Commercial software is commonly used for creating algorithms, computations, and simulations as an instant programming tool to perform data visualization, data analysis, and computational methodologies. The computational results of ship simulations could be collected as a maritime databank to form big data, which can be used in the future to plan the ML strategy leading to AI execution.

Table 1 Characteristics of MC transportation

Study design	Study purpose	Key findings	Algorithmic software usage	Maritime big-data possibility	AI feasibility	Future direction
Simulation of 3D flow of maritime LNG control valves [40]	Determine the advanced design of maritime LNG control valves with high pressure drop	Good agreement of computational results with conventional control valves, improvement of flow pattern, reduction of cavitation, and prediction of performance	Commercial CFD-ACE+	N/A	N/A	N/A
Simulation of submarine pipelines to examine the interaction of ocean transports with submarine landsides [41]	Predict submarine pipelines imposed by submarine landslides, a comparison of different shapes (wedge, airfoil, double-ellipse, and arc-angle hexagon) and conventional circular shape	Revealing the disadvantages of conventional circular pipelines in terms of lift force and drag force when interacting with submarine landsides, a recommendation using other shapes	Commercial ANSYS	N/A	N/A	N/A
Simulation of distribution of LNG imposed by air and sea surface temperatures [42]	Predict the LNG dispersion process to spill and smoke clouds to examine sea transport as a major application of maritime fuel	Good agreement of computational results with experiments; sea surface temperatures impact LNG dispersion more than air temperatures do	Commercial ANSYS Fluent	N/A	N/A	Hazard of evaluating LNG spill and vapor cloud dispersion

Table 1 Characteristics of MC transportation (continued)

Study design	Study purpose	Key findings	Algorithmic software usage	Maritime big-data possibility	AI feasibility	Future direction
Simulation of 3D flow of maritime LNG control valves [40]	Determine the advanced design of maritime LNG control valves with high pressure drop	Good agreement of computational results with conventional control valves, improvement of flow pattern, reduction of cavitation, and prediction of performance	Commercial CFD-ACE+	N/A	N/A	N/A
Simulation of submarine pipelines to examine the interaction of ocean transports with submarine landsides [41]	Predict submarine pipelines imposed by submarine landslides, a comparison of different shapes (wedge, airfoil, double-ellipse, and arc-angle hexagon) and conventional circular shape	Revealing the disadvantages of conventional circular pipelines in terms of lift force and drag force when interacting with submarine landsides, a recommendation using other shapes	Commercial ANSYS	N/A	N/A	N/A
Simulation of distribution of LNG imposed by air and sea surface temperatures [42]	Predict the LNG dispersion process to spill and smoke clouds to examine sea transport as a major application of maritime fuel	Good agreement of computational results with experiments; sea surface temperatures impact LNG dispersion more than air temperatures do	Commercial ANSYS Fluent	N/A	N/A	Hazard of evaluating LNG spill and vapor cloud dispersion
Simulation of high-speed catamaran transport to examine fuel economic efficiency [43]	Predict full-scale resistance values of the ship	Good agreement of computational results with experiments; the full-scale drag of large catamarans	Open-source OpenFOAM	N/A	N/A	Simulate medium-speed catamarans in shallow water conditions
Simulation of virtual ship maneuvering using a captive model test [44]	Determine hydrodynamic coefficients for predicting ship maneuver	Good agreement of computational results with experiments; primarily designing maritime transport performance	Commercial STAR-CCM+	Collect computational results of the model ship (DTMB 5512)	Using the same hydrodynamic model, problems, and initial conditions	N/A
Simulation of 3D hydrodynamics of NACA 0012 airfoil (wing) moving above a free surface for super-high-speed ships [45]	Predict flow field and pressure distribution around the wing on a free surface	Treating a free surface as a rigid wavy wall, examining the lift/drag ratio involved in a propulsion system	N/A	Collect computational results of the NACA 0012 airfoil wing	Using the same geometry, problems, and initial conditions	N/A
Creation of a new solver for transport equation [46]	Create a new solver method	Acceptable results compared to standard solver	Open-source OpenFOAM	N/A	N/A	N/A

Table 1 Characteristics of MC transportation (continued)

Study design	Study purpose	Key findings	Algorithmic software usage	Maritime big-data possibility	AI feasibility	Future direction
Prediction of hydrodynamic performance of marine propeller [47]	Predict the hydrodynamic performance using a neural network	A neural network can be trained by CFD data	Commercial ANSYS Fluent	Yes, the collection of CFD data	Yes, ML and CFD data	N/A
Simulation of a boil-off gas generation for LNG [48]	Predict the thermodynamic and hydrodynamic of an LNG tank	Understanding the thermal behavior and characteristics of an LNG tank	Commercial ANSYS Fluent	Collect the same computing results of an LNG tank	Using the same scale model, problems, and initial conditions	N/A
Simulation of a semi-submersible floating offshore wind turbine [49]	Analyze the accuracy of the simulation	A guideline is provided for the verification and validation of the simulation	N/A	N/A	N/A	N/A
Optimization of a fin-and-tube heat exchanger [50]	Investigate the optimal tube settings for a fin-and-tube heat exchanger	Significant improvements in thermal-hydraulic efficiency	Open-source OpenFOAM	N/A	N/A	N/A
Prediction of dynamic responses of the ultra-large floating body on maritime airport [51]	Analyze a case study on an ultra-large floating body under typhoon-wave	A reference for the design and construction of maritime airports under typhoon conditions.	N/A	Collect the same computing results of maritime airports	Using the same scale model, problems, and initial conditions	N/A
Prediction of high-speed craft [52]	Present geometric deep learning models for engineering design optimizations	Acceptable results of the deep learning-based surrogate model using CFD data as a ground truth	N/A	Yes, the collection of CFD data	Yes, ML and CFD data	N/A
Assessment of a marine diesel engine fueled with natural gas [53]	Calculate the emission and performance of marine diesel engine	Temperature is a major reason for the increasing use of natural gas and biodiesel content.	N/A	Collect the same computing results of marine diesel engine	Using the same scale model, problems, and initial conditions	N/A

Fig. 5 shows a bottom view of the flow computation throughout the control valves of maritime LNG structures. An example of data visualization in MC transportation revealed velocity streamlines paired with contour plots. Among the included studies, those focusing on MC transportation were the smallest in number because an increasing number of ocean studies have recently been conducted. Hence, the future direction of research on MC transportation is expected to be economic efficiency and environmental sustainability.

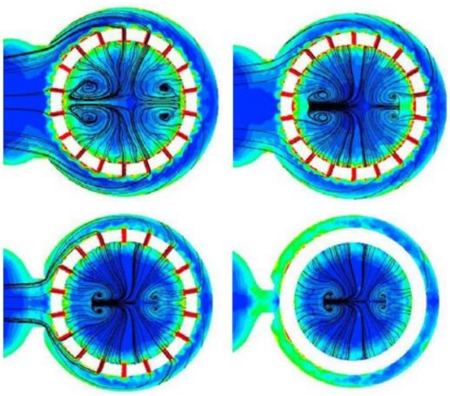


Fig. 5 MC transportation visualization showing LNG control valves [40]

4.4. MC environment

The MC environment focuses on environmental simulations and oceanic issues. Table 2 lists the collection of MC environments. Studies in this area have reported important ocean issues, such as the detection of microparticles of heavy metals in the ocean, the presence of coastal waste particles, underwater robotic observers, renewable energy generated by a tidal stream generator, oxygen dissolved in coastal water, ocean noise reduction, diesel engine emission reduction, and the effect of abalone aquaculture on the ocean. Several studies have presented their codes (in-house software) instead of using commercial software for computations, algorithms, and simulations. Big data and AI can be used to solve similar computational problems, models, and initial conditions. Data obtained from the computing results can be collected if the same geometrical domains are used, such as diesel engines and waste sorting models.

Table 2 Characteristics of the MC environment

Study design	Study purpose	Key findings	Algorithmic software usage	Maritime big-data possibility	AI feasibility	Future direction
Simulation of deployment patterns of tidal stream turbines in the ocean [54]	Determine single and arrayed tidal stream turbines to generate maritime energy	Revealing the design of deployment of tidal turbine arrays offering new opportunities to progress renewable energy	In-house software	N/A	N/A	N/A
Simulation of the automatic design process of environmental ocean microfluidic chip [55]	Detect maritime ecological toxicity of heavy metals in microalgae	Detect ocean microfluidics-integrated heavy metals (Cu, Hg, Cd, and Zn) using hydraulic analogy	Commercial CFD-ACE+ and OrCAD	N/A	The automatic design process of microfluidic dilute network for ocean ecological toxicity assessment	Routine microalgae bioassays for expanding cell-based screening of environmental health risks
Simulation of coastal waste particles in a wind-power sorting system [56]	Determine different airflow rates to classify coastal waste particles into both combustible and noncombustible characteristics	Identify the arrangement of coastal waste particles to ensure recycling and reduction of coastal waste	Commercial ANSYS	Collect the same computing results of coastal waste particles and airflow rates	Using the same scale model, problems, and initial conditions	N/A
Simulation of marine diesel engine for catalytic reduction system (CRS) [57]	Predict NOx emission reduction using a computing approach and comparison with experimental data	Revealing the reasonable potential of computational simulation to compute the actual NOx reduction rate of CRS	Commercial AVL Fire	Collect the same computing results of CRS, nozzle model, and NOx emission data	Using the same scale model, problems, and initial conditions	N/A
Simulation of a two-arm marine robotic vehicle to examine hydrodynamic behavior [58]	Determine the propulsion and manipulation of bioinspired underwater robotic vehicles for observing the marine ecosystem	Revealing flow development and hydrodynamic force around the bioinspired arms of underwater robotic vehicles	In-house software (developed own code)	N/A	N/A	Simulate more arm designs and kinematic parameters to optimize the current robotic system
Simulation of pumped surface water downwelling and dynamic response of OXYFLUX device (dissolved oxygen in coastal water) [59]	Determine 1/16 OXYFLUX model's dynamic response and pumping performance (estuarine and coastal marine ecosystems)	Revealing the nonlinear effects of the reduction in the dynamic behavior of OXYFLUX and the small wave caused by the low-intensity winds of summer (involves predicting anoxia)	Commercial STAR-CCM+	N/A	N/A	Improve time-domain computational model and floater shape; extend surge mode (currently have heave mode and pitch mode) and mooring system

Table 2 Characteristics of the MC environment (continued)

Study design	Study purpose	Key findings	Algorithmic software usage	Maritime big-data possibility	AI feasibility	Future direction
Simulation of submersible abalone cages for marine-deployed aquaculture [60]	Simulate advanced abalone cages and conventional abalone cages in the exposed ocean environment	Performing surface and submerged simulations of both advanced and conventional abalone cages; new design of abalone cage	Commercial Flow-3D, Fluent, and MSC.MARC	N/A	N/A	Perform economic analysis and risk calculation for newly designed abalone cage
Simulation of the hydrodynamics of a spherical underwater robot [61]	Predict the movement of the spherical underwater robot	Examine hydrodynamic force, velocity, and pressure, basic movement characteristics of robot moving underwater	Commercial ANSYS	N/A	N/A	Improve the control accuracy of spherical underwater robots
Simulation of acoustic sounds generated from flows around circular cylinder [62]	Determine noises occurring while transport moves at increasing speed	Revealing simulated acoustic sound waves and sound pressure	In-house software	N/A	N/A	N/A
Simulation of floating tidal stream for renewable energy [63]	Assess floating tidal concepts compared to seabed mounted systems	Good agreement of computational results with experiments	Open-source OpenFOAM	N/A	N/A	N/A
Simulation of a marine environment containing chloride sea salts [64]	Evaluate a crack growth of chloride-induced stress corrosion cracking in a dry storage system	A long-term environmental temperature had an impact on the erosion of long-term storage	Commercial ANSYS Fluent	Collect the same computing results of a storage system and marine environment	Using the same scale model, problems, and initial conditions	N/A
Simulation of underwater gas leakage and dispersion behaviors [65]	Investigate environmental pollution caused by underwater gas leakage	Current speed and gas leaking rate mainly affect the underwater gas migration process	Commercial ANSYS Fluent	N/A	N/A	N/A
Simulation of environmental loads impact ship maneuverability [66]	Investigate a real seaway to understand a ship's maneuvering performance	Good agreement of computational results with experiments	Open-source OpenFOAM	Collect the same computing results of environmental loads and vessel model	Using the same scale model, problems, and initial conditions	Prediction of the ship maneuver in waves with different wavelengths and heights
Simulation of multiphase oil behaviors [67]	Calculate risk assessment and pollution control of oil spills	Found that the presence of ice makes the spreading of spilled oil slower	N/A	N/A	N/A	N/A
Simulation of marine cabin's ventilation for reefer containers [68]	Analyze refrigeration efficiency in a severe marine environment	Good agreement of computational results with experiments	Commercial ANSYS Fluent	Collect the same computing results of reefer containers and the marine environment	Using the same scale model, problems, and initial conditions	N/A

Fig. 6 shows the tidal stream generators in the natural environment of the ocean. In this case, data visualization in the MC environment was performed using velocity streamlines designed to optimize the arrangement position of tidal stream generators in the ocean to generate renewable energy. Future studies can focus on improving the accuracy of the computing results by redesigning the simulations. Some included studies focused on MC environments because of the effects of fossil fuels and renewable energy on the global economy and sustainable development goals.

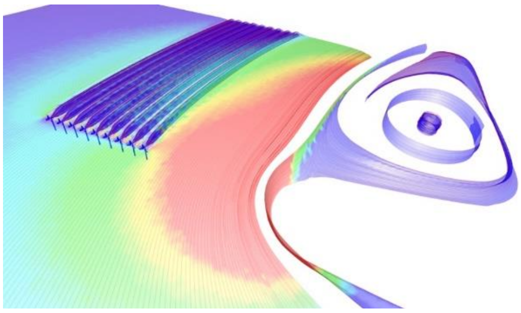


Fig. 6 MC environment visualization revealing tidal stream generators in natural flow surroundings [54]

4.5. MC development

MC development involves the study of geometrical simulations and ocean-shaped designs linked to the sea. Table 3 lists the characteristics of MC development. Study designs indicated that maritime development primarily focused on the design and modeling of oceanic objects, such as ships, sailboats, propellers, propeller blades, breakwater slopes, wave gliders, bio-inspired robots, submarines, and deep-water risers. Most studies on maritime development have used the knowledge of fluid dynamics and hydrodynamic foundations, as well as the propulsion prediction of objects related to the ocean. Open-source and commercial software programs are regularly used to create algorithms, simulations, and computations. The analysis results indicated that maritime big data and AI are likely achievable with similar geometrical domains, initial conditions, and maritime issues.

Table 3 Characteristics of MC development

Study design	Study purpose	Key findings	Algorithmic software usage	Maritime big-data possibility	AI feasibility	Future direction
Simulation of numerous marine hydrodynamic problems [69]	Develop their own software for naval architecture and ocean engineering	Visualize marine hydrodynamics	Open-source OpenFOAM	Collect similar computational results for AI	Using the same scale model, problems, and initial conditions	Efficiency and accuracy of computing solver
Simulation of sheet cavitation flow around marine propellers [70]	Predict cavitating flows at low Reynolds numbers of the transition-sensitive turbulence flow model	Good agreement of computational results with experiments	Commercial ANSYS Fluent	Collect the computational results of the same propeller model	Using the same flow model, problems, and initial conditions	N/A
Simulation of wave-seabed and breakwater slope [71]	Predict the impact of wave-seabed on breakwater design	Increment of the slope of a breakwater altered seabed and liquefaction	Open-source OpenFOAM, Commercial COMSOL and MATLAB	Collect similar wave-seabed and breakwater designs	Using the same scale model, problems, and initial conditions	N/A
Simulation of optimization of marine contra-rotating propeller [72]	Determine the best hydrodynamic performance of marine contra-rotating propeller	Developing a new optimization method for maritime propeller	Commercial ANSYS Fluent	Collect the computational results of the same propeller model	Using the same scale model, problems, and initial conditions	Efficiency improvement of computing results considering time consumption and technological cost
Simulation of a wave glider in a head sea [73]	Predict the dynamic performance of a wave glider in a head sea	Dependence of propulsion efficiency on the surge of surface boats and passive eccentric rotation of hydrofoil	Commercial FINE/Marine and STAR-CCM+	Collect the computational results of the same simulation and wave glider model	Using the same scale model, problems, and initial conditions	Improvement of propulsion efficiency, optimum simulation, and design of hydrofoil in different head sea conditions

Table 3 Characteristics of MC development (continued)

Study design	Study purpose	Key findings	Algorithmic software usage	Maritime big-data possibility	AI feasibility	Future direction
Simulation of the ship with two flapping foils [74]	Determine the best hydrodynamic performance of a ship with two alike penguin flippers	The Function of Strouhal number, efficiency, and force coefficients of flapping foils	Commercial ANSYS Fluent	Collect similar computational results of ship model and function of flapping foils	Using the same scale model, problems, and initial conditions	N/A
Simulation of deep-water marine riser [75]	Determine vortex-induced vibration and fatigue damage caused by a very long marine riser	Good agreement of computational results with experiments	N/A	Collect similar computational results of the same marine riser model	Using the same scale model, problems, and initial conditions	N/A
Simulation of a four-bladed marine propeller [76]	Determine the best performance of marine propellers	Good agreement of computational results with previous results	Commercial ANSYS Fluent	Collect similar computational results of the same marine propeller	Using the same scale model, problems, and initial conditions	Improvement of velocity and rotational speed
Simulation of SUBOFF model maneuver [77]	Determine the flow change around the stern and entire SUBOFF for maneuverability	Good agreement of yawing moment and yawing force with experimental data	Commercial ANSYS	Collect similar computational results of the SUBOFF model	Using the same scale model, problems, and initial conditions	N/A
Simulation of bio-inspired marine propulsor by imitating uniform fish fin [78]	Optimize the movement of maritime fish fin propulsor	Lunate-shaped fish fin demonstrates the highest efficiency improvement	Commercial ANSYS Fluent	N/A	N/A	Efficiency improvement of computing results by modifying and redesigning the study model
Simulation of a five-bladed metal marine propeller [79]	Determine hydrodynamic performance with a change in marine propeller geometry	The deformation of the marine propeller causes a negligible change in hydrodynamic performance	Commercial ANSYS Fluent	Collect similar computational results of the same marine propeller	Using the same scale model, problems, and initial conditions	Analysis of a composite propeller and a comparison with the current result
Simulation of a composite marine propeller [80]	Optimize the hydroelasticity performance of the composite marine propeller	Optimizing the design of the composite marine propeller can reduce the vibratory hub loads	Commercial ANSYS	Collect similar computational results of the same marine propeller	Using the same scale model, problems, and initial conditions	N/A
Simulation of marine propeller and SUBOFF submarine [81]	Predicting that the propeller makes submarine underwater noise	Reduction of submarine underwater noise requires the control of propeller thrust excitation.	N/A	N/A	N/A	N/A
Simulation of fluid displacement under the bow of a ship model [82]	Predict the breaking wave and flow patterns at the bow of the ship model	Visualizing the breaking bow wave and wave patterns at the bow of the ship model	In-house software (developed own code)	N/A	N/A	Examining the interaction of bow wave with shoulder wave for a comprehensive understanding of complex phenomena
Simulation of novel composite tube (toting wheel) marine current turbines under free flow conditions [83]	Predict ocean current energy generation from single and arrayed marine current turbines with ten tubes	Revealing significant power extraction of ocean current energy from arrays of marine current turbines with ten tubes	Commercial ANSYS Fluent	N/A	N/A	Refinement of simulation system, such as changing wheel design (amend blade) to extract more ocean current energy

Table 3 Characteristics of MC development (continued)

Study design	Study purpose	Key findings	Algorithmic software usage	Maritime big-data possibility	AI feasibility	Future direction
Study of flow around three commercial ships (container ship and two crude-oil ships having bow and stern bulbs) [84]	Determine flow characteristics around the three commercial ships, a study of ship hydrodynamics	Measuring flow wave patterns and velocity components depending on the speed of the ship	N/A	N/A	N/A	N/A
Simulation of the unsteady motion of a ship in waves [85]	Predict the performance of the ship in waves	Reveal the viability of computing ship motion with two degrees of freedom	In-house software	N/A	N/A	The Realistic computational approach to simulate six-degrees-of-freedom motion with nonlinear phenomena
Simulation of flow around a ship model [86]	Calculate viscous flow passing through the ship hull with and without a free surface	Computational approach by comparing computing results with measurement data	In-house software	N/A	N/A	N/A
Simulation for the design of a sailboat [87]	Compute the design of hull-form development of the sailboat	Reveal the prediction of both steady and unsteady sailing performances of boats	In-house software	N/A	N/A	Improve simulation
Simulation of an X-plane submarine [88]	Compute the maneuvering coefficients of the submarine	Good agreement of computational results with experiments	SNUFOAM based on Open-source OpenFOAM	Collect similar computational results of X-plane submarine	Using the same scale model, problems, and initial conditions	N/A
Simulation of the planing hulls [89]	Analyze complex hydrodynamics problems of the planing hulls	CFD automated workflows can be used to study the planing hull hydrodynamics	Open-source OpenFOAM	N/A	N/A	N/A
Simulation of ship model maneuvers for autonomous vessels [90]	Compute the dynamic maneuvers of a container ship with self-propelled free running	Good agreement of computational results with experiments	Commercial STAR-CCM+	Collect similar computational results of the same marine propeller	Using the same scale model, problems, and initial conditions	Validate and implement a more sophisticated propeller model
Simulation of ship navigation [91]	Analyze the energy efficiency of ships	A reference for performance monitoring and maintenance prediction of international maritime affairs	N/A	Yes, the collection of CFD big data	Using the same scale model, problems, and initial conditions	Collect the accumulated navigation mileage of every ship
Simulation of blade shape optimization [92]	Optimize the shape of the blades of the savonius wind turbine	The optimized blade performed better than a classical semicircular blade	Commercial ANSYS	Collect similar computational results of the blade model	Using the same scale model, problems, and initial conditions	Improvement of simulation and blade shapes
Simulation of towing tank [93]	Investigate the effect of muddy seabeds on marine vessels	Accuracy of the Bingham model for marine vessels sailing through fluid mud	ReFRESCO CFD code	N/A	N/A	N/A

Fig. 7 shows a study of ship hydrodynamics to model a ship maneuverer moving in the ocean. This research illustrates a computing example of maritime development, and the developed model explains virtual ship hydrodynamics. Future studies can focus on improving the precision and productivity of the computing results, reducing computational costs, improving simulations, and using future technological advancements. Most included studies focused on MC development because of the relationship between modeling and design in the field of MC.

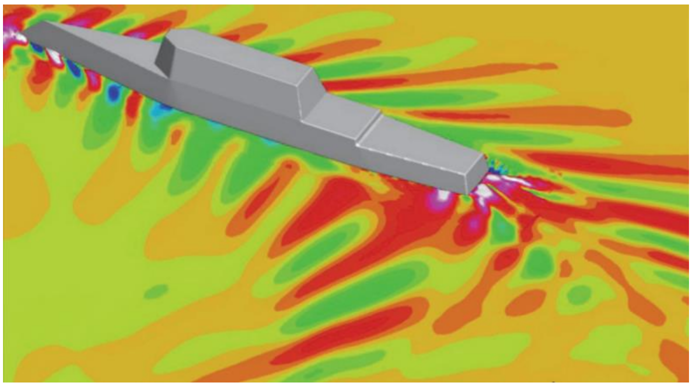


Fig. 7 MC development visualization illustrating the motion of a ship while it turns on the sea surface [69]

5. Discussion

In the present research, articles that focused on MC transportation, environment, and development were analyzed. Systematic reviews and metadata methodologies were used to search and analyze original full-text research articles on maritime literature retrieved from online digital databases. The field of MC focuses mainly on transportation, environment, and development. These MC areas are key inputs for economic benefits, demographic trends, security factors, increasing seaborne and trade demands, skilled workers, automation and technology, and sustainable development goals [12].

This research majorly contributes to the literature in several ways:

(1) This study expands research on the MC perspective by providing evidence showing how the key classification of the MC domain promoted ocean-based businesses.

(2) It is the first report to discover how MC domain configurations support management technologies. Since ocean-based businesses in several countries are a major economic contribution to the world economy through research, business, trade, and innovation, e.g., Great Britain, the United States, Taiwan, and China.

(3) The results of the current study provided the history of using computers for ocean-based businesses through the MC domain and assisted in planning future business, research, and innovation. This finding represented an opportunity to use the computational results of the same study designs to build big data and intelligent computation about MC data trends.

This study focuses on ocean-based businesses, particularly in the area of maritime studies, to obtain insights into the field of MC. The MC literature contains CFD involved in naval architecture, marine engineering, computer technology, visualization, and computational methodologies. In contrast, other maritime applications (e.g., shipping, freight, airlines, air transport, fisheries, finance, and investment) and other computational studies (those based on blockchain, the internet of things, social networks, and digital marketing) are excluded. Consequently, the main aim of MC is to support economic science and bioeconomy.

As shown in Fig. 4 MC began with the mathematical matrices based on numerical computation in 1990. Traditional computing methodologies are typically limited to the invention of computer technology to visualize data and findings. The computational results were mostly presented as 2D contours, line plots, and scatter plots [94-95]. Prior to that, computer technology was evolving, focusing on the improvement of microprocessor and semiconductor technologies, and industrialized

[34]. Therefore, MC was absent during the 1980s and 1970s (Fig. 4). When GPU technology was considerably improved in the 2010s [96], studies on MC began to be increasingly conducted (Fig. 4); these findings are presented in Fig. 3 (from 2012 to 2019, the number of first authorships increased).

An analysis of the original maritime literature indicates that computing and technology are paramount for education, new skill sets, and practical work. Maritime development reveals modeling is an essential ground skill set of all other MC areas (Fig. 4, development is highlighted as a root). Simultaneously, maritime transportation and environment (Fig. 4) were in line with the sustainable development goals [97-98]. However, maritime transportation studies have provided benefits not only for increasing trade opportunities, but also improving economics and supply chain management [12, 99-100]. Thus, MC transportation is a crucial economic factor.

Further maritime trends depend on clean energy, renewable energy, environmental recovery, trade, and real-time digital efficiency cost management [101-103]. MC development demonstrates modeling literacy and skills enabled apprentices, learners, and researchers to translate non-time-dependent activities, such as the maritime logistics process of supply chains for scheduling issues, into a time-dependent computer model, depicting a well-structured problem [21, 104-105]. The results shown in Tables 1-3 indicate that big data and AI are likely achievable through the data collection of similar computational results for applying the ML approach.

The maritime visualization and computational methodologies discovered in this report are used in ocean studies. The maritime visualization outputs of this report in terms of MC transportation, environment, and development are shown in Figs. 5, 6, and 7, respectively. Moreover, data visualization methodologies are identified, including organizing data into a table, 1D/2D contour plot, 2D cross-sectioned plot, line graph, bar graph, vector plot, streamline plot, streamline contour, streamline surface, vorticity magnitude contour, wave pattern, 3D graphical abstract, 2D geographical map, scatter plot, actual problematic photo compared with computing results, 3D streamlines, 3D particle tracers, 3D cross-sectional views, 3D computer domains, flowchart, and workflow diagrams.

Mathematical models and techniques for computation used in MC include the Navier–Stokes equation, fluid-structure interaction, marker-and-cell method, Navier–Stokes–Poisson equation, Reynolds-averaged Navier–Stokes (RANS), Reynolds stress model, microalgae bioassay, microfluid networks, circuit design, fluid dynamics, hydrodynamics, experimental study, unsteady RANS, structural model, wave model, coupled blade element momentum (BEM)-CFD model, renormalization group k-epsilon model, 2D schematic diagram, 3D computer design, statistical analysis, error estimation, large-eddy simulation, detached-eddy simulation, kinematic equations, lattice gas method, lattice Boltzmann method (LBM), lattice gas cellular automation, finite difference LBM, arbitrary Lagrangian–Eulerian method, electronic design automation, and computer-aided design.

Furthermore, the meshing element approaches comprise both the finite volume approach and the finite element method. In addition, open-source, in-house, and commercial software programs are used in MC to create computations, algorithms, and simulations. However, the open-source software used to develop in-house programs is based on OpenFOAM [106].

The aforementioned MC domain primarily consists of transportation, environment, and development. MC characterizes the computer simulation planning of people's ocean business processes and tasks. The MC approach generally includes maritime visualization and computational methodologies. MC supports the translation of maritime data and ideal design information into real-world objects, models, and applications [20, 107]. A business process substantially requires a clear goal associated with its producible outputs. Hence, these procedures should be simple with tractability and should strongly focus on producing maritime computational results and outputs [21, 108]. MC offers support to economic science and the bioeconomy [15-16, 109-110].

The analyzed studies published in the years 2020-2022 demonstrated the applications of the proposed concept of ML, CFDs, and big data [47, 52, 91]. Fig. 4 shows the evolution of computer technology; clearly, the complex problem modeling and computation techniques progressed together with the invention of computers [34]. It seems that the trends of data visualization and computational methodologies will be included soft computing and intelligent computation in the 2020s (Fig. 4). Furthermore, the global policies on climate change and sustainable development have directly influenced MC research. As a result, the analyzed results in Fig. 3 depict the rise of MC transportation and environment significantly in the years 2020-2022.

This study has some following limitations:

(1) As a comprehensive search was performed in different databases to retrieve full-text original articles, most of the search results did not yield original studies. Thus, in some databases, such as Google Scholar, it is difficult to categorize original research.

(2) The sources of digital maritime literature are changing daily owing to the regular publication of new articles, new research submissions, and updated scientific databases. Thus, maritime digital databases and literature do not have up-to-date oceanic information. Nevertheless, the use of MC began to rise in the 2010s (Fig. 4).

(3) An automated procedure for document search and analysis is not investigated. Hence, a manual analysis is performed to identify the original studies on MC.

(4) An automated document search and analysis need to be performed to complement this study. Furthermore, no articles from the IET Digital Library or IEEE-Xplore databases met the inclusion criteria. Additionally, the same articles were indexed in several databases which are the Web of Science, Scopus, ScienceDirect, and Google Scholar. This complicates the final combination of search results.

(5) The systematic search is time-consuming, requiring a considerable time to read articles thoroughly to ensure that they met the selection criteria for inclusion in this meta-analysis.

6. Conclusion

It is the first report to discover how MC domain configurations support management technologies. In this systematic review and meta-analysis, MC studies were identified and reviewed. The areas of MC development, environment, and transportation were successfully categorized. The results show that MC can provide new oceanic knowledge and education to support economic science and bioeconomy. From the analysis, the following observations are made:

(1) Studies on MC began to increase in the 2010s, while maritime modeling is a key skill set. Maritime transportation studies focus on the usage of LNG, maneuvering ship’s speed, and submarine pipelines. The maritime environment has been explored for ocean recovery and protection. The trends of maritime data visualization and computation methodologies were observed to be associated with computational coding techniques and the invention of computers.

(2) The ML strategy can be applied to the big data collection of similar computing results to implement AI strategies. Additionally, MC improvement mainly focuses on promoting MC to the public for an increment of MC research studies. This update will add innovations and technologies; hence it creates an economic impact on ocean-based businesses.

(3) Future improvements to the MC may involve the use of quantum bits as an alternative to current digital bits for better modeling of specific problems for processor processing. The gap in connecting ML models to CFD results remains; thus, more research is needed to guide the generation of CFD results, and also makes all ML models are interconnected. The simple partial differential equation (PDE) of Navier–Stokes is one of the best methods for hybrid visualization and CFD practices. This hybrid model can be used as a standard guide for individuals to understand how to create specific questions using PDE and maritime modeling. Therefore, the efficiency of maritime modeling can be improved.

The present report indicates that MC is important in maritime society to accomplish sustainable development goals. Based on these primary results, further studies focusing on a case study of each MC classification are required to corroborate the present findings.

Conflicts of Interest

The author declares no conflict of interest.

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