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Review on Fixed and Floating Offshore Structures. Part II: Sustainable Design Approaches and Project Management

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Abstract: Offshore structures exist in a variety of forms, and they are used for a variety of functions in varied sea depths. These structures are tailored for certain environments and sea depths. Different actions for suitable equipment selection, platform type design, and drilling/production processes are required for the applications of these offshore structures, as given in Part I. This paper is the second part, which outlines various processes, loads, design approaches and project management of offshore platforms. To achieve these, proper planning must be conducted for lifting, transportation, installation, design, fabrication, and commissioning of these offshore platforms. Some historical developments of some offshore structures are presented, and some project planning routines are undertaken in this research. The ultimate goal is to provide a general overview of the many processes of offshore platform design, construction, loadout, transportation, and installation. Some discussions on the design parameters such as water depth and environmental conditions were presented. It also lists various software programs used in engineering designs covering software programs for structural analysis, 3D rendering, computer-aided design (CAD), hydrodynamic design, oceanic flow analysis, offshore structures analysis, mathematical modelling, coding/algorithm development software, and programming software to aid analytical calculations. The review also includes information on cutting-edge offshore platforms and industry advancements. Ultimately, for long-term operations, various types of offshore platforms for specific seawater depths are available.

Keywords: offshore structure; offshore platform; fixed platform; floating platform; oil and gas platform; production platform; drilling platform rig; marine structure; coastal structure; offshore facilities; project management; sustainable design; design and construction

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1. Introduction

Oil and gas facilities include offshore structures and onshore structures, onshore oil tanks, as well as both downstream and upstream assets [1–3]. Although offshore wind farm facilities are renewable energy facilities, while Very Large Floating Structures (VLFS) could have offshore applications, they are sometimes classified as offshore structures. However, the main categories include fixed and floating offshore structures [4–6]. Fixed offshore structures, monopods, and guyed wire caissons are examples of offshore structures. In the same vein, complex deep water assets such as Floating Production and Storage Offloading (FPSO), Mobile Offshore Production Unit (MOPU), Tension Leg Platform (TLP), and semi-submersible structures, are also examples of offshore structures. Advances in ocean engineering are currently being undertaken, with a variety of new offshore structure designs spanning from fixed platforms to floating platforms [6–10]. These offshore platforms can also be used for dynamic positioning, exploratory activities, drilling/production, navigation, ship (un)loading, fluid transport, and bridge support [11–16]. Hence, the facilities on the offshore structures require project management, asset/facilities management, and general maintenance. In addition, there are supporting attachments for these offshore installations that are used for a variety of functions and in a variety of water depths and environments globally. These components included drilling/production marine risers [17–23], composite risers [24–30], mooring lines [31–39], and marine hoses [40–49]. Figure 1 depicts some offshore platform installations.

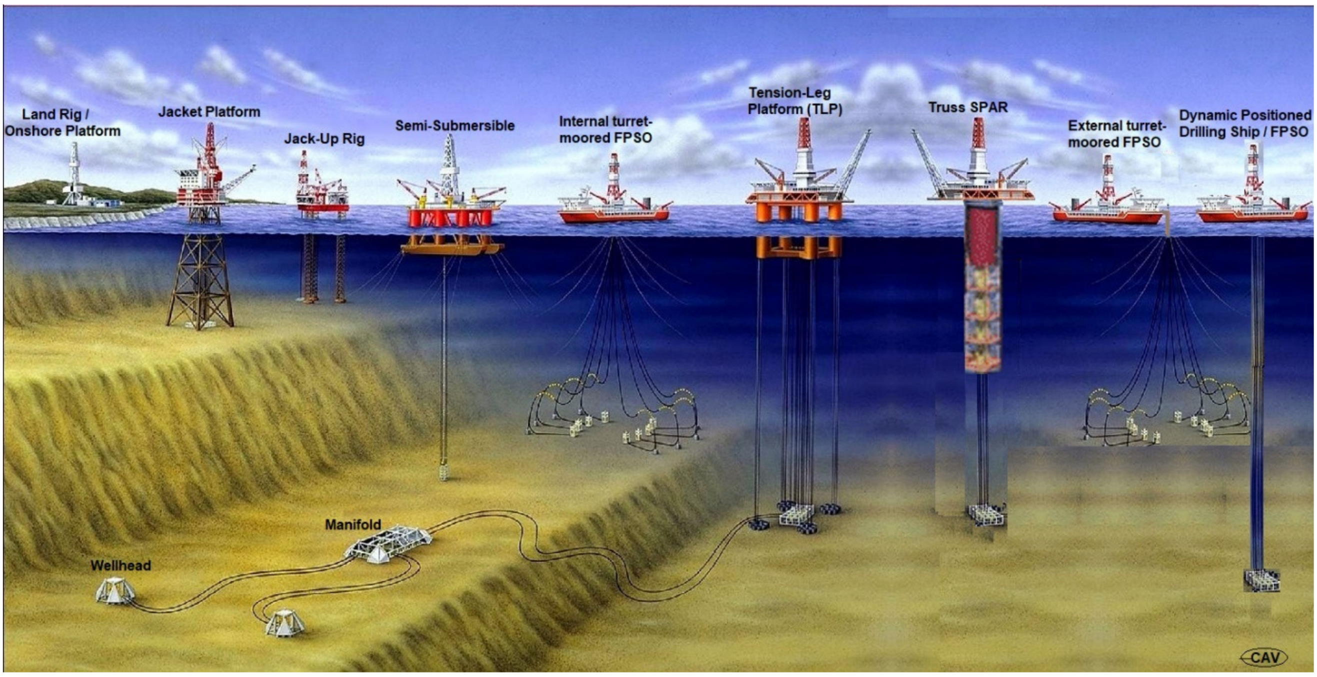

Figure 1. Different types of deep-water offshore facilities for drilling and production, showing land rig/onshore platform {10–100 m}, conventional fixed platforms{150–412 m}, jacket platform {150–412 m}, semisubmersibles {457–1920 m}; floating production, storage and offloading (FPSO) unit {1345–1500 m}; tension leg platform (TLP) {457–2134 m}; Truss SPAR {610–3048 m}; subsea wellhead, completion and tieback to a host facility, and subsea manifold.

Offshore platforms have been employed in a variety of aquatic situations and could be used as artificial reefs for many years. As a result, designing and maintaining them is incredibly challenging. Hence, careful consideration should be given to the design and maintenance of offshore structures in order to avoid early decommissioning, significant corrosion hazards, oil spillage, and other permanent environmental damage. Different activities for proper equipment selection [50–57], design of platform types [58–64], engineering management of well bores [65–73], and other drilling/production procedures [74–80] are required for the uses of these off-shore structures. One of the most obvious of these applications is offshore oil production, which presents a substantial challenge to the product designer or offshore engineer [81–83]. Environmental loadings [84–88], hydrodynamics [89–96], hydroelasticity [97], corrosion [98], failure analysis [99], ocean wave mechanics [100–108], fluid content loadings [109–115], fatigue limits [116–120], reliability [121–128], and so on are all factors to consider during the design process. As a result, the designer must ensure that the product is safe, stable, has a high fatigue resistance, has a long service life, and is cost-effective for the customer. Secondly, it is important that these offshore structures have high service life to ensure sustainability and durability, so that the oil producers can produce enough oil and gas products to meet the global demand. Figure 2 shows the daily demand for crude oil globally, showing dependence on fossil fuels.

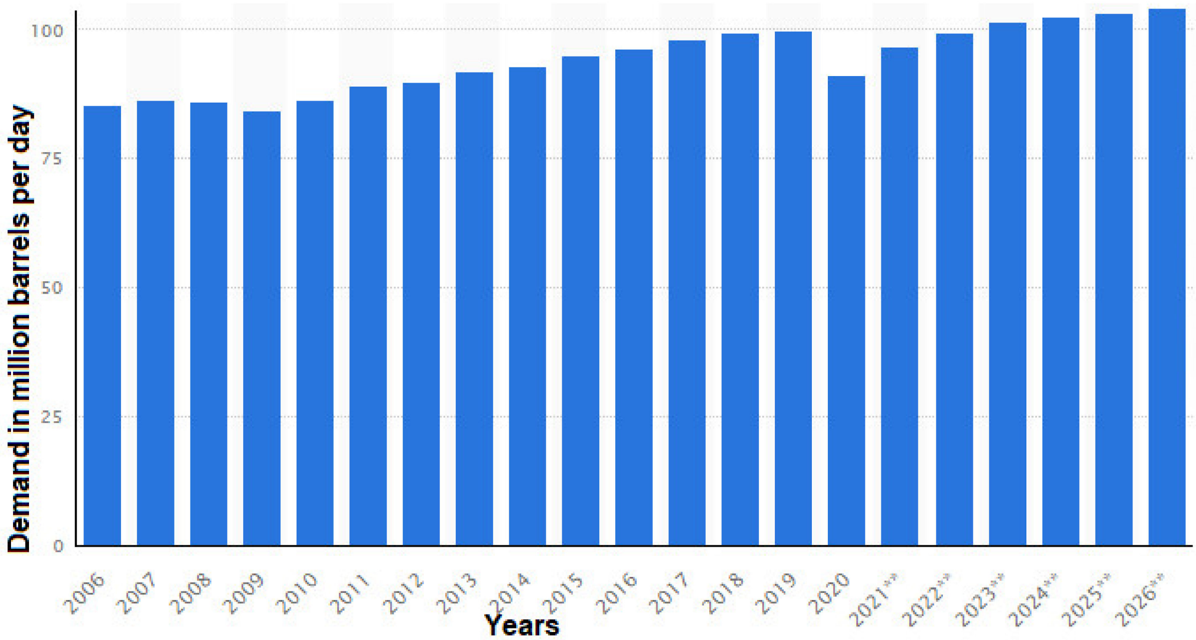

Figure 2. Daily demand for crude oil worldwide from 2006 to 2020, with a forecast until 2026 (in million barrels per day) {** shows the predicted daily demand from the forecast} (Courtesy: IEA & Statista, data retrieved in 2021).

Since offshore structures are exposed to extremely harsh marine environments and changing sea depths, these offshore assets must generally run securely for at least twenty-five (25) years. As a result, the designs are carried out using peak loads generated by hurricane wind and waves during the platform design life [129–135]. In addition, fatigue loads induced by waves over the platform's lifetime, as well as platform motion, are all essential design challenges addressed by standards [136–152]. Strong currents can occasionally impact the platforms, putting the integrity of the entire system at a threat, hence the need for designing offshore structures against harsh weather conditions [153–157]. To ensure the integrity of the structure is maintained, monitoring is essential for the design [158,159]. Furthermore, the scale of an offshore structure is considered during the design for its stability and hydrodynamics [159–163]. The material density is also taken into account in the design. The majority of offshore platforms are built in shipyards using enormous steel or in-situ using concrete, as is the case with gravity-based structures. These fixed and floating offshore constructions are mostly utilised for energy generating or oil production, while some are used as breakwater devices and wave-energy converters (WECs) [164–173]. Offshore platforms can be small or massive, depending on the functionality. However, offshore structures are recorded as among the world's highest man-made structures built. Also, the material grade must have high corrosion resistance to be used in ocean environments, such as high-grade steel [174–179]. The oil and gas are separated on the platform and transported to shore via pipelines or tankers [180–192]. The lifting, transportation, installation, design, fabrication, and commissioning of these offshore platforms must all be carefully planned to meet these goals [193–203]. The foundation of this semi-submersible in deeper waters requires excellent payload integration [204–212] for minimal motion responses across all degrees of freedom (DoF) due to the direction of the superstructure [213–215]. Hence the need for more understanding of the offshore structures, with the types of applications reviewed in Part I [5].

This paper is the second part of the review (Part II), which is conducted on sustainable design approaches for fixed and floating offshore structures. Section 2 provides a general overview of some sustainable drilling/production operations as well as the platform classifications and applications. Section 3 presents design considerations and design parameters for offshore structures, such as environmental conditions and water depth, while Section 4 outlines some design loadings, and lists various software programs used in engineering designs. Section 5 presents some design approaches, while Section 6 presents project management for offshore facilities. The ultimate goal of this paper is to give an overview of the various processes of offshore platform design and construction. Other activities include loading out, transporting, and installation of the platform's components.

2. Design Considerations

The development and design of floating and fixed platforms are based on some design criteria. All operating considerations and environmental data that potentially affect the platform's detailed design are included in the design parameters discussed here.

2.1. Operational Factors

2.1.1. Location

Before the design is finished and the work is completed on the engineering design layout, the platform's position should be determined. Environmental circumstances vary by location; within a particular geographic area, foundation conditions, as well as design wave heights, periods, and tides, will differ. There are different types of offshore floating platforms operating in varying water depths are illustrated in Figures A1–A3 of Appendix A. Figure 3 shows some floating structures like the drilling barge used during early explorations in the Gulf of Mexico (GoM), USA. The details of some platforms are given in Table 1.

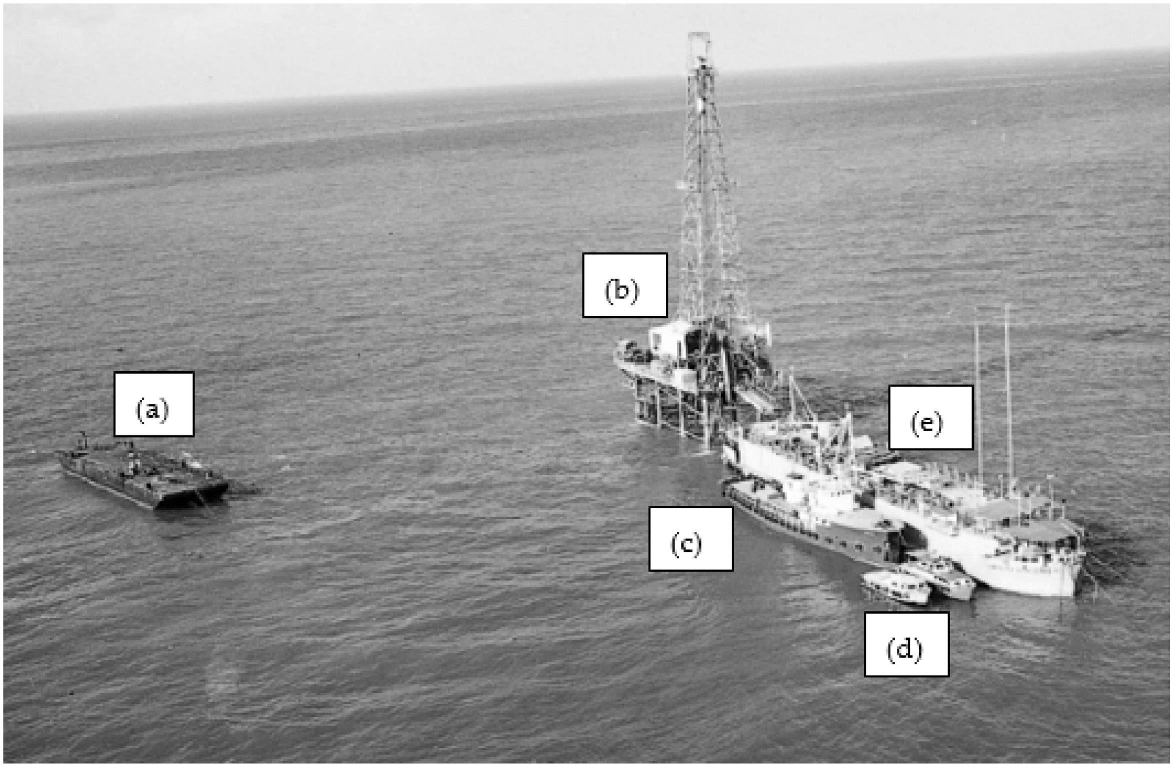

Figure 3. Drilling structures used during early explorations in the Gulf of Mexico (GoM) showing (**a**) floating barge, (**b**) typical offshore drilling rig, (**c**) service vessel, (**d**) tugboat, and (**e**) FPSO vessel.

Table 1. Some deep sea facilities with installation details.

Platforms	Sea Depths	Installed Years	Platform Type	Oil Field
Perdido	2450.0 m	2010	SPAR	GoM
Thunder Horse	1841.0 m	2010	SemiSubmersible	GoM
Magnolia	1400.0 m	2003	ETLP	GoM
Mad dog	1311.0 m	2005	SPAR	GoM
Bonga	1000.0 m	2005	FPSO	Nigeria
Marlin	988.0 m	1999	TLP	GoM
Ram-Powell	980.0 m	1997	TLP	GoM
Olympus	914.0 m	2014	TLP	GoM
URSA	1204.0 m	1999	TLP	GoM
Mars	896.0 m	1996	TLP	GoM
Auger	872.0 m	1993	TLP	GoM
Jolliet	536.0 m	1989	TLP	GoM
Bullwinkle	412.0 m	1988	Fixed Platform	GoM
Appomattox	2195.0 m	2019	Semisubmersible	GoM
Na Kika	1829.0 m	2003	Semisubmersible	GoM
Atlantis	2134.0 m	2007	Semisubmersible	GoM
Heidrun	351.0 m	1995	TLP	GoM
Snorre	310.0 m	1992	TLP	North Sea
Cognac	304.0 m	1978	Fixed Platform	GoM
Hutton	148.0 m	1984	TLP	North Sea
Vito	1189.0 m	2022	Semisubmersible	GoM
Argos	1311.0 m	2022	Semisubmersible	GoM

2.1.2. Function

Drilling, producing, storing, materials processing, living quarters, or a combination of these are the most common functions for which a platform is created. A study of the layouts of equipment to be located on the decks should be used to decide the platform configuration. Before deciding on final dimensions, the clearances and spacing of equipment should be carefully considered. Function determines the classification of the offshore structure. The function of jack-ups could be for drilling or decommissioning or the installation of wind turbines. Figure 3 shows the floating drilling barge used in early explorations in the Gulf of Mexico (GoM), USA.

2.1.3. Orientation

The platform's orientation refers to its location in the design with respect to a fixed axis, such as true north. The direction of prevailing seas, winds, and currents, as well as operational requirements, are frequently used to determine orientation.

2.1.4. Water Depth, Waves and Current

Following the increased need for energy, fossil fuels have recently gained market share from various energy sources. However, both renewable energy sources and non-renewable energy sources have competed fairly based on the use of onshore and offshore platforms. To choose the right oceanographic design parameters, information on sea depth, ocean waves, current and tides is required. The water depth should be as precise as is feasible so that elevations for fenders, decks, boat landings, and corrosion protection may be set. Floating offshore wind turbines (FOWTs) are also designed by considering the water depth, waves and current. Some of the newer offshore platforms contain advanced technologies derived from existing offshore platforms employed in oil and gas development. Some wind turbines have foundations designed based on other platforms like semisubmersibles [213–220]. For breakwater and wave energy devices, they require shallower water depths. However, these devices have been able to operate under a diverse range of wave environments as seen in the diverse range of technologies, and devices such as the single column and multi-column wave energy converters (WECs) [164–173].

2.1.5. Deck Elevation

When waves contact a platform's bottom deck and equipment, they produce large forces and overturning moments. Unless the platform is intended to withstand these forces, the deck's height should be sufficient to offer appropriate clearance above the design wave's crest. Additionally, an "air gap" should be considered to allow for the passage of waves greater than the design wave. There are some guidelines for the air gap.

2.2. Environmental Factors

API and other relevant industry standards include general meteorological and oceanic factors such as in API WSD 2000 Cl. No. 1.3.1 and API RP-2MET-INT [153–156]. When establishing the relevant meteorological and oceanographic parameters impacting a platform location, experienced specialists should be engaged. The sections that follow provide a broad overview of the information that may be necessary. After consulting with both the platform designer and a meteorological oceanography specialist, the information needed at a place should be chosen. Data from measurements and/or models should be statistically examined to provide the necessary descriptions of typical and extreme environmental conditions.

All relevant information on the environmental data used should be meticulously documented. The estimates on the structural reliability, fatigue life prediction and the source for all design data should be noted for validation, verification, trustworthiness, and dependability. Lastly, both the parameters used and the methodology listing all the procedures used to convert existing data into desired environmental values should be recorded. Typical environmental conditions are seen in the North Sea's weather conditions where the Transocean Enabler semisubmersible drilling rig operates (see Figure 4).

Figure 4. Transocean Enabler semi-submersible drilling rig built in 2016 and designed to operate in harsh environments (Courtesy: Transocean).

2.3. Loading Factors

In ocean engineering, the term "environmental load conditions" is used in the design of offshore structures and other marine structures to include wind, waves, currents, and tides, depending on the environment under consideration. Operating environmental load conditions are the forces placed on the structure by a minor occurrence that is not severe enough to obstruct normal operations as stipulated by operators. The forces imposed on the structure by minor events that are not harsh enough to hinder any normal operation, as prescribed by the operators, are known as operating environmental load conditions. The forces placed on the platforms by the selected design scenario are known as design environmental load conditions. Design loading conditions are introduced as seen in industry standards, such as API-WSD 2000 Cl. No. 1.3.1 and API 2MET-INT, to design these structures. Maps of environmental data showing rising sea levels and wave energy are respectively represented in Appendix A Figures A4 and A5.

The platform should be built to withstand the loads that will have the most severe consequences for the construction. The following loading conditions should be included in the loading conditions: environmental conditions, as well as appropriate dead and live loads:

1. Operating environmental parameters, including dead loads and maximum live loads, that are appropriate for the platform's usual operations;
2. Operating environmental parameters, including dead loads and minimum live loads that are adequate for the platform's usual operations;
3. Establish environmental factors in the design with maximum live loads and dead loads that can be combined with extreme conditions;
4. Establish environmental conditions in the design with a minimum of dead loads and a maximum of live loads that can be combined with harsh conditions;
5. Environmental loads should be factored in according to the likelihood of any simultaneous occurrences in the loading scenario under consideration, except seismic loading. Where applicable, a seismic (or earthquake) load should be applied to the platform as a distinct environmental loading condition;
6. The operating environment should be realistic of the platform's relatively severe weather conditions. They do not have to be hard and fast rules that cause the platform to shut down if they're broken. In the Gulf of Mexico, a 5-year winter storm from 1-year weather is typically employed as an operational condition, however recent designs have longer design times as seen in API 2MET-INT;
7. Both production and drilling platforms should have a maximum live load that takes into account production, drilling, and work over mode loadings, as well as any acceptable combinations of drilling or work over operations with production;
8. To maximise design stress in the platform members, consider variability in supply weights and the positions of mobile equipment such as a drilling derrick.

2.4. Structural Attachments: Mooring lines and Marine Risers

The design of an offshore structure is usually dependent upon the function of the structure. For offshore structures that are used in drilling and production purposes, there are structural attachments, particularly mooring lines and marine risers. It is important to state that a typical offshore production platform could have up to 35 risers, each with up to 90 large diameter tube segments (riser joints) that run the length of the platform. Production risers made of high-grade steel are currently used in the offshore oil and gas industry, and their weight limits the ability of offshore operations to move into deeper seas. With rising depths of the sub-sea wellhead, the weight of a riser and, as a result, the top tension required to retain it in the desired position increases. At the same time, the offshore platform's top-tensioning capacity limits the number of risers that may be attached to it. As a result, if the weight of a single riser can be lowered, it will be able to utilize natural resources in deeper waters or incorporate more risers to existing platforms, increasing their production capacity. A tension application is supplied to the top of a top-tension riser (TTR) to remove compressive stresses and maintain the vertical position of the riser, and sometimes strakes are used to suppress vortex-induced vibrations (VIV) on the risers. However, steel risers are heavy and add to the weight called the deck load, as such there is the need to have a weight-optimised riser. Thus, the need for other structures like flexible risers, hybrid composite risers, and steel catenary risers (SCR) [204–212]. A typical hydrodynamic model developed using environmental data for a floating semisubmersible platform in Orcaflex 10.3d is given in Figure 5.

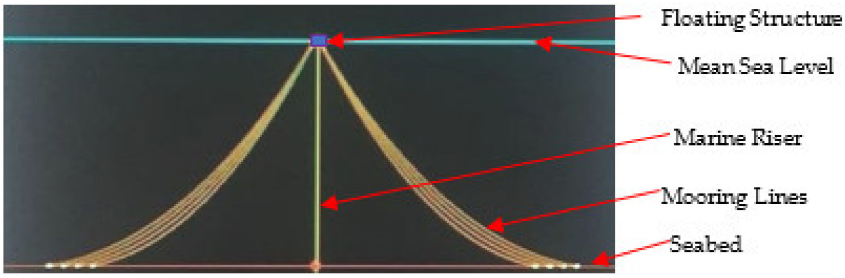

Figure 5. A labelled 3D hydrodynamic model of a semisubmersible platform showing the moorings and marine riser, designed in OrcaFlex 10.3d.

3. Classifying Design Loads

The loads acting on an offshore structure are subjected to different types of loads, mainly classified as: the loads that result from the function on the structure (called Functional loads) and the loads resulting from the environment (called Environmental loads). The first group consists of static or dynamic loads that result from the structure's operation, the buoyancy, the weight of the structure, etc. The second group includes loads that come from the direct or indirect interaction of the environment with the structure, such as current loads, seismic loads, wave loads, wind loads, etc. [7,8]. The classification of design loads is presented in this section, including dead loads, live loads and other types of loads used in the design of offshore structures.

3.1. Live Loads

Live loads are the loads that are applied to the platform while it is in use, and they can change during an operation mode or from each medium to the next. Live loads should be included with these items:

1. The weight of drilling and production machinery and related equipment that can be added to the platform or taken away from it is part of the live loads;
2. The weight of the platform's heliport, platform's living quarters, and other life support equipment (LSE), as well as diving, utility, and life-saving equipment that can be added or withdrawn;
3. The weight in storage tanks of drilling fluids, other liquids and consumable supplies are part of live loads. Operations such as helicopter loadings, drilling, offloading, vessel mooring, and material handling, impose forces on the structure;
4. The stresses exerted on the structure from the use of a deck crane are all part of external forces. The suspended load, the platform motion, and the dead load are used to calculate these forces.

3.2. Dead Loads

The platform's weight when suspended in the air, in addition to the weight of riser pipes, the weight of piles, the ballast, and grout are needed as part of the design loads. The second part is the weight of the machinery, all the equipment and ancillary structures that are mounted permanently on the platform, as they hold a lot of weight. The third part involves external pressure and buoyancy, which are both part of the hydrostatic forces that act upon the structure underneath the waterline.

3.3. Gravitational Loads

The gravitational loads are part of those loads used during the design process. It includes fabrication, load out, transportation, and installation loads which are all included in the design process and are further described.

3.3.1. Removal and Reinstallation Loads

Loads emanating from removal, offloading, loading, transportation, upgrading, and reinstalling offshore structures are part of the gravitational loads. In addition to the above construction loads, there are other loads for platforms for transportation to foreign locations. The loads arising from reinstallation, upgrading, removal, transportation, and (un)loading, should be considered.

3.3.2. Dynamic Loads

The loads exerted on the platform are known as dynamic loads. These are a result of a cyclic stimulation or reactions to an impact. Waves, wind, earthquakes, and equipment can all induce platform excitation. Fatigue loads are also some important loads that are exerted on the platform in a cyclic manner due to the dynamic response.

3.3.3. Impact Loads

Drilling activities may lead to impact as well as the motion of a and mobile drilling unit, a tugboat, a support boat or a barge that berths against the platform can both lead to impact loads.

3.4. Environmental Loads

Natural phenomena such as snow, ice, earthquake, wind, current, waves or tides, as well as ground movement, exert loads on the offshore platform. Some variations in hydrostatic pressure and buoyancy on the offshore structure which resulted from some changes in water level as a result of waves and tides are seen as environmental stresses. Ocean engineering designs should consider defined environmental conditions, which are available from data books or live weather-measuring sources. However, the environmental loads should be expected from any direction, unless special factors make a different assumption that presents more logical justifications. There are available environmental ocean specifications developed for metocean conditions like the Gulf of Mexico [153–156]. These industry specifications are useful in the design of offshore structures.

The design of these structures is usually conducted under different environmental conditions—normal, extreme and survival conditions. The operating environmental load scenarios are the forces exerted on the structure during normal operation while the extreme scenario are the forces that could be considered 'worse' conditions. The survival conditions are greater than the extreme conditions, but it does not impede normal operations as stated by the operators. Figure A4 in Appendix A shows the global map of extreme weather conditions with sea level rising conditions, showing zonal risk levels.

3.5. Wave Load

The procedures involved in the study, design, and construction of offshore constructions are incredibly challenging for engineers to undertake. In addition to the typical challenges faced by offshore structures, onshore (or land-based) structures, and other related facilities are situated in hostile environments where significant wave loads, and wind loads become crucial design factors [2]. Wave loads could be defined as those loads having random nature that results in dynamic behaviour. The wave loads on a platform are constantly changing since they have a dynamic nature. The wave loads can be utilised to effectively approximate the behaviour of offshore structures. However, in some designs, tides are considered especially in shallow water depths. The wave loads may not accurately capture the true dynamic stresses created on the platform in deeper waters or where platforms are more flexible. Hence, a load analysis considering the structure's dynamic activity is required for proper analysis of such platforms. Wave loads are also used in designing breakwater devices and wave energy converters (WECs) [164–173]. Figure A5 in Appendix A shows the global annual wave energy distribution.

3.6. Wind Load

The derrick, the deck house and other sections of the platform that is above water, as well as any equipment on the offshore platform, are subjected to wind forces. The classification for wind speeds is as follows:

1. The average length of stay for a guest is averagely less than 1 min or longer timeframe. Wind data should be normalized to a standard elevation, (for example 8 m) above the mean water level, then averaged for one hour. Using standard profile and guest variables, wind data can be changed to any desired averaging time or elevation;
2. In some cases, the speed around the average wind spectrum and its changes should be supplied. Complaint structures in deep water, such as tension leg platforms and guyed towers, may have a natural sway time of one minute or more, during which significant energy is lost due to wind speed fluctuations;
3. For each month or season, the frequency with which specific sustained wind speed occur from distinct directions;
4. The persistent occurrence of sustained wind speeds exceeding prescribed levels from season after season or month after month.

4. Sustainable Design Approaches

This section presents some sustainable approaches for the design construction and installation of offshore structures. It covers the methodology and the design approach considered in the design investigation of offshore structures.

4.1. Designing with Environmental Conditions

An important aspect of the offshore designer's task is identifying the environmental Conditions where the offshore structure will be operating. Some standards, including API-2INT-MET, outline global loads and hurricane weather conditions for use in constructing offshore structures. Additionally, several API recommended practices, such as API-RP-2AWSD, API-RP-2A-WSD, and API RP-2L, can be utilized to design and analyze fixed and floating offshore platforms. The API establishes minimal design standards for a 100-year design storm. Helipads, often known as helicopter landing pads or decks, on offshore platforms must adhere to API RP-2L.

Typical environmental characteristics for offshore platform analysis include wave heights of up to 21 m (depending on sea depth) and wind velocities of 170 km/hr for the Gulf of Mexico, as well as tides of up to 4 m in shallow areas. According to Sadeghi [14,83], the design of platforms takes into account wave heights of up to 12.2 m and wind speeds of up to 130 km/h in the Persian Gulf, as well as tides of up to 3 m, depending on the design. For a 100-year return time, the design wave height in the Southern Caspian Sea can be over 19 m, while in the North Sea, it can be over 32 m, depending on the region. Other specifications include the lowest deck must have a minimum 1.5 m air gap between the bottom of the deck beams and the wave crest during the maximum expected level of water, taking into account wave height and tides, as specified in API RP-2A. Also, the platform must be able to withstand the loads imposed by the environment, as well as loadout, transit, and installation loads, as well as other loads imposed by onboard equipment. See some environmental data in Figure A4 in Appendix A and Table 2.

In that case, different environmental conditions (such as sea and weather conditions) can be investigated using the wave spectra considered to obtain the global characteristics of a floating structure. For global design, the weather conditions are used based on weather reports and real-time data. As seen in Table 2 and Figure A4 in Appendix A, there are different variations of environmental conditions for both the including oceans, waves, currents, and weather conditions around the world. This data is necessary to ensure that the offshore structure is safely designed and that the design can operate in deep water environments. As given in Table 1, it can be observed that Australia and the Gulf of Mexico (GoM) have a massive effect on the motion response. However, the level of the effect from GoM are among the highest in global oceans. This data in Table 2 is applicable in different areas, as it enables an understanding of different components. For instance, the effect of riser integration on the supporting structure, the effect of mooring lines, and the level of motion response from the marine riser system across various regional seas.

Table 2. Different environmental and ocean weather conditions globally.

Parameters	Gulf of Mexico (GoM)	Africa	East Asia	Australia
Winds	Loop current	Seasonal winds and River flow	Monsoon and internal waves	Loop current, Monsoon and internal waves
Currents	Winter storms and Hurricane	Bi-modal state and Long period swells	Monsoons and Typhoons	Monsoons, Typhoons, Winter storms and Hurricane
Waves	Winter storms and Hurricanes	Trade winds and Squalls	Typhoons, Squalls and monsoons	Monsoons, Typhoons, Winter storms and Hurricanes

4.2. Designing with Water Depth

Another important aspect of the platform design is the water depth which is used to determine the type of offshore platform. Each platform/rig type is chosen primarily based on water depth and the deck equipment required to fulfil its duty. For instance, the jackup platforms can be employed in sea depths as shallow as 150 m (about 500 feet). Fixed template (jacket) platforms come in a variety of sizes and heights and can be used at water depths of up to 300 m, while they are most usually employed in water depths of less than 150 m. In sea depths more than 300 m, Tension Leg Platforms are used. In sea depths up to 1800 m, semi-submersible platforms/rigs are used. The SPAR platforms are used to explore very deep water which have currently been deployed as seen in the tallest SPAR platform, called Shell's Perdido SPAR in the GoM, USA at water depths of about 2450 m. Despite the stretch of any water depth, each offshore platform is different and unique, as such the designs should be well computed. Generally, oceans are classified into three (3) groups, with relation to the relative depth h/L; as deep water ($h/L > 0.5$), intermediate depth ($0.05 < h/L < 0.5$), and shallow depth ($h/L < 0.5$), respectively, where where h is the water depth, and L is wave length (which is the distance between two adjecent wave crests). Table 3 shows the three categories of water depths.

Table 3. Categories of water depths.

Types of Water Depth	Relative Depth (h/L)
Shallow Water	$h/L < 0.5$
Intermediate Water	$0.05 < h/L < 0.5$
Deep Water	$h/L > 0.5$

With an ever-increasing demand for crude oil and energy, the offshore industry is moving towards deep and ultra-deep environments for new oil reserves to exploit as shown by the statistics given in Figure 6. However, at such depths pressure and hydrodynamic forces are significantly greater causing increased fatigue and structural damage to subsea operations put in place, subsequently affecting long term operation of the wells being used. At such depths, weight becomes a more pressing issue as the increase in weight causes increased stress and strain, at these intense pressures increase the risk of critical shear and longitudinal load allowances being exceeded resulting in structural failure of the asset and subsequent extensive marine environment damage.

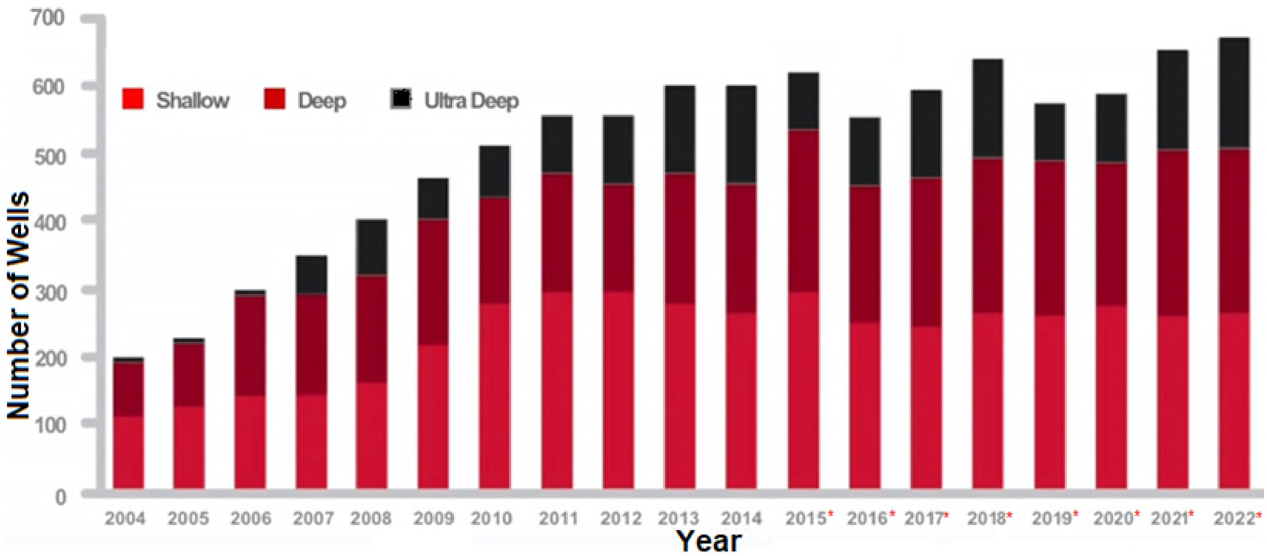

Figure 6. Number of wells drilled over time from 2004–2021, with forecast for 2015*–2022* using data from Statoil (Image Courtesy: Author 1-C.V.A.).

4.3. Software for Designing with Geotechnical Information

Soil investigation is also an important aspect of the design of offshore buildings. Since the soil ultimately resists the tremendous stresses and motions present in the piling, at the bottom of the ocean, caused by the presence of the platform in storm conditions, soil study is critical to the design of offshore buildings. There are different materials that can make up the under-seabed soil and the importance of a site-specific soil report. An important issue is the seabed scour due to cyclic wave loads on different under-seabed soil. Clay, sand, silt, or a combination of these can make up the under-seabed soil (which differs from the subsoil).

Each project requires a site-specific soil report that details the stratification of the soil and its properties for load bearing in tension and compression, shear resistance, and load-deflection characteristics of axially and laterally loaded piles. This sort of report is created by drilling holes in the ground at the desired site and then conducting in-situ and laboratory testing to generate data that can be used by the platform design engineer [14,83]. Information on the soil bearing capacity, behaviour of the soil to the piles, pile tip-end bearing values, soil reports and platform design pile diagrams should all be made available. With the recent use of computational techniques, geotechnical engineers can provide these design values and related reports to the engineer. These are then used in modelling and designing the geotechnical model and then the structural analysis model is developed. This can be conducted using various in-house or commercial tools such as ANSYS Structural, ABAQUS, COMSOL, StruCad, FASTRUDL, or SACS software. Table 4 gives some structural software, and computer-aided design (CAD) software with developer details. However, more discussions on software are conducted in Section 4.4.

Table 4. Table of some structural software programs, and computer-aided design (CAD) software programs with developer details.

Name of Software	Year Founded	Type of Software and Program Specialisation	Software Company/ Vendor/Manufacturer	Location
ANSYS Workbench	1970	CAE/multiphysics engineering simulation software for product design, testing and operation	ANSYS	Pennsylvania, U.S.A.
COMSOL Multiphysics	1986	cross-platform finite element analysis, solver and multiphysics simulation software	COMSOL Inc	Stockholm, Sweden

Table 4. *Cont.*

Name of Software	Year Founded	Type of Software and Program Specialisation	Software Company/ Vendor/Manufacturer	Location
StruCAD	1986	a specialised 3D modelling package used in the structural steel industry, detailing, fabrication and information management system	STRUMIS LTD's AceCad Software Ltd.	Derby, UK
ABAQUS	1978	finite element analysis and computer-aided engineering (CAE)	Dassault Systèmes' SIMULIA	Vélizy-Villacoublay, France
Solidworks	1981	Design and Analysis of Structural elements (beams, columns, walls, slabs, CAD, drafting)	Dassault Systèmes	Vélizy-Villacoublay, France
CATIA	1981	Design and Analysis of Structural elements (beams, columns, walls, slabs, CAD, drafting)	Dassault Systèmes	Vélizy-Villacoublay, France
STAAD.Pro	1997	Design and Analysis of Structural elements (Foundations, beams, columns, walls, slabs)	Bentley Systems	Pennsylvania, U.S.A.
RAM Structural	1984	Design and Analysis of Structural elements (Foundations, beams, columns, walls, slabs)	Bentley Systems	Pennsylvania, U.S.A.
Solid Edge	1995	Design and Analysis of Structural elements	Siemens Digital Industries	Texas, U.S.A.
RISA	1987	Design and Analysis of Structural elements (Foundations, beams, columns, walls, slabs)	Risa Tech, Inc.	California, U.S.A.
ADAPT-Builder	1983	Design and Analysis of Structural elements (foundations, beams, columns, walls, slabs)	Risa Tech, Inc. & ADAPT Corporation	California, U.S.A.
SAFE	1975	Design and Analysis of Structural elements (beams, foundations, and slabs)	Computer and Structures, Inc. (CSI)	California, U.S.A.
ETABS	1975	Design and Analysis of Structural elements (beams, columns, walls, and slabs)	Computer and Structures, Inc. (CSI)	California, U.S.A.
SAP2000	1975	Design and Analysis of Structural elements (beams, columns, walls, and slabs)	Computer and Structures, Inc. (CSI)	California, U.S.A.
Robot Structural	1982	Design and Analysis of Structural elements (foundations, beams, columns, walls, slabs)	Autodesk	California, U.S.A.
AutoCAD	1982	3D Design and Analysis of Structural elements (beams Columns, walls, and Slabs)	Autodesk	California, U.S.A.
Autodesk Inventor	1999	Design and Analysis of Structural elements (beams Columns, walls, and Slabs)	Autodesk	California, U.S.A.
S-Frame	1981	3D Structural Analysis Linear, Non-Linear, Static, Dynamic	Altair Engineering Inc.'s S-Frame	Michigan, U.S.A.
S-Concrete	1981	Design and Analysis of Structural elements (beams, columns, and walls)	Altair Engineering Inc.'s S-Frame	Michigan, U.S.A.
S-Steel	1981	Design and Analysis of Structural elements (beams, columns, and walls)	Altair Engineering Inc.'s S-Frame	Michigan, U.S.A.
MARC	1971	nonlinear FEA software used to simulate behavior of complex materials and interaction under large deformations and strains.	MSC Software Corporation	California, U.S.A.

Table 4. *Cont.*

Name of Software	Year Founded	Type of Software and Program Specialisation	Software Company/ Vendor/Manufacturer	Location
MSC/Nastran	1971	nonlinear FEA software used to simulate behavior of complex materials and interaction under large deformations and strains.	MSC Software Corporation	California, U.S.A.
PROKON	1989	Design and Analysis of Structural elements (foundations, beams, columns, walls, slabs)	Prokon Software Consultant (Pty) Ltd.	Johannesburg, South Africa
PTC Creo (formerly Pro/Engineer)	1988	a family of Computer-aided design (CAD) apps supporting product design for discrete manufacturers, 3D/2D, FEA & simulations	PTC (Parametric Technology Corporation)	Massachusetts, U.S.A.
RFEM/RSTAB	1987	structural analysis/FEA software used to simulate behavior of materials and interaction under large deformations and strains	Dlubal Software	Philadelphia, U.S.A.

4.4. *Software for Platform Designs and Rendering*

There is a diverse range of specialised software used in designing offshore platforms, as given in Table 4. The software for conducting structural analysis, includes Autodesk's AutoCAD, ANSYS Structural, ABAQUS, COMSOL, SACS, FASTRUDL, OSCAR, MARCS, SESAM or StruCAD. Currently, rendering, and other visualisation tools are used in producing 3-D CAD animations and renderings of the offshore platform. With the increasing need for more sustainable offshore platforms, there is a wider range of software for Platform Designs. These include software for structural analysis, hydrodynamic computations and for hydrodynamic analysis. Examples of software for rendering are: Lumion, Blender, 3D Max, Rhino, Mental Ray, Thea Render, Cinema 4D, Viz Renderer, Unity, Houdini and Maya. Table 5 gives some CAD rendering software.

Table 5. Table of some 3D rendering software programs with developer details.

Name of Software	Standalone Version OS	Price	Rendering Platform	Integrations	Developer
Blender	Windows, Mac OS, Linux	Free	CPU, GPU	NA	Blender
Maya	Windows, macOS, Linux	Free (trial ware, academic), £1575/year	CPU, GPU	RebusFarm, Adobe Substance 3D Designer, Adobe Substance, 3D Painter, V-Ray, SyncSketch, Verge3D, Maxwell, OctaneRenderer, Houdini, Anima, Redshift, Iray.	Autodesk Inc.
3ds Max	Windows	Free (academic), $1785/year, $225/m	CPU, GPU	V-Ray, Space Designer 3D, Shapespark, Verge3D, Maxwell, Corona Renderer, Houdini, Anima, Redshift, Iray	Autodesk Inc.
Rhino3D/Rhinoceros	Windows, macOS	$995 (€995) (single use), €595 (upgrade)	CPU	Revit	Robert McNeel & Associates
Lumion 3D	Windows	From $1760	GPU	NA	Lumion
V-Ray	NA	From $60/month	CPU, GPU	Revit, Rhinoceros, SketchUp, Unreal, 3ds Max, Blender, Cinema 4D, Houdini, Katana, Maya, Modo, Nuke	Chaos Group

Table 5. *Cont.*

Name of Software	Standalone Version OS	Price	Rendering Platform	Integrations	Developer
Keyshot	Windows, macOS	$995	CPU, GPU (Nvidia)	Solidworks, Maya, Cinema 4D, SketchUp, Rhino	KeyShot
DS Solidworks Visualize	Windows	Price on request	CPU, GPU	NA	Solidworks
Enscape	Windows	$69.90/ $478.80 per m/year	GPU	ArchiCAD, Revit, Rhinoceros, SketchUp, Vectorworks	Enscape
OctaneRender	NA	From $19.99/month	GPU (Nvidia)	Rhinoceros, SketchUp, Softimage, Unreal, Maya, Modo, Nuke, Poser, Revit, 3ds Max, ArchiCAD, Blender, AutoCAD, Carrara, Cinema 4D, DAZ Studio, Houdini, Inventor, Lightwave,	Octane Render
Corona Renderer	Windows	~$30/month	CPU	3ds Max, Cinema4D	Corona
3Delight	Windows, macOS, Linux	Free (limited to 12 cores) $30/$60/ $360 per w/m/year $720 perpetual	CPU	NA	3Delight
Maxwell Render	Windows, macOS, Linux	From ~$580 (495€)	CPU, GPU (Nvidia)	Modo, Rhinoceros, SketchUp, 3ds Max, ArchiCAD, Cinema 4D, Form-Z, Maya	Maxwell
Thea Render	NA	~$290 (249€)/year	CPU, GPU	Rhino, SketchUp	Thea Render
Cheetah 3D	macOS	Free demo, $99 (single license), $49 (upgrade)	CPU	NA	Cheetah3d
Artlantis	Windows, macOS	~$910 (780€)	CPU (Network)	ArchiCAD, VectorWorks, Revit, 3ds Max, SketchUp, Rhino, MODO, Maya, formZ, Cinema 4D, AutoCAD, Arc+	Abvent's Artlantis
Clarisse	Windows, macOS, Linux	Free (educational) $59/ $499 per m/ year $999 perpetual	CPU, GPU	NA	Isotropix
Arnold	Windows, macOS, Linux	$40/ $360 per m/year	CPU	NA	Arnold
LuxCore Render	Windows	Free	GPU	NA	LuxCoreRender
Redshift	Windows, macOS, Linux	From $500	GPU (Windows/Linux—Nvidia only; macOS—M1/AMD)	3ds Max, Cinema 4D, Houdini, Maya	Redshift
Marmoset Toolbag	Windows, macOS	$14.99/month $299 perpetual	GPU	NA	Marmoset Toolbag
RenderMan	Windows, macOS, Linux	$595	CPU, GPU (Nvidia)	Blender, Houdini, Katana, Maya	RenderMan
Iray	NA	$295/year	GPU (Nvidia)	3ds Max, Maya, Rhinoceros	Nvidia Iray
FluidRay	Windows, macOS	$14.99/month	CPU	NA	FluidRay
Guerilla	Windows, Linux	Free (single-seat, connected) From ~$2340 (2000€)	CPU	Maya	Guerilla
Felix	Windows	$50–$800 (credit packs); $1–900/month (subscriptions)	NA	3ds Max, AutoCAD, Rhinoceros	Felix
Indigo Renderer	Windows, macOS, Linux	$835	CPU, GPU	3ds Max, Blender, Cinema 4D, Revit, SketchUp	Indigo Renderer

Table 5. *Cont.*

Name of Software	Standalone Version OS	Price	Rendering Platform	Integrations	Developer
FormZ	Windows	$439/year, $995 perpetual	CPU, GPU	NA	AutoDesSys, Inc
Twinmotion	Windows	Free (trial, non = commercial, Academic), ~$584.29 (£490.80)	CPU	formZ, CItyEngine, CET, Navisworks, SketchUp, 3ds Max, BricsCAD, RIKCAD, Solidworks, Rhino, Revit, ArchiCAD, VectorWorks	Epic Games, Inc.
D5 Render	Windows	Free	CPU (DXR)	Blender, SketchUp, 3ds Max, Rhino, Revit, ArchiCAD, Cinema 4D	d5render

There are a variety of analysis tools which are used for the design and analysis of lines like marine risers. Riser analysis tools are special purpose programs used to analyse top tensioned risers, steel catenary risers, flexible risers, and other slender structures, such as subsea pipelines and mooring lines. These are classified according to the analysis type, such as:

- General purpose finite element programs: ANSYS, ABAQUS, COMSOL, etc;
- Riser Analysis Tools: Orcaflex, Riflex, Flexcom, etc;
- Riser VIV Analysis Tools: VIVANA, VIVA, DeepVIV, Shear7, etc.;
- Coupled motion analysis programs: HARP, etc;
- Riser Installation Analysis Tools: Pipelay, Orcaflex, OFFPIPE, etc.
- Riser, pile and motion interaction using CFD based programs: ANSYS Fluent, ANSYS CFX, OpenFOAM, Simscale, STAR-CCM+, FAST, etc.

There are other numerical models like the FAST model (Fatigue, Aerodynamics, Structures, and Turbulence), which is a tool to predict the complex behavior of floating platforms coupled with towers (e.g., wind turbines). Additionally, the software for hydrodynamics computations, includes ANSYS AQWA, ABAQUS AQUA, Orcaflex, MooDy, Moses, Seamoor Maxsurf, or Hydromax [12–15]. Figure 7 shows the geometry model of a boat developed in ANSYS while Figure 8 shows a 3D view of the hydrodynamic model of a semisubmersible platform in OrcaFlex. Table 6 gives some ocean engineering software.

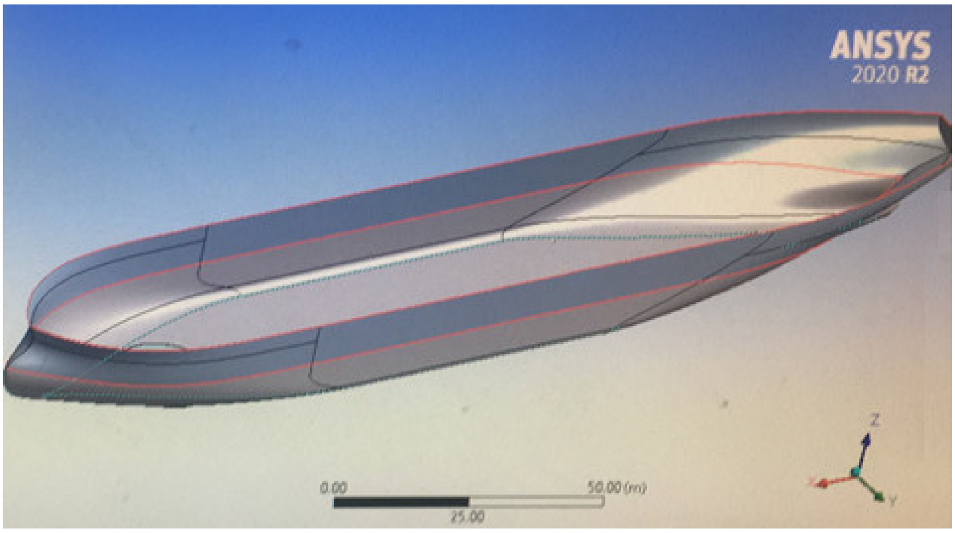

Figure 7. The model of a boat developed in ANSYS R2 2020 software.

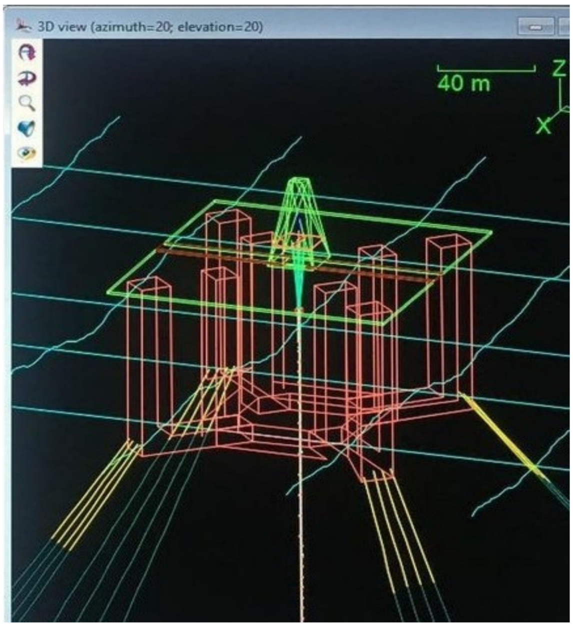

Figure 8. Model for hydrodynamic analysis of a floating semisubmersible platform showing its mooring lines, top deck, derrick and marine risers conducted in OrcaFlex software.

Table 6. List of some ocean engineering and hydrodynamic analysis software programs with developer details.

Name of Software	Year Founded	Type of Software and Program Specialisation	Software Company/Vendor Manufacturer	Location
ANSYS AQWA	1970	Hydrodynamic software designed for industries, like Marine and Offshore structures	ANSYS Inc.	Pennsylvania, U.S.A.
ABAQUS AQUA	1978	Hydrodynamic software designed for industries, like Marine and Offshore structures	Dassault Systèmes' SIMULIA	Vélizy-Villacoublay, France
FASTRUDL/NSO^{TM}	1981	finite element analysis software designed for industries, like Marine and Offshore structures	PRINCIPIA	La Ciotat, France
Deeplines	1981	finite elements method and forms an integrated software solution for installation analyses of offshore structures; Global analysis of risers, moorings and flowlines	PRINCIPIA	La Ciotat, France
NSO/ISYMOST	1981	ISYMOST (Interactive SYstem for MOdeling of STructures) manages the modeling, analysis, pre- and post-processing of structures; Frames and Finite Elements solver	PRINCIPIA	La Ciotat, France
Flexcom	—	offshore marine engineering simulator that for the engineering design of installations, risers, moorings, umbilicals, pipelines & FOWT.	Wood Group PLC	Aberdeen, U.K.
PipeLay	—	an engineering tool for pipeline installation, complex finite element analysis and post-processing, automation challenges with installation scenarios in deep and shallow water	Wood Group PLC	Aberdeen, U.K.
OrcaFlex	1986	Design, 3D modelling and dynamic analysis of offshore marine systems	ORCINA	Ulverston, U.K.
OrcaLay	1998	Design, 3D modelling and dynamic analysis of for pipelaying designs	ORCINA	Ulverston, U.K.

Table 6. *Cont.*

Name of Software	Year Founded	Type of Software and Program Specialisation	Software Company/Vendor Manufacturer	Location
OrcaBend	1989	Design, 3D modelling and dynamic analysis of bend stiffener design to derive an optimum stiffener profile	ORCINA	Ulverston, U.K.
VIVANA	1968	VIV, hydrodynamic and hydrostatic analysis of offshore platforms and ships	DNV	Oslo, Norway
DeepC, Helica & HydroD	1968	hydrodynamic and hydrostatic analysis of fixed and floating structures like offshore platforms and ships	DNV	Oslo, Norway
Sesam	1968	Structural and hydrodynamics analysis, FEM for design to analysis of marine operation; interaction for hull, riser and mooring lines	DNV	Oslo, Norway
PIPESIM & OLGA	—	Steady-state multiphase flow simulator to overcome fluid flow challenges and optimize production	Schlumberger	Texas, U.S.A.
WAMIT	1987	WAMIT, "WaveAnalysisMIT" for computing wave loads and motions, interaction of offshore structures, vessels or other structures	WAMIT Inc.	Massachusetts, U.S.A.
MOSES	1984	Hydrodynamic software designed for industries, like Marine and Offshore structures	Bentley Systems	Pennsylvania, U.S.A.
RIFLEX	1968	Riser System Analysis Program (RIFLEX) is a tailor-made and advanced tool for static and dynamic analysis of slender marine structures	DNV	Oslo, Norway
ANFLEX	1995	an in-house nonlinear dynamic analysis of lines and risers software; for static and dynamic analysis of slender marine structures	PETROBRAS/CENPES/ DIPREX/SEDEM	Rio de Janeiro, Brazil
HYDPROD	2011	Drilling hydraulics software and the suite of drilling software to meet the challenges that operators and service companies face	Pegasus Vertex Inc. (PVI)	Texas, U.S.A.
ProteusDS	2006	in-house dynamic analysis software package; time domain solvers to model hydrodynamic response of offshore structures like FOWTs	DSA Ocean	Victoria BC, Canada
SeaFEM	—	seakeeping 3D multi-body radiation and diffraction simulations; a suite of tools for the computational analysis of the effect of waves, wind and currents on naval and offshore	Compass Ingeniería y Sistemas	Barcelona, Spain
SIMA & SIMO	—	SIMA workbench offers a complete solution for simulation and analysis of marine operations and floating systems	SINTEF	Trondheim, Norway
aNySIM	—	time domain solvers to simulates the motions of both stationary offshore vessels, sailing ships and offshore structures like FOWTs	MARIN	Wageningen, The Netherlands
HydroDyn	—	time domain solvers to model hydrodynamic response of offshore structures like FOWTs	NREL	Colorado, U.S.A.
3DFloat	—	integrated wind turbine simulation software; time domain solvers to model hydrodynamic response of offshore FOWTs	IFE	Kjeller, Norway
BECAS	1986	BECAS, the BEam Cross section Analysis Software, determines cross section stiffness properties using a finite element based approach	DTU Wind Energy	Roskilde, Denmark
HAWC2	1986	HAWC2 (Horizontal Axis Wind turbine simulation Code 2nd generation) is an aeroelastic code to model the dynamic response of offshore structures like FOWTs	DTU Wind Energy	Roskilde, Denmark

Both the structural Analysis and the developed structural model of the platform are generally conducted using one of these related standard offshore engineering software packages. They are also used to perform the structural study of the platform, all key parts of the platform, as well as appurtenances and major equipment, which should be included in the model. A typical pile-supported offshore construction will have a deck structure with the Main Deck, Cellar Deck, Sub-Cellar Deck, and Helideck.

For jacket platforms, the deck legs are connected to the tops of the piles and support the deck construction. The piles run from the surface of the water to the mudline and into the soil. For the underwater aspects, the piles are encased within the legs of a "jacket" structure that acts as lateral bracing for the piles. The jacket may also be used as a template for driving through leg piles for the first time (the piles may be driven through the inside of the jacket structure's legs). When skirt piles are used, the piles can be driven from the outside of the jacket structure's legs. Hence detail, precision and speed are important in these designs.

Computer programs also help the designers in making decisions, results and developing these models, and optimizing them. Hence, some optimization schemes, design schemes, monitoring schemes and general analyses, have seen more advancements. However, further studies on these schemes and approaches will help to improve awareness of these offshore structures' design approaches. These other methods include response surface optimisation, multi-objective optimization, genetic algorithm (GA), and artificial neural networks (ANN). There are also different assessments which include dynamic response assessment, robust fault-tolerant control, reliability studies, optimal probabilistic seismic demand model and failure mode analysis (FMA). These optimisations are conducted with customized/specialised codes, mathematical software and programming codes for these engineering designs, such as the ones listed in Table 7.

Table 7. Table of some mathematical codes, and programming software programs with developer details.

Name of Software	Year Founded	Type of Software and Program Specialisation	Software Company/Vendor/ Manufacturer	Location
MathCAD	1986	Analysis of matrix-based problems & performing specialized mathematical tasks	Parametric Technology Corporation (PTC)'s Mathsoft	Massachusetts, U.S.A.
MATLAB	1979	Analysis of matrix-based problems & performing specialized mathematical tasks	Mathworks	Massachusetts, U.S.A.
Simulink	1984	a MATLAB-based graphical programming environment for modeling, simulating and analyzing multidomain dynamical systems	Mathworks	Massachusetts, U.S.A.
GNU Octave	1993	Analysis of matrix-based problems & performing specialized mathematical tasks	John W. Eaton et al.	Texas, U.S.A.
Scilab	1990	Analysis of matrix-based problems & performing specialized mathematical tasks	ESI Group	Rungis, France
Mathematica	1988	Analysis of matrix-based problems & performing specialized mathematical tasks	Wolfram Research	Illinois, U.S.A.
Maple	1982	Analysis of matrix-based problems & performing specialized mathematical tasks	Waterloo Maple (Maplesoft)	Ontario, Canada
Macsyma	1968	Macsyma "Project MAC's SYmbolic MAnipulator" is a general-purpose computer algebra systems still available	Symbolics's Macsyma, Inc	Massachusetts, USA
LabView	1986	a system-design platform and development environment for a visual programming language; for state machines and flow charts	National Instruments	Texas, U.S.A.
RStudio	2011	an integrated development environment for R, a programming language for statistical computing and graphics; free and open-source software for data science.	RStudio, PBC	Washington, U.S.A.

Table 7. *Cont.*

Name of Software	Year Founded	Type of Software and Program Specialisation	Software Company/Vendor/ Manufacturer	Location
MathJax	2009	displays mathematical notation in web browsers, using MathML, LaTeX and ASCIIMathML markup, scans the page, and typesets the mathematical information	American Mathematical Society	Rhode Island, U.S.A.
SageMath	2005	SAGE, "System for Algebra and Geometry Experimentation" is a computer algebra system (CAS) on aspects of mathematics	Prof. William Stein et al.	Washington, U.S.A.
SimulationX	2002	CAE software to efficiently model, simulate, and analyze technical, mechanical, hydraulic, pneumatic, electrical, and combined systems	ESI Group's ESI ITI GmbH	Rungis, France
SU2 (Stanford University Unstructured) Code	2012	suite of open-source software tools in C++ for numerical solution of partial differential equation (PDE) constraints and optimization	Dr. Francisco Palacios & Dr. Thomas D. Economon	Stanford, U.S.A.
Simscale	2012	computer-aided engineering (CAE) software-as-a-service simulation application for performance testing based on cloud computing	SimScale GmbH	Munich, Germany
ANSYS Fluent	1988	commercial Computational Fluid Dynamics (CFD) software application for performance testing	ANSYS	Pennsylvania, U.S.A.
STAR-CCM+	1980	Computational Fluid Dynamics (CFD) software application for performance testing	Siemens Digital Industries Software	Texas, U.S.A.
OpenFOAM	2004	free, open source CFD software application for performance testing and the solution of continuum mechanics problems	ESI Group's OpenCFD Ltd.	Rungis, France

4.5. Construction and Fabrication

The construction and fabrication of the offshore platform is a key aspect of the design. Most times, a smaller model of the actual platform is first produced for visualisation, or some renderings are produced.

During fabrication, the cutting of the sheet metal and welding are conducted using the working drawings for the platform. Hence, there must be high level of quality assurance from the materials and man labour. All the materials, welds, and welders should all be thoroughly inspected. Different material standards are also applied. Engineering drawings are required for cutting, fitting, welding, and assembly for each part down to the smallest screw, nut, or bolt. A suitable fabrication yard along the water's edge should be chosen. This fabrication yard must be well-equipped and large enough to accommodate platform fabrication and loading. To ensure the materials are formed and delivered on time, newer technologies are applied in the laser cutter, water jet cutters, metal sheet former/rollers, and computerised lathe machines. Safety is very important on the site. Also, details, precisions and accuracy are necessary elements as the material measurement tolerances must be complied with.

4.6. Loadout and Transportation

The loadout and transportation are other important aspects of the project delivery. For an economical construction procedure, offshore constructions are typically built onshore in "fabrication yards." These structures must be loaded and transported offshore to the final assembly site on board a vessel once they are completed, as seen in Figure 9. As a result, a loadout and transportation analysis must be included in an offshore design and analysis of a structure. All stages of the structure's loadout should be considered, and the stresses should be verified.

Figure 9. Load-out 18,000 t topside and transportation from a yard in Zhuhai, China (Courtesy: Ocean energy resource).

4.7. Sea Fastening Operations

A sea fastening analysis is performed before the platform is transported, and the platform parts (jacket, decks, and appurtenances) are connected to the barge. Where necessary, platform motion analysis is conducted to determine the accelerations and loads acting on the platform to examine its strength to support dynamic loads. The sea fasteners, grillages and load-spreading components are necessary to distribute the stresses. They are designed depending on the type of structure and adopted sea fastening techniques [213–217]. Figure 10 shows some sea fasteners for offshore platforms.

Figure 10. Sea fasteners for offshore platforms, showing the front and zoomed-out views.

4.8. Lifting, Launching and Upending

The motions of roll, pitch, heave, and yaw should be addressed in the transportation analysis. To perform a load out and transportation analysis, the engineer will need an environmental report detailing the worst sea-state conditions at that time of year along the desired route. It is reasonable to assume a scenario using a 20 degrees angle of roll with a 10 s roll period and a 12.5 degrees angle of pitch with a 10 s period, as well as a heave acceleration of 0.2 g, based on industry standards for transportation. Lifting/launching, upending, uprighting, and other installation stresses must all be considered while designing an offshore platform's structural parts. The launching and upending sequences of a platform are illustrated in Figure 11.

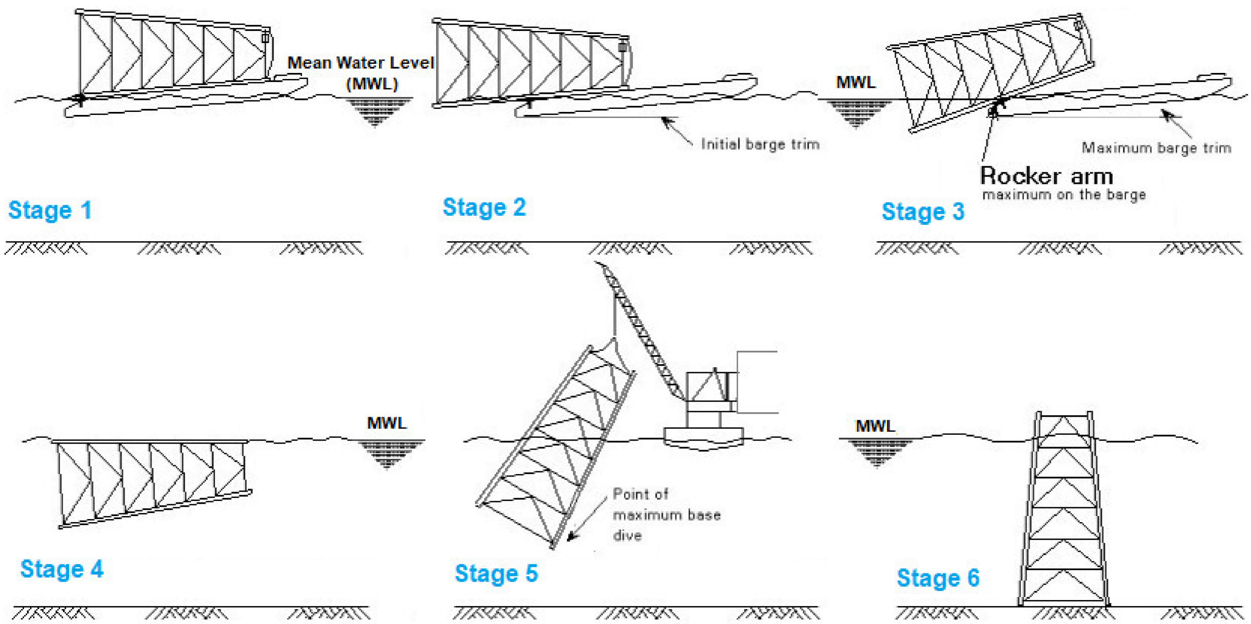

Figure 11. Launching and Upending sequences of a platform jacket.

4.9. Floatover Installation and Platform Integration

Design engineers enhance the design and construction of offshore structures by providing solutions that ensure that the structures are more durable, reliable, and sustainable. One of such approaches is the floatover installation. This approach is extremely weather-dependent, with severe constraints on the highest current, wave, and wind speed that it can withstand. Depending on the design, sometimes the existing floating crane vessels may be unable to raise the structures as topsides get larger and heavier. This problem gave way to a more cost-effective solution: the floatover approach.

For platform integration, the topsides modules are transported by a vessel, which then manoeuvres into the substructure slot, positions the vessel, and lowers the topsides onto the substructure while maintaining the vessel's position and increasing the draught. Through the jacket slot, the floatover vessel is employed for logistics and installation. The most difficult aspect of a floatover operation is the weather. Figure 12 shows the transportation of the topsides for platform integration.

Figure 12. Jacket platform topside being transported floatover installation towards platform integration (Courtesy: Saudi Aramco).

5. Project Management of Offshore Facilities

This section covers project management of offshore structures.

5.1. Planning Offshore Projects

Planning and pre-planning offshore projects is an important part of delivering offshore platform projects. However, there are various stages of offshore construction which are necessary for the sustainable delivery of an offshore platform, from design and construction to completion. According to Sadeghi [14,83,209–211], the phases of an offshore platform construction project are as follows:

- Survey of the construction site;
- Site visits and dive inspections on the installation site;
- Investment feasibility studies, and;
- Procurement;
- Design approval by governing authorities;
- Preparation of platform elements for transportation;
- Fabrication of steel structures;
- Transportation, and installation procedures;
- Loadout;
- Sorting offshore installation processes;
- Commissioning.

5.2. Pricing Offshore Projects

The cost of an offshore project is highly determined by oil price, cost of materials, cost of other similar projects, location of the offshore project and the magnitude of the project. Hence, the quotation must be well prepared to cover the cost of manpower (or labour), equipment cost, construction, transportation, materials and all the stages of the project. In studies by Sadeghi [12–15], the price of the contract for detail design is between 3 to 5% of the overall price while the pricing of the procurement portion is around 55% of overall price. These parameters and design data including the water depth, are factored into the pricing of the oil projects.

Hence, the costing must be well considered to reduce variations in the project. Most times, bids are invited from the public or selected contractors by the oil corporations. Hence the contractor must get adequate information about the platform's details—dimensions, weights, prices of materials, and cost of labour. The knowledge of experienced Project Engineers and Project Managers is very crucial, which helps to achieve different developed facilities, ranging from semisubmersibles [218–228] to FPSOs [229–234] and offshore wind turbines [235–240].

By rough estimates, an offshore platform that weight around 30,000 t could cost around 350–500 million dollars, plus another 60–120 million dollars for three tugboats. However, there are various studies that cover the accounting and costing of oil facilities and the financial aspect of project management [240–251].

5.3. Conducting Material Checks

The design of the offshore structure depends on the material used and the magnitude of the offshore structure. The larger the size of the offshore structure, the greater the material utilization. However, recent advances have considered the deployment of composites and additive manufactured materials on offshore platforms. Successfully, composites have been applied in developing marine risers, which is a smaller offshore structural component which serves as a conduit for drilling/production purposes. One important material utilized on various offshore structures is steel [172–179], as seen in Table 8. An example of the industry specification is the API RP-2A, which specifies the material qualities that should be used in the fabrication of structural steel plates, steel forms, and structural steel pipes. Depending on then steel grade, the selected steel plates and structural forms must meet the American Society for Testing and Materials (ASTM) grade A36 (yield strength, 250 MPa) minimum requirements (which is the AISC). The pipe must meet API 5L, grade X52, for higher strength applications. An application of heavy offshore steel grades is seen in the use of steel plates S355G10+M and S355G8+M for the offshore crane OSA Goliath in Figure 13. The classification of offshore steel grades has found to be a function of the yield strength and process route used, as given in Figure 14 and Table 8.

Figure 13. Application of heavy offshore steel plates S355G10+M and S355G8+M for the offshore crane OSA Goliath (Courtesy: Oakley Steel).

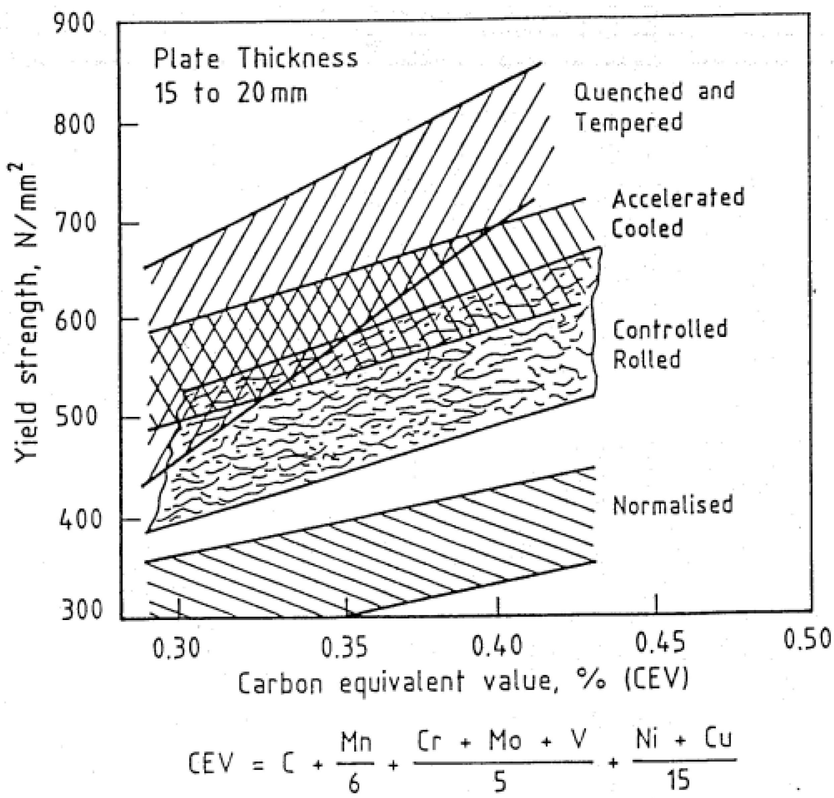

Figure 14. Effect of carbon equivalent value (CEV) and steel processing route on plate strength (This section is re-used/reproduced with permission of the Health and Safety Executive under the terms of the Open Government License, from Ref. [179]. Copyright year: 2003, copyright owner: HSE. Courtesy: HSE & HSE Books).

Table 8. Application of some high strength steels in the offshore industry.

Steel Grade	Strength	Application Area	Standard	Process Route
X52	350	Structures	EN 10225	N
		Structures & Pipelines	EN 10225	M
X65	450	Structures	EN 10225	Q & T
		Pipelines	EN 10225	M
X80	550	Moorings & Structures	EN 10225	Q & T
		Pipelines	EN 10225	M
	650	Jack-ups & Moorings	EN 10225	Q & T
	750	Jack-ups & Moorings	EN 10225	Q & T
	850	Jack-ups & Moorings	EN 10225	Q & T
API 2MT1	~	Small scale construction	API 2M	M, Q & T
API 2H Grade 42	~	Small scale construction	API 2H	M, Q & T
API 2H Grade 50	~	Small scale construction	API 2H	M, Q & T
API 2W Grade 50	~	Small scale construction	API 2W	M, Q & T
API 2Y Grade 50	~	Small scale construction	API 2Y	M, Q & T
S355G8+M/S355G10+M	500/660	construction of offshore platforms and oil rigs	EN 10225	M
S420G1+M/S450G1+Q	500/660	construction of offshore platforms and oil rigs	EN 10225	M, Q & T
S420G1+M/S450G1+Q	500/660	construction of offshore platforms and oil rigs	EN 10225	M, Q & T
S235/S355	350	Heavy steel plates for construction of offshore platform	EN10025-2	M, Q & T
S355G10/S355MLO/S355NLO	350	construction of offshore platforms and oil rigs	EN10025-2	M
ASTM A36	250	Structures & Pipelines	API RP-2A	M, Q & T

Note: N (Normalised); M (thermo-mechanically processed); Q & T (Quenching and Tempering).

5.4. Conducting Design Checks

An important aspect of any design contract is checking, signing, and verification checks. These activities are to ensure that the client is satisfied with the service of the design team and that the offshore platform was properly designed and double-checked. A typical design of a marine hose structure by an industry manufacturer—Trelleborg, is presented in Figure 15. It shows the design definition, configuration, material properties, global environment, and design parameters.

However, it is important to state that the design of offshore structures also depends on the use, unit, size and materials. In most cases, these checks are conducted by senior engineers who are experts in the field and have practicing licenses to sign off on the job in that engineering firm. Sometimes, consultants are hired to oversee such project tasks. Also, the client must approve the complete design, installation, and functioning.

Basically, there are many elements that must be considered while designing and analysing offshore platforms. These elements include the following crucial parameters:

- Initial transportation needs;
- Environmental (weather, and in-place 100-year storm conditions);
- Soil characteristics;
- Code requirements;
- Intensity degree of failure consequences.

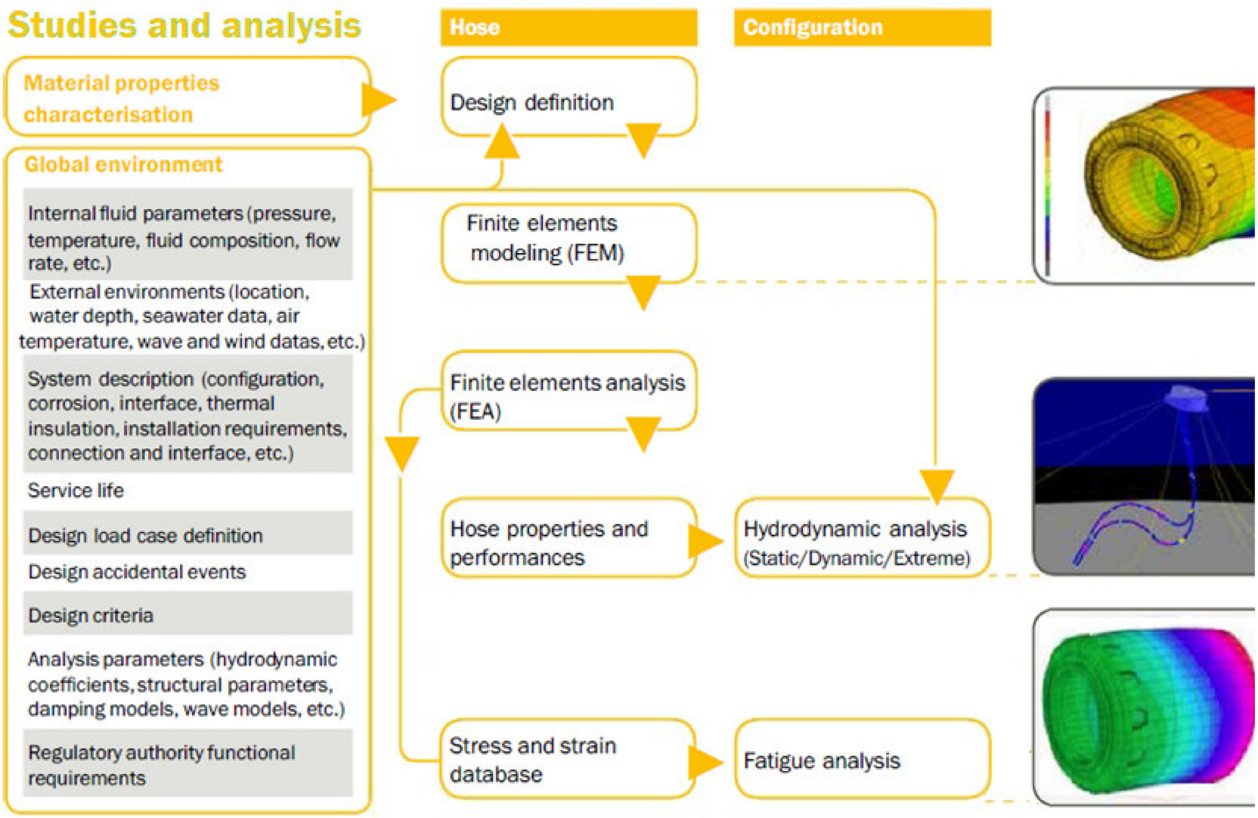

Figure 15. Typical design flowchart of a marine hose structure (Courtesy: Trelleborg).

5.5. Conducting Document Checks

Another important aspect of the design is to conduct the necessary document checks. These checks are conducted based on the requirement of the industry standards, the client's needs and the scope of work agreed upon for the project. For offshore structures, numerical models are developed and analysed before the structure is fully designed, coupled, constructed, installed and commissioned.

Considering a jacket/template platform, various analyses are required. These assessments are broadly classified as theoretical, experimental and numerical assessments. These are used to prepare various reports put together on the design's final report that will be given to the client or other contractors, like the ship-yard that will construct the platform. These reports also include the draughtman's blueprint for the offshore platform and the component design plans.

For the construction of an offshore platform that is massive like a Truss SPAR or a jacket platform, the following are the primary analyses necessary for the development of the offshore platform:

- In-place analysis or On-the-spot analysis;
- Seismic Analysis;
- Fatigue Analysis;
- Extreme loads analysis;
- Temporary assessment;
- Loadout assessment;
- Transportation assessment;
- Appurtenance assessment;
- Lift/Launch assessment;
- Upending assessment;
- Uprighting assessment;
- Unpiled stability assessment;

- Drivability study of piles and conductor pipes;
- Cathodic protection analysis;
- Transportation analysis;
- Installation analysis.

5.6. Obtaining Client Permits and Approval Process

An important aspect of the project is obtaining the relevant client permits and going through different processes for approvals required. Some of these processes require payments to the licensing bodies, regulatory bodies, or city councils in charge of the area. It also depends on the location—if an onshore site or an offshore site. Sometimes, there will be the need to hire equipment to use in developing the platform, which must also be included in the plan for the construction and installation.

The client must approve all offshore platform designs (structural and facilities). The results of the analysis must show that the platforms were developed using standard accepted procedures and that the structures would function sufficiently within the design parameters specified by the API RP-2A and the American Institute of Steel Construction (AISC) codes, or other related codes. The analysis report (and, if required, an explanation of the adjustments) must be included in the permit application package, as well as the maximum foundation design loads and unity checks. Copies of the soil report and verified structural construction drawings must be attached. The drawings, detailed analyses, and the entire model designs must be signed. They must also be checked, reviewed and submitted to the client by the consultant lead engineer and the project manager.

5.7. Project Management Stages

This research presents some stages of offshore construction projects. The offshore platform building services, like other fields of activity, can be given turnkey from its feasibility study for the Investment, basic design scope of work, detailed design, procurement, steel structure installation, equipment installation, and commissioning are all part of this process. Every offshore construction project must be conducted under the supervision of an independent certifying body. Also, the project must have a project schedule and a project manager(s), to ensure that these afore-mentioned project steps in the workplan can be completed, and a certificate of class can be issued as a result. There are certificates of completion issued at the end of each major stage completed, upon delivery and reports need to be delivered, checked off and signed.

For the construction aspect, the availability of materials and its proximity to the shipyard is highly important. Steel constructions for facilities such as offshore platforms are normally fabricated in ship-building yards located some distance from the installation location. Hence, the source of the materials and their delivery to the construction site must also be taken into cognisance. Hence, aside from fabrication, transportation of such big parts is a complex task that necessitates a one-of-a-kind design that includes structural strength calculations for the transportation conditions. Also, there are different offshore construction activities conducted in the shipyard [252–259]. After that, they are moved via barges and other transportation techniques like loadout floating methods to move them to the installation locations. Due to time restrictions, some design, engineering, material/equipment supply, and steel structure manufacturing processes are typically carried out concurrently. However, it should be noted that some studies have looked at different software packages used by comparing, applying and validating them, using designs for marine risers, FOWT and WEC [91,260–271]. These studies have been validated to achieve safe, efficient, and quickly delivered engineering designs and their analysis.

Hence, the design confidence necessitates rapid reaction to coordinate the total engineering design and project management required. Proper project management ensures quick delivery on the project. Lastly, these activities all require a workflow, adequate planning and know-how on the project to ensure that each deadline is met [272]. Figure 16 shows a typical workflow for project management stages used in designing offshore structures, showing concept design, detail design, final design and design approaches used.

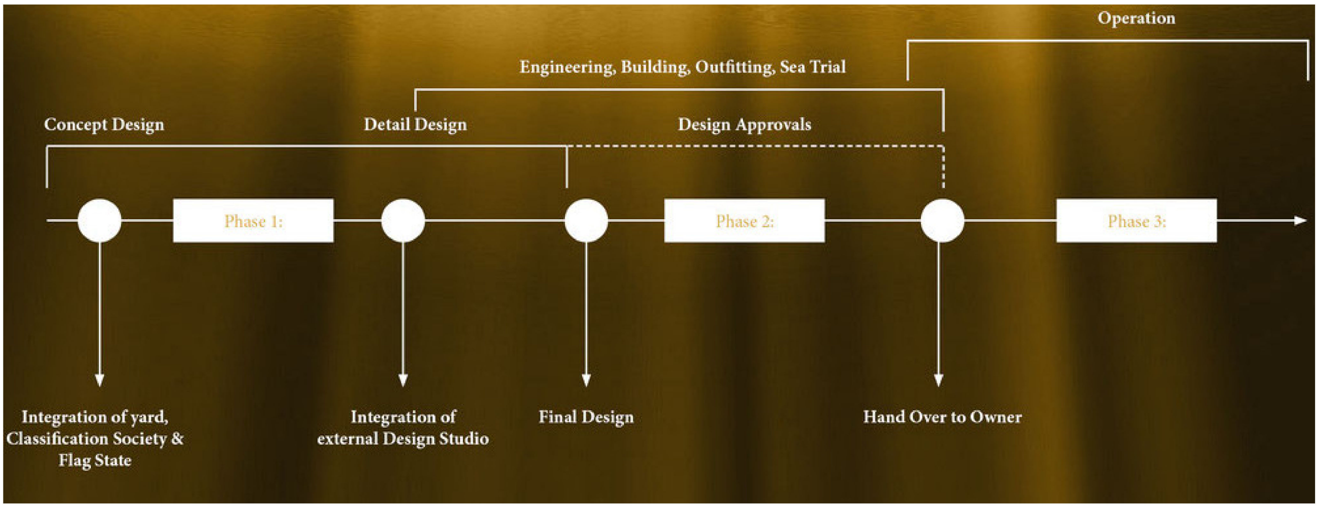

Figure 16. Typical workflow for project management stages used in designing offshore structures, showing concept design, detail design, final design and design approaches (Courtesy: Migaloo).

6. Conclusions and Recommendations for Future Research

The manuscript presents a comprehensive review on fixed and floating offshore platforms. This review is conducted on fixed and floating offshore structures, with sustainable design and management approaches. It is very interesting and provide a valuable tool in support the design and management of these structures. The manuscript includes an introduction on ocean engineering with a description of the current position of the different types of offshore facilities. It also gives the purpose of the offshore structures with some in-depth considerations of most relevant parameters influencing the design process. It also covers considerations regarding the management of the offshore facilities. A brief historical exploration is conducted to present the state-of-the-art review on some offshore platforms and achievements made in the industry are also included. The historical development of different offshore platforms varies over some timelines, as seen in designs, process inventions and patents. However, the design of offshore structures has similar foundations as covered in this review. Simply put, the development and design of offshore platforms differ based on the type of structure, although they have similar project management routines, as presented in this research.

In more recent design, the application of new design approaches has been applied and more of these techniques aid reliable design of offshore structures. However, adequate validation to verify each design is recommended. It could be specified that validation refers to both physical and numerical models. In these cases, the most up-to-date and substantial design and construction processes are used. They are also used in integrity tests, structural validations, and unique monitoring techniques. Hence, some optimisation schemes, design schemes, monitoring schemes and general analyses, have seen more advancements. However, further studies on these schemes and approaches will help to improve awareness of these offshore structures' design approaches. It is worth stating that different validations have also been conducted on both hydrodynamic, finite element analysis (FEA), and Building Information Modeling (BIM), structural design and structural integrity software to confirm their use for offshore structures [260–271].

Furthermore, the efficient component factors required to thoroughly improve the service life and failure patterns of these offshore structures should be done. Finally, suitable types of offshore platforms for various seawater depths are offered for long-term operations, high productivity, high serviceability, and sustainability. Despite the type of offshore platform, the design methods are general, but each type has particular design considerations and unique loads. These designs are also carried out in a variety of geographical locations and environmental conditions. This review also presents strong pointers for choosing offshore platforms as viable choices for offshore exploration and production. In a nutshell, it is our opinion that this review can be useful in providing a comprehensive view on this topic for offshore structures.

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Abbreviations

2D	Two-Dimensional
3D	Three-Dimensional
AISC	American Institute of Steel Construction
ANN	artificial neural network
API	American Petroleum Institute
ASTM	American Society for Testing and Materials
BOP	Blowout Preventer
CFD	Computational Fluid Dynamics
CEV	Carbon Equivalent Value
CPU	Central Processing Unit
DD	Semi Deep Draft Semisubmersible
DNV	Det Norske Veritas
DoF	Degree of Freedom
DTS	Dry-Tree Semisubmersible
FOWT	Floating Offshore Wind Turbine
FPSO	Floating, Production, Storage and Offloading
GA	genetic algorithm
GoM	Gulf of Mexico
GPU	Graphics Processing Unit
h/L	Relative water depth or Ratio of mean water depth to wave length
HSE	Health and Safety Executive
LSE	Life Support Equipment
MET-INT	Metocean Interim
MOPU	Mobile Offshore Production Unit
NA	Not Applicable
NREL	National Renewable Energy Laboratory
RAO	Respond Amplitude Operator

RP	Recommended Practice
SCR	Steel Catenary Risers
SemiSub	SemiSubmersible
SPAR	Single Point Anchor Reservoir
TLP	Tension Leg Platform
TTR	Top Tension Riser
U.S.A.	United States of America
VIV	Vortex Induced Vibration
VLFS	Very Large Floating Structures
WEC	Wave Energy Converter
WSD	Working Stress Design

Appendix A

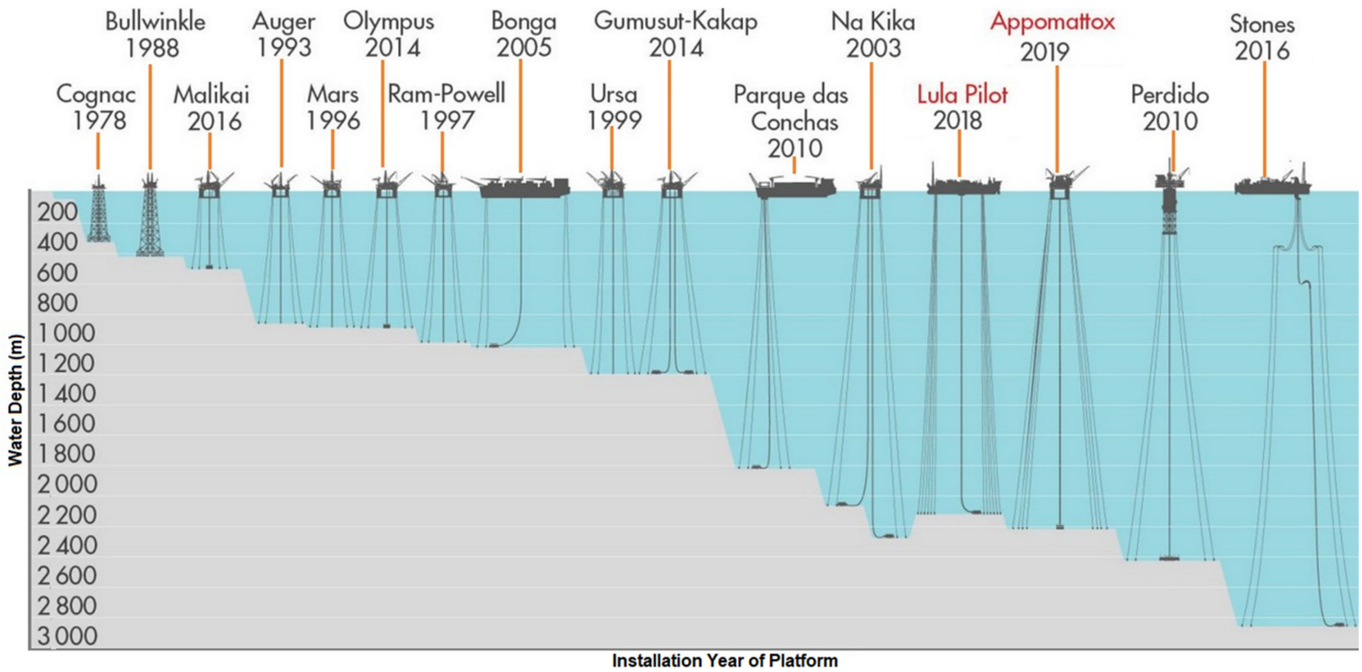

Figure A1. Historical development of deepwater platforms (Courtesy: Shell).

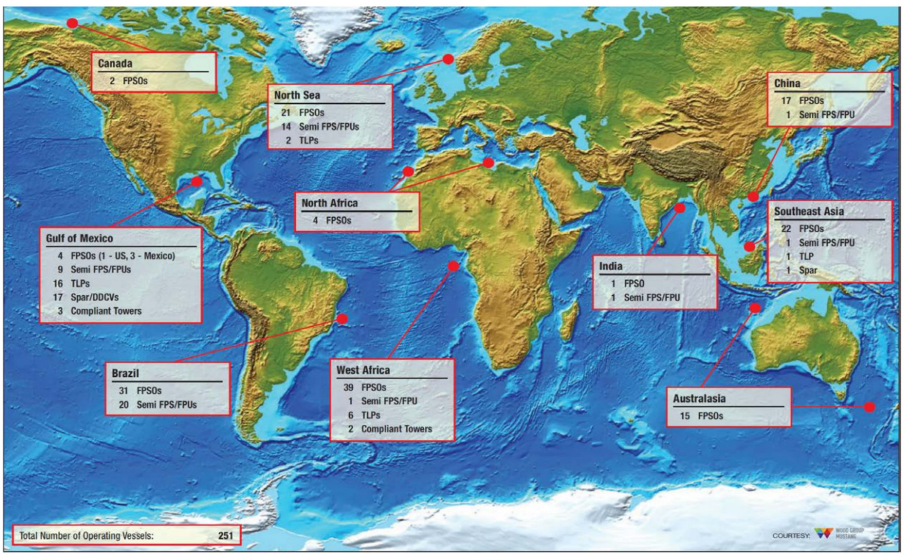

Figure A2. Deepwater Systems Global Distribution showing different offshore platforms and the total number of operating vessels (Courtesy: Wood Group Mustang).

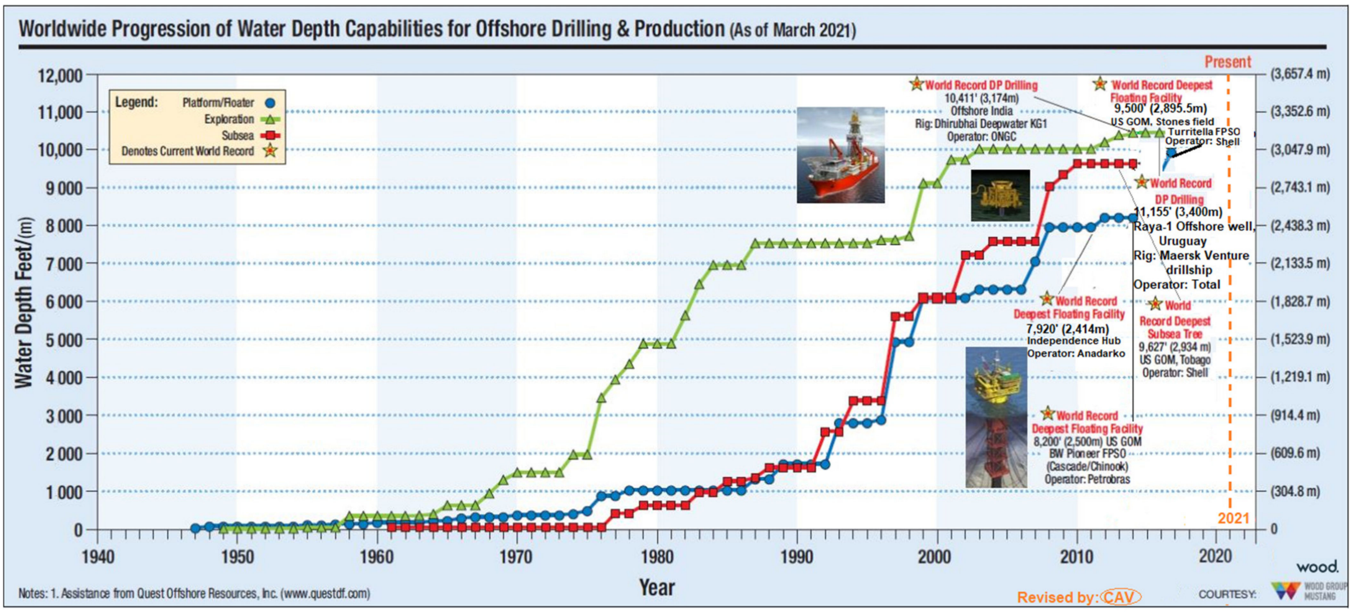

Figure A3. Worldwide progression of water depth capabilities for offshore drilling and production (Courtesy: Wood; Revised by C.V.A.).

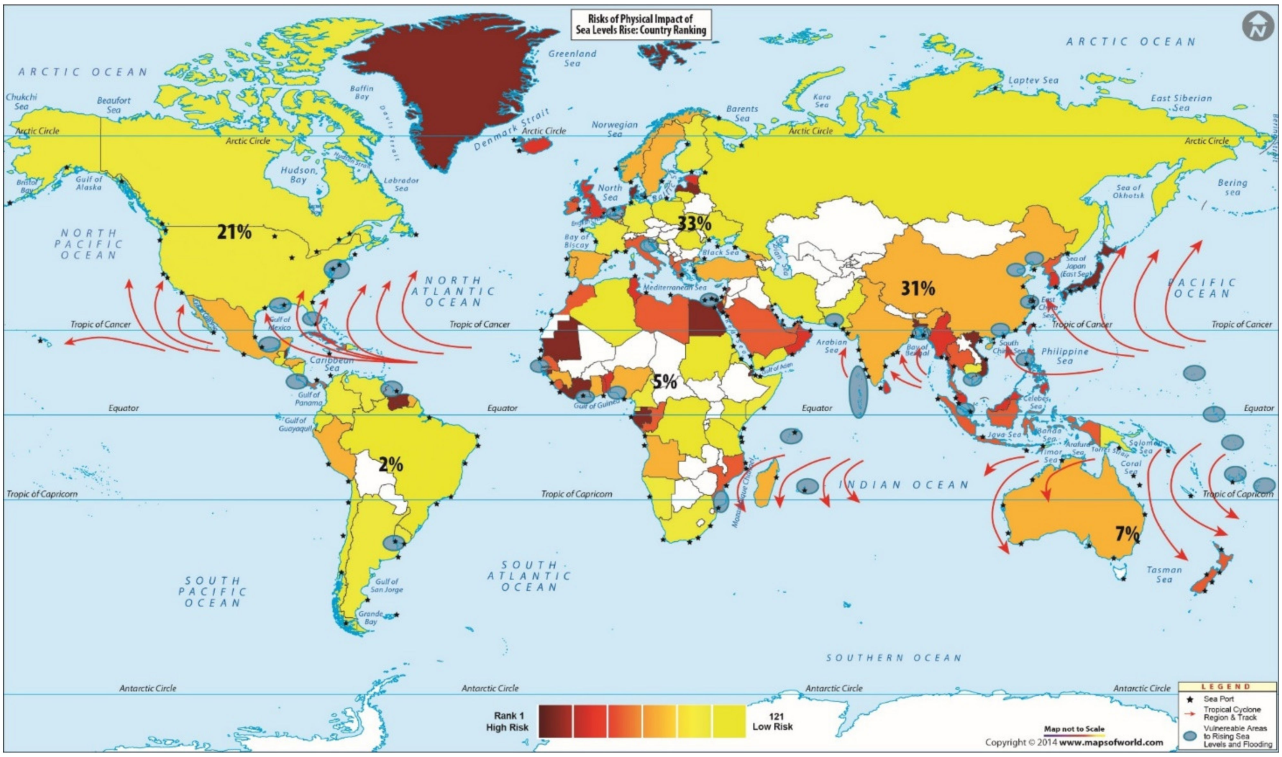

Figure A4. Map of extreme weather, its risks of physical impact by country ranking and sea level rising conditions globally (Courtesy: Mapsofworld).

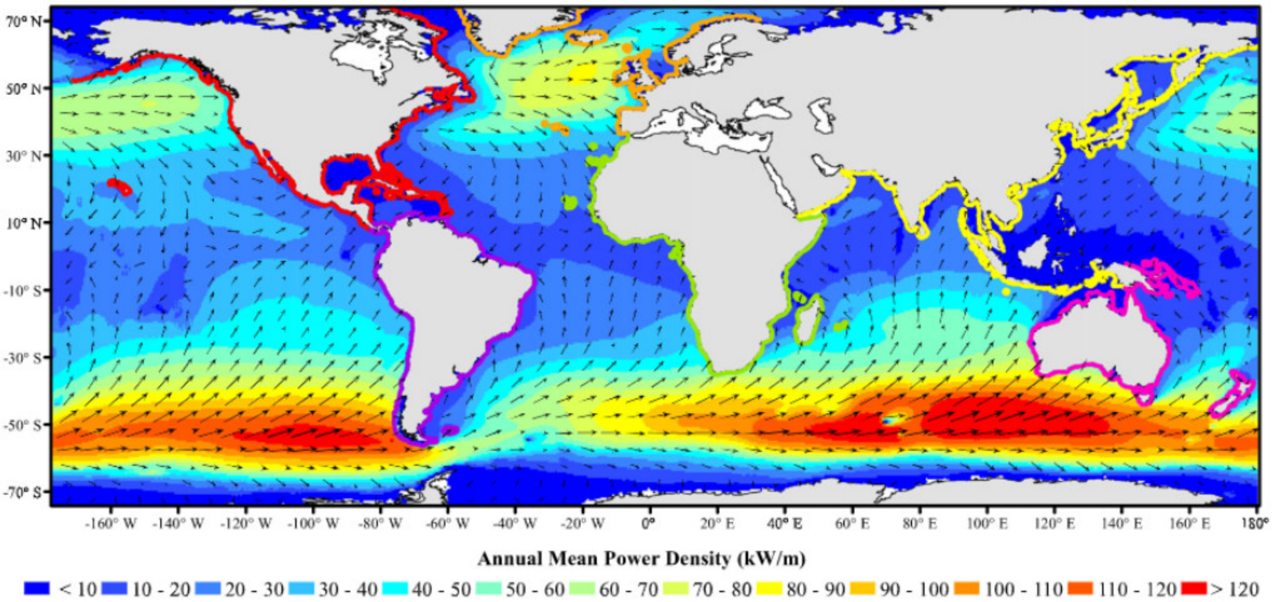

Figure A5. Map of global distribution of wave energy density showing annual mean power density Large Wave Power Density regions exist around 50° N and 50° S (red represents highest wave power density and arrows represent predominant direction). (Permission obtained to reuse image from Elsevier. Author: Kester Gunn and Clym Stock-Williams; Publication: Renewable Energy; Publisher: Elsevier; Date: August 2012; Source [273]).

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