THE STRATEGIC ROLE OF FPSO IN DEEPWATER EXPLORATION: INTEGRATING SOCIAL MANUFACTURING SYSTEMS WITHIN INDUSTRY 5.0

O PAPEL ESTRATÉGICO DO FPSO NA EXPLORAÇÃO EM ÁGUAS PROFUNDAS: INTEGRAÇÃO COM SISTEMAS DE MANUFATURA SOCIAL NA INDÚSTRIA 5.0

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PORTELLA, Anderson Gonçalves, MSc.
COPPE/UFRJ, Rio de Janeiro, Brasil, E-mail: andersonportella@yahoo.com.br
ORCID: https://orcid.org/0000-0001-6520-4301.

DE ABREU, Victor Hugo Souza, DSc.
PET/COPPE/UFRJ, Rio de Janeiro, Brasil, E-mail: victor@pet.coppe.ufrj.br
ORCID: https://orcid.org/0000-0002-2557-2721.

DOS SANTOS, Marcos, DSc.
IME, Rio de Janeiro, Brasil, E-mail:
marcosdossantos_doutorado_uff@yahoo.com.br
ORCID: https://orcid.org/0000-0003-1533-5535.

ABSTRACT

This study analyzes the role of Floating Production, Storage, and Offloading units (FPSO) in deepwater oil and gas exploration within the context of Industry 5.0, focusing on integrating social manufacturing systems. Reviewing common offshore exploration methods, the study identifies FPSOs as key catalysts for innovation, energy efficiency, and sustainability. The research concludes that combining FPSO with Industry 5.0 can optimize horizontal and vertical production processes, enhancing predictive maintenance, advanced safety, and waste management. Continuous innovation is highlighted as vital for addressing future challenges in deepwater exploration.

Keywords: FPSO; Deep and Ultra Deep Waters; Industry 4.0; Industry 5.0; Oil and Gas.

RESUMO

Este estudo analisa o papel das Unidades Flutuantes de Produção, Armazenamento e Transferência (FPSO) na exploração de petróleo e gás em águas profundas no contexto da Indústria 5.0, focando na integração de sistemas de manufatura social. Utilizando uma revisão de métodos comuns de exploração offshore, o estudo identifica FPSO como catalisadores chave para inovação, eficiência energética, e sustentabilidade. A pesquisa conclui que a combinação de FPSO com a Indústria 5.0 pode otimizar processos produtivos horizontais e verticais, promovendo manutenção preditiva, segurança avançada, e gestão de resíduos. A inovação contínua é ressaltada como vital para enfrentar desafios futuros na exploração em águas profundas.

Palavras-chave: *FPSO; Águas Profundas e Ultra Profundas; Indústria 4.0; Indústria 5.0; Óleo e Gás.*

1. INTRODUCTION

Offshore oil and gas exploration is crucial for the global energy supply of hydrocarbons but faces significant challenges in deep and ultra-deep waters. With the increasing demand for energy resources, particularly in these challenging environments, it is imperative to enhance the technologies and methods associated with exploration.

This article provides a comprehensive analysis of the challenges and opportunities related to offshore exploration, with a special focus on Floating Production, Storage, and Offloading (FPSO) units (MORAIS, 2013). The central issue addressed in this work is the effectiveness and integration of FPSO, which are fundamental to deepwater exploration.

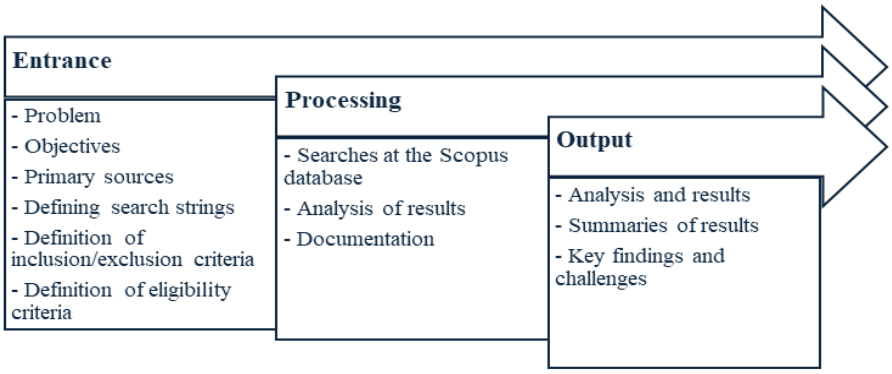
The main objective is to evaluate how FPSO, as established technologies, can be optimized and integrated with Industry 5.0 principles, delivering substantial benefits in terms of efficiency, safety, and cost reduction. Given the complexities of offshore environments, it is crucial to understand the specific challenges faced by FPSO, from technological demands to methodological aspects, and to explore how Industry 5.0 can offer innovative solutions to enhance deepwater and ultra-deepwater exploration. This study aims to contribute to a deeper understanding of these issues, driving advancements in the offshore energy industry (CHRISTODOULOU, 2015).

The research question guiding this study is: How can the integration of Industry 5.0 principles optimize FPSO and contribute to advancements in deepwater exploration? The article is structured into the following sections: Introduction, Methods, Industry 5.0 Integration, Related Studies, and Final Thoughts. Through this structure, the study aims to address the research question and promote progress in the offshore energy industry.

2. METHODOLOGICAL PROCEDURES

This research involves a literature review utilizing the SCOPUS online database as the primary information source. A comprehensive search was conducted on knowledge production related to offshore exploration in deep waters. The aim was to support the article's content and present the state of the art on the subject, as illustrated in Figure 1.

Figure 1: Research method.



Source: Authors.

The search considered titles, abstracts, and keywords for the broad selection of potentially relevant works. The inclusion criteria included texts published between 2019 and 2023, conference papers, articles, and reviews. Using terms like ("oil" OR "oil industry") AND ("offshore") AND ("exploration and production") AND ("deep waters"), 22 articles were initially identified and classified based on citation numbers.

Ultimately, 15 articles were selected and organized into forms containing identification data and synthesis to capture relevant concepts for offshore exploration in deep waters, specifically focusing on FPSOs and their integration with social manufacturing systems in Industry 5.0.

3. INDUSTRY 5.0 INTEGRATION AND CHALLENGES IN OFFSHORE EXPLORATION WITH FPSO

Industry 5.0 integration in offshore exploration with FPSO offers chances to improve efficiency and sustainability, focusing on human-intelligent system collaboration and technologies like AI and robotics. However, the harsh environments and safety concerns require innovative multidisciplinary solutions. Thorough analysis and effective strategies are necessary for successful adoption and ensuring competitiveness in facing these challenges.

3.1. Integration of Social Systems in Industry 5.0 and Offshore Challenges

In the Industry 4.0 era, digital transformation has revolutionized production, impacting industries and daily lives. The integration of manufacturing processes with information and communication technologies, particularly the Internet of Things, forms Cyber-Physical Systems (CPS) (DALENOGARE *et al.*, 2018).

This integration offers technological opportunities, transforming configuration times, labor, input costs, and processing times, leading to productivity gains. Business leaders increasingly demand integrated industrial processes and strategies to meet market demands. Industry 4.0 utilizes cloud-stored data for incremental gains in production autonomy and cybersecurity. The paradigm shift highlights the importance of humans in operating systems, with concerns about the underrepresentation of human factors in research flows (NAHAVANDI, 2019).

In this context, Neuman *et al*. (2020) list the nuances of digitalization:

> "Speaking broadly, I4.0 refers to the further digitalization and integration of information technologies including applications such as the Internet of things (LU, 2017), cloud-based systems (LU, 2017), cobots (BORTOLINI *et al.*, 2017), big data analytics (WANG *et al.*, 2016), additive manufacturing (HOFMANN and RÜSCH, 2017), and cyber-physical systems (XU *et al.*, 2018). These systems enable a "smart factory" (FRANK *et al.*, 2019; OSTERRIEDER *et al.*, 2020), in which humans, machines, and products communicate with each other via both physical and virtual means (KAGERMANN *et al.*, 2013), and can contribute to increased sustainability (BAI *et al*., 2020)." (NEUMAN *et al.*, p.1, 2020)

González *et al*. (2022) emphasize the importance of educational proposals aligned with Industry 4.0 (I4.0) to foster skills and inclusive opportunities. However, a gap exists between educational needs and structures, hindering the effective integration of new skills. Process optimization in I4.0 raises concerns about social impact, including job reduction and resistance from unions and politicians.

In this context, process optimization brings with it a human cost, marginalizing those without the skills to deal with distributed and intelligent computing. The advancement of this model provokes resistance from unions and politicians due to the reduction of jobs, resulting in social precariousness and a perceived loss of well-being, despite technological advances.

In offshore exploration with FPSO, digitalization is crucial for addressing challenges and reducing the CO2 footprint. Industry 5.0 (I5.0) emerges as a response to I4.0 challenges, promoting smart factories with reduced human labor. FPSOs are adopting I5.0 principles for improved processes and quality. I5.0 emphasizes collaboration between machines and humans, focusing on creativity, decision-making, and empathy, aiming to drive environmental sustainability and social responsibility while maintaining efficiency.

3.2. Offshore oil exploration

Oil drilling dates to 256 B.C., with significant progress made in 1853 with George Bisell's oil sample and Colonel Edwin Drake's large-scale onshore exploration in 1859 (YERGIN, 1992; NOZAKI *et al*., 2020). Offshore oil exploration began in the late 1940s in the Gulf of Mexico and Caspian Sea. Petrobras, authorized in 1953, faced challenges in Brazil, such as a lack of qualified professionals.

Brazil's first successful oil discoveries occurred in 1939, followed by offshore discoveries in 1968-73 in the Campos Basin. Water depths of 0-300m, 300-1,500m, and above 1,500m define shallow, deep, and ultra-deep waters (MORAIS, 2023). Deepwater and ultra-deepwater exploration access untapped hydrocarbon reserves but present high pressures, extreme temperatures, and harsh environments. Technology innovations are needed for the Brazilian oil industry to address such challenges.

PETROBRAS holds a 22% share in global deepwater and ultra-deepwater production, despite uncertainties and dependence on imports (MORAIS, 2023). Exploration starts with marine seismic imaging and exploratory drilling, using fixed or floating platforms.

Challenges overcome over time included uncertainties about the existence of hydrocarbons in the country, insufficient volume of discovered sources, dependence on imports, and lack of skilled labor (IBID., 2023, p.28).

Exploration begins with marine seismic, where ships tow "streamers" equipped with sensors to capture seismic waves reflected from the subsurface, providing detailed images of the geological layers below the seabed (PETROBRÁS, 2023).

Offshore production systems include fixed or floating platforms, subsea systems, or FPSO (MORAIS, 2023) depending on factors like water depth, climate, and resource quantity. FPSO excels in deep and ultra-deep waters, being the definitive production system, less carbon-intensive, in the process of exploring and producing.

After production system installation, development drilling and well completion take place to control oil/gas flow. Transportation involves pipelines or tankers for FPSO systems. Decommissioning includes equipment and structure removal and well abandonment when production becomes unviable (PETROBRÁS, 2023).

3.3. The Importance of FPSO in Offshore Exploration

FPSOs are crucial in offshore exploration, offering mobility, deepwater operation, flexibility, and cost savings over fixed platforms. It is essential to highlight the advantages and disadvantages of the chosen production systems, as shown in Table 1.

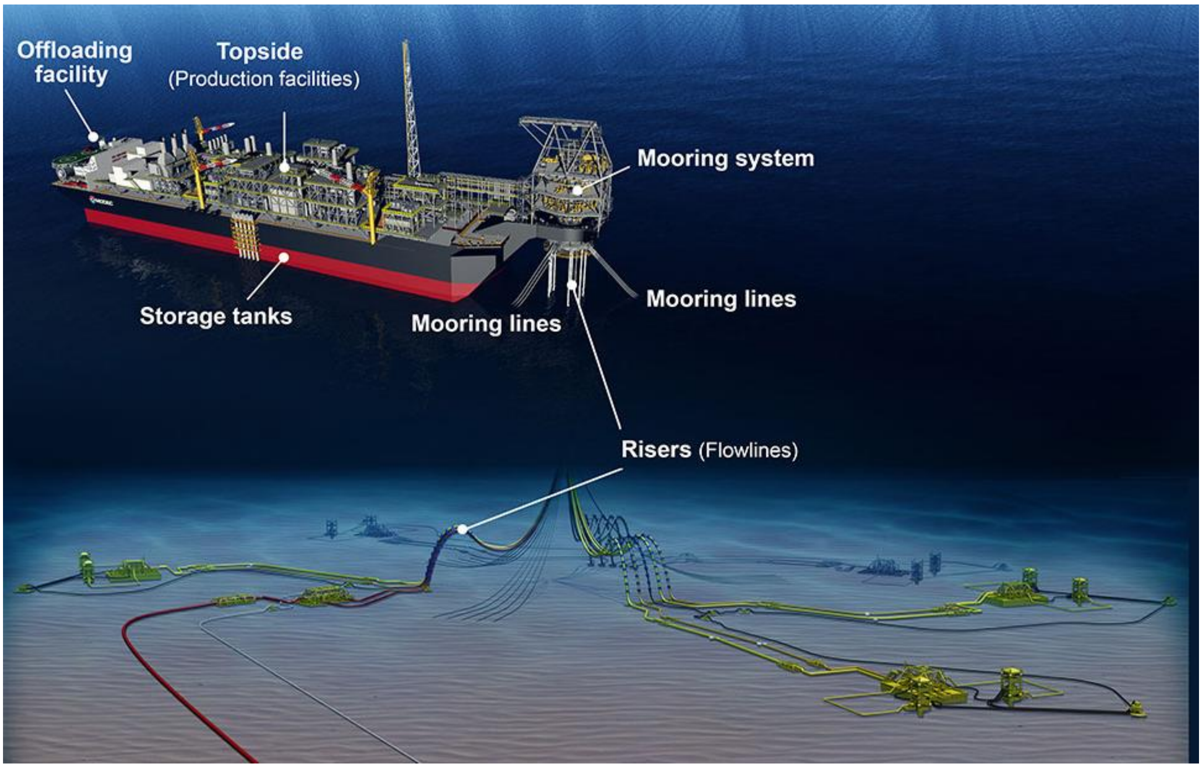
Table 1: Advantages and disadvantages of production systems.

System	Advantage	Disadvantage
Fixed platforms	Stability, robustness, suitable for harsh weather, ideal for long-lasting fields, lower operating cost	Limited to 500 meters depth, higher installation and decommissioning cost, less flexibility, costly decommissioning
Floating platforms (e.g. Tension Leg Platform - TLP, Spar Platform, Semi-submersible Platform)	Suitable for larger depths (3,000 meters+), adaptable, lower installation and decommissioning costs	Higher operating cost, sensitive to weather and sea movements, costly decommissioning
Subsea Production Systems - SPS	Suitable for extremely large depths (3,000 meters+), lower environmental impact, lower installation, and decommissioning costs	Higher operational, and maintenance costs, difficulties in monitoring control
FPSO	Flexible, easy to relocate, storage and offloading capabilities, suitable for short-lived/remote fields, simpler, less expensive decommissioning	Higher operating cost, sensitive to weather and sea movements

Source: Authors.

An FPSO, usually converted from tankers (Very Large Crude Carriers, VLCCs) or purpose-built, has processing equipment on top, separating oil, gas, water, and impurities. Crude oil is stored in the ship's tanks for further discharge into tankers or onshore refinement. The lashing, crucial for stability, is adapted to the environment, ensuring continuous operations for 20 years or more (MODEC, 2023), as Figure 2.

Figure 2: Image of an FPSO.



Source: MODEC (2023).

FPSO uses the Differentiated Anchoring and Compliance System (DICAS) for positioning, incorporating scattered mooring in calm waters and disconnectable mooring systems in cyclone- or hurricane-prone environments. This adaptability enables the vessel to be removed and returned to its position during adverse weather events (MODEC, 2023).

Subsea pipelines and risers facilitate oil and gas (O&G) extraction, transporting them to the FPSO for separation and treatment. Treated oil is stored, while gas can be reinjected, used as fuel, or exported. Offloading transfers oil to a tanker for further transportation (MORAIS, 2023).

Ideal for remote or challenging O&G fields, FPSO offers a solution where fixed infrastructure is impractical. They are suitable for short-term fields or those with uncertain reserves and can be easily relocated or decommissioned efficiently and cost-effectively (IBID., 2023).

3.4. Characteristics of modern FPSO

Modern FPSO, exemplified by FPSO Cidade de Campos dos Goytacazes (MV29), Figure 3, leverage technological advancements for enhanced production, efficiency, and safety, recognized by the World Economic Forum in 2020 (WEF, 2020).

Despite the Oil & Gas sector's traditional resistance to innovation, FPSO emerged as a definitive exploration solution, as declared by Petrobras (WEF, 2020).

Figure 3: FPSO Cidade de Campos dos Goytacazes MV29.

Source: MODEC (2023).

These FPSOs employ converted or purpose-designed tanker hulls, providing increased storage capacity and optimized functionality for specific conditions, including extreme weather (BELL *et al.*, 2005). Advanced processing systems, such as multi-stage separators and gas compression, contribute to improved product quality reducing environmental impact (FREIRE *et al.*, 2019).

Furthermore, modern FPSOs adopt sophisticated mooring systems like the Turret Mooring System, optimizing safety and efficiency during production and unloading operations (HOWELL *et al.*, 2001).

Various mooring systems are available, with the choice based on environmental conditions, such as the use of an inner tower in the hull for locations prone to cyclones and severe marine conditions, like off the northwest of Australia and Hong Kong (WEF, 2023).

Figure 4: Mooring Systems.

Internal Disconnectable Turret

External Turret

Tower Yoke

Spread Mooring

Source; MODEC (2023).

These modern FPSOs integrate advanced automation and control systems to remotely monitor and control operations, improving efficiency, and safety, and reducing the need for manual interventions, as displayed in Figure 5.

Figure 5: Onshore Monitoring Center.

Source: MODEC (2023).

FPSO employs efficient and sustainable power generation systems like gas turbines or low-emission diesel engines, along with energy-efficient technologies such as waste heat recovery systems, aligning with Net Zero Carbon commitments (CORREIA *et al*., 2023).

Emphasis on safety and environmental protection is evident through features like fire detection and suppression systems, oil spill prevention, and wastewater treatment, adhering to strict standards like MARPOL (International Convention for the Prevention of Pollution from Ships) and SOLAS (Convention for the Safety of Life at Sea) (VASCONCELLOS *et al*., 2005).

FPSOs are customized for specific oil or gas field requirements, following customer guidelines, and varying in features and technologies. This adaptability positions FPSO as a tools for continuous digital transformation.

3.5. Challenges of deepwater exploration with FPSO in Industry 5.0

The implementation of social manufacturing systems (also known as Cyber-Physical Production Systems - CPPS) in FPSO was not a widespread practice, however, we can list some of the concepts that are already being applied, and others that may soon contribute to optimizing production and maintenance, as detailed in Table 2.

Table 2: Social manufacturing systems to optimize the production and maintenance of FPSO.

Proposals/Concepts	**Detailing**
Integration of Sensors and Smart Devices	Implementation of IoT (Internet of Things) sensors to monitor equipment performance and operating conditions in real-time
	Use of smart devices to collect data on production, energy consumption, and environmental conditions.
Advanced-Data Analytics	Application of big data analytics and machine learning algorithms to analyze large operational data sets and identify patterns
	Use of predictive analytics to anticipate equipment failures and schedule preventive maintenance
Real-Time Communication and Collaboration	Implementation of real-time communication systems to facilitate collaboration between production and maintenance teams
	Use of collaborative platforms for information sharing and quick problem resolution
Additive Manufacturing (3D Printing)	Adoption of additive manufacturing technologies to produce spare parts and custom components, reducing downtime
Augmented Reality (AR) and Virtual Reality (VR)	Implementation of AR and VR technologies for operator training, remote problem diagnosis, and computer-aided maintenance.
Automation and Remote-control	Integration of automated control systems to optimize production processes
	Development of remote-control capabilities for operation and monitoring of FPSO from onshore control centers
Cyber Security	Implementing robust cybersecurity measures to protect sensitive data and critical systems from threats

Source: Authors.

The use of sensors and data analysis in FPSO allows for early problem detection, predictive maintenance, and improved sustainability by optimizing production and reducing costs (IBP & OTC, 2023). Companies must address challenges by embracing social manufacturing systems and adopting innovative, cleaner solutions, including digital technologies like AI, machine learning, and IoT, which enhance FPSO operation and maintenance.

The oil and gas exploration industry faces significant challenges in the context of the energy transition and growing environmental concerns. To adapt to this scenario, the industry is looking for innovations and solutions that increase efficiency, reduce environmental impacts, and align with sustainability goals (IBP and OTC, 2023).

Aligning their challenges with the principles of implementing social manufacturing systems, oil and gas companies need to coordinate their efforts on several fronts to adapt and evolve to remain competitive and sustainable. The adoption of innovations and the search for cleaner and more efficient solutions will be key to meeting the challenges and seizing the opportunities of this new energy context.

The implementation of digital technologies such as artificial intelligence, machine learning, and the Internet of Things (IoT), can optimize the operation and maintenance of FPSO. Process automation and the use of advanced robotics can also improve the efficiency and safety of operations, preserving lives and avoiding environmental impacts (IBP and OTC, 2023).

In the environmental context, the integration of renewable energies, such as solar and wind power, into FPSO can reduce dependence on fossil fuels and decrease greenhouse gas emissions. This may include the installation of solar panels and wind turbines to complement or replace conventional power generation systems, to repurpose and optimize the consumption of these ships (IBID., 2023).

Renewable energies and energy-efficient tech cut fossil fuel use and greenhouse gases. Sustainable practices, biodegradable fluids, and biodiversity protection lessen environmental impact. Improved monitoring, fire detection, and spill containment boost safety in deep waters.

Implementing carbon capture and storage (CCS) technologies on Floating Production Storage and Offloading (FPSO) units can significantly reduce CO2 emissions from oil and gas production by storing captured CO2 in underground geological formations or using it for industrial processes such as enhanced oil recovery. To minimize environmental impacts, adopting sustainable practices like biodegradable drilling fluids and marine biodiversity protection is critical, alongside investing in ongoing research and development to discover further innovative solutions (IBID., 2023).

Advanced monitoring and control systems, including high-resolution sensors and cameras, enhance the safety and efficiency of FPSO operations. Additionally, fire detection, suppression systems, and oil spill containment systems help mitigate risks in deep and ultra-deep-water offshore operations. Collaboration among industry stakeholders, technology providers, and research institutions is essential to drive innovation, with platforms such as the Offshore Technology Conference (OTC) facilitating the sharing of technical solutions and advancements that contribute to the upstream segment of the Oil & Gas industry (IBID., 2023).

In addition, public-private partnerships and joint research initiatives facilitate knowledge sharing and resource-driven FPSO evolution (IBP & OTC, 2023).

4. RELATED STUDIES

The exploration of oil and gas (O&G) in deep and ultra-deep waters has been driven by a series of technological innovations that enable operations in increasingly challenging environments. These technologies are essential for overcoming the physical and operational limitations associated with offshore exploration, providing greater efficiency and safety.

However, there is a gap in the literature regarding a comprehensive analysis of the specific technologies that contribute to the success of these operations, especially within the context of Industry 5.0. This study aims to fill this gap by exploring the key technologies employed in offshore O&G exploration, focusing on their integration with social manufacturing systems and the enhancement of innovative practices.

4.1. Offshore O&G Exploration Technologies

Seyyedattar *et al.* (2020) stress the importance of technological advances in exploring deep and ultra-deep waters, highlighting the need for modern and innovative methods. It identifies a gap in the literature regarding a comprehensive analysis of specific contributing technologies, which this study aims to fill.

Nnabuife *et al*. (2022) concentrate on offshore production and flow control, advocating for a comprehensive riser flow control approach in deepwater exploration. They recommend slugging as a robust flow pattern but do not explore its potential integration with Industry 5.0 principles, a key focus of the present research.

4.2. Deepwater Drilling Practices and Challenges

Patel *et al.* (2018) spotlight the preference for non-harmful non-aqueous fluids (NAF) in reservoir drilling, presenting the innovative Clay Free Invert Drilling Fluid (CFIDF). Developed with a polymeric rheology modifier, CFIDF offers a clay-free system with constant rheology across temperatures, crucial for deepwater drilling. Field tests show positive performance in drilling rate, ECD control, and well cleanliness, reducing the potential for circulation loss.

Ojeh-oziegbe *et al.* (2019) address the need for development in various fields, emphasizing cost containment and efficient technologies in the offshore energy industry. They introduce an innovative single-trip well completion technique for economy, safety, and efficiency, covering design evolution, contractor management, equipment interfaces, operational steps, risks, and lessons learned.

Shann *et al.* (2020) assess the Sureste Basin in southern Mexico as a potential super basin for hydrocarbon exploration, emphasizing uncertainties in deepwater exploration. While their study provides insights into challenges, it lacks exploration of the potential benefits of integrating social manufacturing systems in Industry 5.0, a central concern of this research.

4.3. Industry 4.0 and Sustainability

Ghobakhloo *et al.* (2020) scrutinize the sustainability functions of Industry 4.0, employing interpretive structural modeling to unveil complex relationships. The study highlights that economic sustainability, emphasizing production efficiency and innovative business models, takes precedence over socio-environmental sustainability functions. By shedding light on Industry 4.0's potential for global sustainability, the research encourages collaborative efforts for effective and equitable implementation.

4.4. Deepwater Infrastructure and Platforms

Chandrasekaran *et al.* (2020) explore semi-submersible floating structures in deepwater oil exploration, focusing on a restricted positioning system. By evaluating

CNOOC's HYSY-981 platform with a sixteen-point catenary mooring system (case 1) and comparing it with a conventional system using a submerged buoy (case 2), numerical analyses reveal the dynamic behavior at different depths. The addition of the buoy improves mooring service life, but failures in adjacent lines adversely affect service life due to load transfer.

Hari *et al.* (2022) emphasize the increasing energy demand driving hydrocarbon exploration in deepwater and ultra-deepwater, where Tension Leg Platforms (TLPs) play a critical role. Their study examines the dynamic response of the shelf restriction system in extreme sea conditions, highlighting the significant increase in stress cycle variation and averaging during severe offshore weather events.

4.5. Optimization and Efficiency in Deepwater Operations

Ng *et al*. (2019) emphasize preparation for deepwater and offshore hydrocarbon exploration, highlighting Shell Malaysia's Real-Time Operation Centre's role in optimizing well operations. They cover hydraulic management, pressure-controlled drilling, vibration mitigation, well cleanliness, and cost savings through minimized wasted time, underscoring the growing importance of Real-Time Operation Centers.

De Freitas *et al.* (2020) propose a gas-lift optimization workflow for oil wells, crucial for 30% of monthly oil production in Brazil. The method enhances reservoir recovery and gas efficiency, achieving a 0.5% increase in cumulative production, reducing gas consumption, and improving project financials within platform limitations.

Yang & Xiao (2021) optimize ultra-deepwater drilling's operational performance and reduce riser system weight, employing a multi-objective approach with NSGA-II and an RBF metamodel. Objectives include minimizing riser system weight and maximizing operability envelope area, addressing computation and convergence challenges.

4.6. Risk Management and Safety in Offshore O&G Projects

Agbadiba & Maduagwu (2023) examine deepwater O&G exploration challenges, emphasizing floating platforms and FPSO in Nigeria's Gulf of Guinea. Use mixed methods (literature review, interviews, online research) to stress safety culture and incident reporting. Propose an incident reporting model for better risk management, accident prevention, operational sustainability, and profitability in offshore O&G projects.

4.7. Innovative Solutions and Techniques in Deepwater Exploration

Panayirci *et al.* (2019) analyzed the structural robustness of a slimmer well design for the FortunaCo project in Equatorial Guinea using a static nonlinear finite element motor. The numerical model proved suitable for estimating critical buckling loads and optimizing the design efficiently during the conceptual phase.

Nardy *et al.* (2021) explored developing methods for underwater inspection of subsea equipment, vital for deepwater O&G exploration. They proposed an innovative computational system for generating accurate 3D models of underwater structures, beneficial for planning and executing monitoring and maintenance in the offshore oil exploration and production industry. Feasibility tests confirmed the system's potential usefulness.

Tjåland *et al*. (2022) discussed mineral extraction in deep waters and the similarities in challenges between the mineral and O&G industries. They suggested that oil industry technologies, such as FPSO vessels, can be adapted for deepwater mineral extraction, emphasizing the need for innovation to minimize environmental impact.

Karacali *et al.* (2023) introduced a dynamic deepwater well-testing solution for multiple and varying reservoirs. The test program involved a rig with a surface well test package to optimize operations, reduce costs, and support the operator's growth plans.

5. FINAL CONSIDERATIONS

This article focuses on offshore O&G exploration, particularly on FPSO systems, and their advantages and disadvantages compared to other systems. It emphasizes the potential of FPSO to integrate with social manufacturing systems in Industry 5.0, driving industrial development and connecting horizontal and vertical manufacturing processes.

Subsequently, the characteristics of the most modern FPSO were presented, which highlights these ships as opportunities for the integration of social manufacturing systems in Industry 5.0, integrating horizontal and vertical manufacturing processes in an integrated and connected way, creating opportunities for industrial development. Soon after, the challenges of oil and gas exploration using FPSO in deep and ultra-deep waters, where the largest exploration basins are located, were addressed, being a driver for development in industry 5.0.

Challenges of using FPSO in deep and ultra-deep waters are addressed, as well as the benefits of integrating social manufacturing systems, including increased efficiency, safety, and cost reduction. through the scientific studies selected by other researchers, to bring the bibliographic analysis of the theme.

Thus, it was possible to conclude that the integration of social manufacturing systems in deepwater exploration, using FPSO has potential benefits, as has already been widely explored, aiming at increased efficiency, safety, and cost reduction. FPSO plays a crucial role in deepwater exploration, and their integration with Industry 5.0 offers new opportunities for optimization and sustainability.

FPSOs then play a vital role in deepwater and ultra-deepwater oil and gas exploration and their integration with social manufacturing systems in Industry 5.0 opens new opportunities for optimization and sustainability, where continued research and innovation will be essential factors in meeting the future challenges of *offshore* exploration and in implementing this approach, issues of cybersecurity and resistance to industry change will have to be addressed.

Future research should investigate innovative strategies and solutions for challenges like cybersecurity, industry resistance, and the environmental and social impacts of implementing social manufacturing systems in FPSO. Other areas of interest include developing simulation and modeling methodologies, such as Digital Twins, for optimizing integration and improving efficiency, safety, and cost reduction in offshore exploration.

Additionally, it will be relevant to investigate the environmental and social impact of the implementation of these social manufacturing systems in FPSO, seeking to identify sustainable and responsible practices that can be adopted to minimize risks and maximize benefits for communities and the environment.

Another area of interest will encompass the development of simulation and modeling methodologies and tools, such as *Digital Twins* (IoT-specific application), to optimize the integration of social manufacturing systems in FPSO to improve efficiency, safety, and cost reduction in offshore exploration.

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