HOLOS
ISSN 1807 - 1600

RECENT DEVELOPMENTS OF REMOTELY OPERATED VEHICLE IN THE OIL AND GAS INDUSTRY

A. A. DALHATU[1], R. AZEVEDO[2], O. D. UDEBHULU[3], G. DE TOMI [4]
Departmento de Minas de PetrÓleo, Escola Politéctica, Universidade de São Paulo [1,2,3,4]
ORCID ID: https://orcid.org/0000-0002-0105-7338 [1]
abdullahiabba@usp.br [1]

Submetido 17/01/2020 - Aceito 05/07/2021

DOI: 10.15628/holos.2021.9422

ABSTRACT

This work is a review of the scientific literature related to the applications of Remotely Operated Vehicles (ROVs) in the Oil and Gas Industry to allow mechatronics and robotic engineers, and other interested parties, to know the scope of some of the current various types of ROVs in the industry, and some of the current challenges faced. As a result, it is presented in this work, in an organized and orderly manner, some of the current applications and technologies. Papers were collected from various disciplines to form the first phase. The second phase included the selection of scientific journals and conference papers that discuss the use of ROV in the oil and gas industry. Finally, future applications are discussed. There is yet to be a solution for the high cost of using a support vessel in Inspections, Repairs and Maintenance (IRM) operations. Hence, this review has suggested the development of a single-vehicle for cost reduction and increased efficiency.

KEYWORDS: Marine Robotics, Oil and Gas, Remotely Operated Vehicles (ROV), Underwater Robots

DESENVOLVIMENTOS RECENTES DE VEÍCULOS REMOTAMENTE OPERADOS NA INDÚSTRIA DE PETRÓLEO E GÁS

RESUMO

Este trabalho é uma revisão da literatura científica relacionada às aplicações de veículos remotamente operados (ROVs) na indústria de petróleo e gás, para permitir que engenheiros mecatrônicos e robóticos, e outras partes interessadas conheçam o escopo de alguns dos vários ROVs atuais na indústria, e alguns dos desafios atuais enfrentados. Como resultado, são apresentados, neste trabalho, de maneira organizada e ordenada, algumas das aplicações e tecnologias atuais. Foram coletados artigos de várias disciplinas para formar a primeira fase. A segunda fase incluiu a seleção de periódicos científicos e artigos de conferências, que discutem o uso do ROV na indústria de petróleo e gás. Finalmente, aplicações futuras são discutidas. Ainda não há solução para o alto custo do uso de embarcações de apoio nas operações de Inspeções, Reparos e Manutenção. Portanto, esta revisão sugeriu o desenvolvimento de um veículo único para redução de custos e aumento da eficiência.

PALAVRAS-CHAVE: Petróleo e Gás, Robótica Marítima, Robôs Subaquáticos, Veículos Operados Remotamente

1 INTRODUCTION

1.1 Introduction

This is a review that addresses the scientific community related to robotics, mechatronics, oil and gas, and other interested parties with the interest in solving the challenges faced in inspection repair and maintenance of offshore structures.

The objective of this work is to offer an outline of some of the recent developments of ROVs in the field of the oil and gas industry. It is a review of the scientific knowledge from reliable sources aiming to learn about the state of the art of ROVs in the industry and possible future improvements for better efficiency and reduced cost.

ROVs are robots that are tethered and controlled from a surface vehicle or ship, they range in complexity and come in many different sizes and capabilities (Robert, 2015). A typical commercial one is made up of floatation pack that sits on an aluminium chassis, this provides the buoyancy, they are also equipped with camera and lights (Rahimuddin, Hasan, Rivai, Iskandar, & Pirri Hermanses, 2018) and several other add-ons depending upon the requirement of the project. They are extensively used in the development of oil and gas offshore, subsea and in their subsequent inspection, repair and maintenance (Robert, 2015).

Nowadays the development of remotely operated vehicles has a promising future, it was first used by the military and later found its way into the offshore industry which became the main driver of the explosion in the development of the technology for the commercial oil and gas sector. There is however still much to be done, mainly in the need of support vessels and communication mode of these ROVs and ultimately in the increase in efficiency and reduction of their cost.

According to Westwood, Global total capital expenditure of ROVs in 2025 will advance to $5.15 billion. This would be driven by the substantial adoption of ROVs for drilling support, construction support, as well as inspection, repair and maintenance (IRM) activities (“Global Remotely Operated Vehicle (ROV) Market 2017-2025 : Top Key Players are Andrews Survey, C-Innovation, DOF Subsea AS, Forum Energy Technologies, Fugro Subsea Services Ltd - MarketWatch,” n.d.). Drilling support is forecasted to be the largest in demand for ROV use, accounting for 40% of total expenditure, growing at 6% CAGR (Compound Annual Growth Rate). Predominate demand for ROV operations is projected to dominate in Latin America with major activities in Brazil, Guyana and the Falkland Islands bolstering demand. IMR support demand is projected to increase by 11% and expenditure to total $2.2bn over the forecast, driven by an ageing installed base of infrastructure. Subsea resident ROVs (RROVs) remains a long-term goal for oil & gas operators, as developments are sanctioned in ever more challenging and remote locations (“World ROV Operations Market Forecast 2019-2023 - Westwood,” n.d.).

HOLOS ISSN 1807 - 1600

1.2 Background

The first ROV to be build was the poodle and it was developed by Dimitri Rebikoff in 1953 (Vukić & Mišković, 2016). However much of the ROV development was done by the Navies in Britain and the United States of America in the 1950s and 1960s, among them is the early Cutlet from Britain used in the 1950s (Rahimuddin et al., 2018). In the 1960s the CURV and CURV II were realized, they were developed for rescue and recovery of ordnance (Capocci et al., 2017). By the 1970´s ROV´s were already utilized by the Oil and Gas Industry (Robertson, 1991) By 1973 CURV-III, a successor of the CURV and CURV II was used to perform the deepest underwater rescue mission in history, it successfully rescued two men that became stranded in the submersible Pisces III, off the coast of Cork, Ireland with only a few minutes of air remaining, it turned out that they were stranded 480m below sea surface for 76 hours.

It is worthy to note that this military development gave birth to the so-called "work-class" ROV. The offshore petroleum industry was the driving force in the rapid revolution of use of ROVs that occurred in the 1970s. (McFarlane, 2002), (Fard, Eidsvik, Tedeschi, & Schjølberg, 2018), several authors also noted the main market drivers of underwater robotics to be offshore oil & gas industry with the key reason associated with the routine inspections required for long term care and success of the offshore operations, which historically, has become more daunting and daring as the offshore platforms and operations move deeper into the sea, thus the increased use of ROV.

Most manned subs and some divers were replaced by ROVs by the end of the '70s and Frank Busby referred to this as the "Thundering Herd Syndrome". The '70s was referred to as the second revolution, while the first revolution was in the 1960s when US Navy CURV ROV was fielded and the University of Washington fields AUV SPURv (McFarlane, 2002). By 1989 some of the ROV operations in the oil and gas industry were covering: Rig support pipeline inspections, cable surveys/burial, subsea interventions and mine hunting, the list has been increasing over the past decades (Hartley & Prince, 1989). ROV technology has been on the rise ever since its inception and the oil and gas industry is moving towards the use of these emerging ROV technologies to provide increased safety and cost-effectiveness for intervention and evaluation of structural asset condition from a safe location (Wen, Pray, McSweeney, & Gu, 2019).

There are two types of ROVs: Inspection class and Intervention class (Capocci et al., 2017). The Inspection-class ROVs are connected to the surface user via an umbilical and they can be used to replace divers in dangerous conditions (Capocci et al., 2017). ROV-based inspection of offshore structures is very attractive, as it can be performed during drilling operations – unlike diver-based inspection which requires drilling operations to stop and result in costly downtime (Centenaro, Lany, Meyer, & Gasparin, 2019).

Although deepwater ROVs have a problem of high cost of operation and a long tether management problem, the technology is matured enough to meet the needs of the oil & gas industry (Martini, Johnston, & Morello, 2007). Today, ROV technology is employed for all offshore oil and gas facilities, and visual surveys are frequently carried out in sensitive habitats both before and after the drilling event) (Danovaro et al., 2017). Stroud in 1997 (Stroud, 1997) mentioned that Work class ROVs will address the need for future deepwater applications like subsea completions, support of FPSO early completion systems, deployment of well service work packages and tooling concepts, installation of flexible flowlines and support of deepwater pipeline operation.

2 METHODOLOGY

A) In the first phase, papers were collected from various disciplines and they were analyzed and filtered through searching of keywords ROV application in the oil and gas industry. The second phase included a selection of different scientific journals and conference papers that discuss the use of ROV in the oil and gas industry which have been used to map out the current state of ROV use in the oil and gas industry.

B) Find out the general state of the knowledge and current technologies about ROVs and their application in the Oil and Gas Industry by the means of revising literature and its substantiation to understand the current challenges and issues of application in the mentioned areas which has been partly referred in the Introduction and Background of this document and responds to basic questions that might arise about remotely operated vehicles in the oil and gas sector. Identification of problems of ROV application in offshore structures which will be expanded in the revision of the literature.

C) Review the current ROV technologies available for application in the industry describing the advantages and disadvantages of some of the technologies and methods applied in IRM through the use of ROVs utilizing the literature review.

3 RESULTS

3.1 Classification of ROVs

According to the review of Capocci (Capocci et al., 2017) Remotely Operated Vehicles used in the oil gas industry can be classified into two basic categories; Intervention class ROVs and Inspection class ROVs as categorized in Figure 1. It is mentioned in (Christ & Wernli, 2013) that there are currently two types of Underwater vehicles; Manned and Unmanned, and the ROV´s fall under the classification of unmanned underwater vehicles.

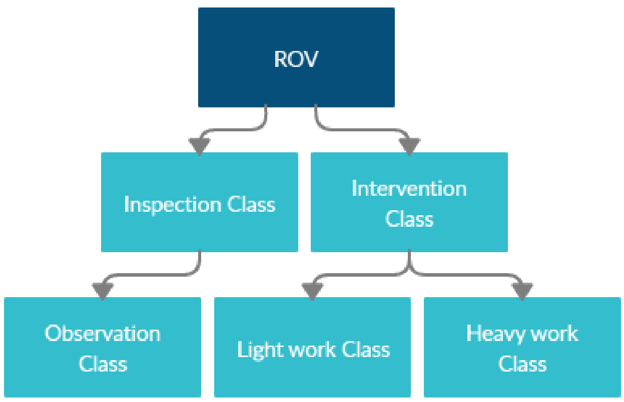

Figure 1: Outline of ROVs in the Oil and Gas Industry

Intervention class ROVs are the workers of the oil and gas industry and the marine engineering industry. Light work class can range from 100kg to 1000kg. This class of ROVs can be purely electric or have hydraulic subsystems for Manipulator control and they can operate at depths up to 3000m. The heavy-duty class can weigh up to 5000kg and can operate at depths of up to 6000m. The intervention class ROVs are generally large and very heavy which is why Launch and Recovery System (LARS) must be employed which in turn requires a support vessel and crew. Inspection or observation class are smaller and they weigh between 30kg to 120kg, they usually do not need a LARS, this class tends to be open frame and support add-ons and some can even carry small tooling operations. They are powered with DC and can be as high as 600VDC with power requirements of up to 6KW (Capocci et al., 2017).

Table 1: Representative vehicle characteristics

ROV Class	Weight	Power	TMS	LAUNCH METHOD	Depth Rating
Inspection	30kg to 120kg	Electric-only	N/A	Hand	+/- 300m
Light Work	100kg to 1000kg	Electric/Hydraulic	Applied	LARS	>1000m to 3000m
Heavy Work	5000kg	Electric/Hydraulic	Applied	LARS	>3000m to 6000m

According to (Christ & Wernli, 2013) Medium-sized ROV´s which are sometimes referred to as the Lightwork class ROVs have a depth rating that is greater than 1000m and the work class ROV´s which are the Heavy class ROV´s have a depth rating that is greater than 3000m. Table 1 is a product of the combination of some of the vehicle characteristics provided by (Capocci et al., 2017) and (Christ & Wernli, 2013), However, there are exceptions as to the limits of work class ROVs as the Japanese Kaiko has performed surveys of up to 11000m as it will be seen in the later text.

Figure 2: Dual-manipulator, 220-hp work class system & Omni Maxx ROV observation and inspection (“ROV Systems | Oceaneering,” n.d.)

3.2 Inspections

Inspections should be performed every 2 - 3 years to maintain acceptable reliability levels. Such inspection frequency would imply large expenses; therefore, remotely operated vehicles (ROVs) could be used instead of divers. (Gintautas & Sørensen, 2018) The inspection of welds in the offshore structures is particularly challenging because of the limited dexterity of underwater manipulators, marine growth cleaning also presents a challenge but an underwater ROV eddy current inspection solution was presented which enables efficient, in-service inspection of welds in these difficult conditions even in the presence of marine growth residues (Centenaro et al., 2019).

Several types of inspections techniques involve the use of ROV´s among which are; underwater visual inspection, acoustic nondestructive testing methods (NDT), electromagnetic methods, electrical nondestructive testing methods and multi-inspection technology approach (Al-Taie et al., 2015). Visual inspection is the most basic form of Non-Destructive Testing (NDT) method, it is simply using the ROV visual camera to see and inspect the structure or equipment. Visual inspection is often executed in three levels: Level 1 - General Visual Inspection (GVI), Level 2 - Detailed Visual Inspection (DVI) and Level 3 - Close Visual Inspection (CVI) (Al-Taie et al., 2015). GVI is used to observe major defects and hence does not require any sophistication, it only involves the camera that has pan and tilt mechanism to be able to see from many angles even in the presence of sea growth. DVI requires some basic cleaning before inspection while CVI requires the complete removal of marine growth to expose the surface of the structure to be able to inspect any visible corrosion. Non Destructive Testing has been successfully used in the inspection and maintenance of the subsea structures, and several have been utilized in the oil and gas industry, these types of methods use probing energy to determine and locate faults (surface, internal or concealed). The characteristics of the required data and the purpose of the inspection or monitoring determines which NDT technique that will be employed (Zhang et al., 2019).

Ultrasonic Testing (UT), Guided Wave Pipeline Inspection (GWPI), Time of Flight Diffraction (TOFD) and Phased Array UT (PAUT) are methods of acoustic NDT. All of these methods induce and receive the Ultrasound in different ways to detect faults and corrosion. On the other hand, the Acoustic emission uses the piezoelectric transducers to receive the emissions that cracks and corrosion products produce in the material. Magnetic Particle Inspection (MPI), Magnetic Flux Leakage (MFL), Eddy Current Testing (ECT), and Alternating Current Field Measurement (ACFM) all use the electromagnetic effect to detect faults and hence belong to the electromagnetic NDT method. Cathodic Protection is an electrical test that is often performed for corrosion, it is an Electrical NDT method and it is done by taking readings of the driven voltage the probe and the external anode that is connected to the metallic material (Al-Taie et al., 2015). Using more than one of these methods at the same time is known as the multiple inspection NDT, several companies have developed their ROVs with multiple inspection capabilities because a combination of multiple inspection technologies on a single tool or a single ROV will increase operational efficiency and provide an effective solution through providing a more complete image of the condition and the integrity of the asset being inspected (Al-Taie et al., 2015).

ROV eddy current-based inspection and monitoring techniques are used in the offshore oil & gas structures and underwater structural elements and welds in difficult conditions, even in the presence of marine growth residues and do not require surface contact or preparation. (Centenaro et al., 2019) Presented an underwater ROV eddy current inspection solution designed from scratch to enable efficient, in-service inspection of welds in these difficult conditions, even in the presence of marine growth residues. It was found out in the Gulf of Mexico that eddy currents excitations during high current events can cause fatigue damage on tendons, to reduce this problem suppression for vortex-induced vibration are post-installed, this minimizes the tendon excitation during high currents (Ramsey & Vuyk, 2003).

Floating Production Systems (FPS´s) stay at fixed locations and hence do not have access to regular dry-docking inspections and repair, over time deterioration of these lines can lead to single or multiple line failures (Brown, Hall, Marr, English, & Snell, 2005), which is why ROV based General Video Inspection, GVI is needed on the mooring system for effective evaluation and decision making for mooring life extension, the ROV based GVI provides detailed knowledge of the current state of the components. In 2016, a General Visual Inspection (GVI) was carried out by ROV survey on the FPS mooring system, given the degradation observed from the ROV survey results, the decision was made to recover some test samples from the mooring lines to access the mooring components conditions in terms of chain corrosion in the thrash and splash zones, as well as the residual strength of unsheathed spiral strand wire rope (Wang et al., 2019). ROVs are also used to verify if floaters are in predicted orientations after their pre-laying (Melilo et al., 2019).

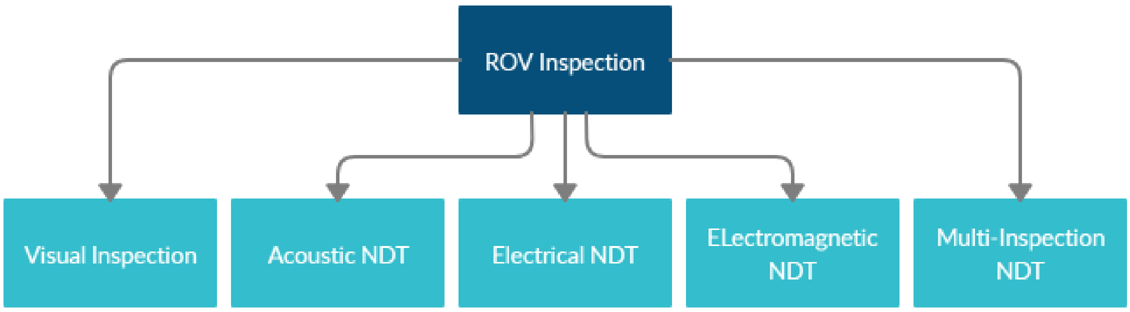

Figure 3: Outline of ROV inspection categories

Internal inspection of critical isolation valves is required to maintain good integrity, work-class ROVs are used to fit blanking plates to allow the removal of the valve by the maintenance team, this is neither an easy task nor a safe task however the use of ROVs have proven effective in most cases (Constantinis & Davies, 2016).

During the last 10-year Japanese scientific programs (Usui & Suzuki, 2019) performed sampling experiments and proved ROVs and submersibles to be very useful and powerful tools for on-site observation and geological characterization of the seafloor ferromanganese deposits (crusts and nodules). When it comes to the separation of oil, gas and water, it traditionally takes place in large tanks on the platform deck and to get the well-stream flowing up to fill the tanks requires assistance from powerful pumps which consumes a lot of energy (Brown et al., 2005), to save cost, subsea separators are now being used. However, the process of sampling becomes more difficult but a method that uses ROV for the subsea sampling has been developed by (Kelner, 2012) utilizing an ROV interface for capturing of representative fluid samples at multiphase meters or other locations.

3.3 Repairs and Maintenance

ROV support areas includes; export pipeline jumper systems, Production trees, Pig launching system and production riser, and the entire drilling and production support relies heavily upon ROV for inspection, observation and intervention. Subsea assembly which includes a series of installations is assisted by the ROV, which follows the Coiled Tubing Run In Hole (CT RIH) operation the entire time (Rodrigues, Delgado, & Frotte, 2019).

Repairs and maintenance are often carried out in the industry, and when there is an increase in efficiency of this operation, cost and operation time is reduced. They are carried out because of failure of equipment, disaster, nature interference or simply for maintenance reasons. Nature interference such as rock outcrops can restrict pull-in of oil export line such as in the case of Norwegian Fensfjorden (Bjelland, Brådland, Rundsag, Ingvar, & Rygg, 2019) where ROVs were used in subsea rock removal where the subsea rock outcrops were restricting pull-in of the oil export line from the Johan Sverdrup field to Mongstad through a borehole, tools for deep water rock removal were developed successfully and an ROV Video survey before the rock removal was made using the Edda Flora IMR and survey operations ship and the ROV was used to insert the hydraulic rock splitter.

The subsea activities that were in response to the tragedy of the Macondo well blowout were performed by Remotely Operated Vehicles (ROV)s. The Schilling Ultra Heavy Duty (UHD) ROV used in the Macondo well incident is of work-class ROV (WROV). It was deployed from a support vessel and was going to provide hydraulic pressure via a tethered hose that would force the Blowout Preventer (BOP) shear to cut through or crush the drilling pipe (Hartley, 1998). Oceaneering maximum WROV with 300 HP hydraulic power was also used and was deployed by a support vessel (Hartley, 1998). With the Macondo well disaster, subsea inspection and maintenance requirements are becoming much tighter necessitating increased inspection and testing frequencies of subsea assets (Ghorbel, Kapusta, & Allen, 2019).

During the life of an offshore structure, opportunistic marine organisms known as marine growth will progressively cover its surface, preventing its inspection. The requirement to clean the surface to bare metal for visual inspection, as well as nondestructive testing (NDT), is particularly costly, as the cleaning of the last layer of hard cement residue left by certain marine organisms is very time-consuming (Centenaro et al., 2019). Marine growths if left unchecked occludes important views and possess many other threats among which are harming the structural integrity. This debris is generally cleared by using commercial divers however smaller

ROVs like the Cougar ROV which is developed by SAAB SEAEYE is small, robust and agile enough to enter and manoeuver around all the structures. This allowed DNT Offshore Srl to develop a highly effective ROV supported cleaning system called the Marine Growth Cleaning Tool (MGCT) which in July/August 2006 was used in their successful marine growth removal campaign in Sicily. An extensive variety of structures including Jackets, FPSO, Semisubmersible mobile and fixed drill rigs, Jack-Ups, mooring systems, subsea wells and sea-lines are subject to the problem of marine growth (Martini et al., 2007).

3.4 Technologies

Improved or new ROV technologies provide better control, imaging and more precision with tools and their manipulation. In the recent years there has been development of ROV technologies and its tooling some of which are in the areas of application of augmented reality, communication, ROV interfacing, Umbilical and tether management system, survey and scanning systems. Fully electric deep water ROVs reduced inefficiencies of up to 30% or more, Compact units and lesser parts, compact umbilicals (nowadays optical cables are used), sophisticated tooling, advanced LARS, enhance communication system, augmented reality, are all new developments in deep water ROVs. Hybrid ROVs (HROVs) have batteries which help in eliminating the need for DP vehicles since only information is passed through the optical cable and hence this reduces the cost of operation (Fard et al., 2018).

3.4.1 Augmented Reality

Currently, augmented reality is being used to overcome the problems that are faced during ROV operations through superimposing the virtual environment on the live feed and this improves visibility, increases safety, increases efficiency and reduces the overall costs (Parente, Stevens, Ferreira, Simao, & Dionisio, 2019). Mobile and Marine Robotics Research Centre developed a smart remotely operated vehicle called ROV LATIS. One of the main software innovations of the proposed system is 3D Real-Time Augmented Reality Display and Advanced Control System (Omerdic, Toal, Nolan, & Ahmad, 2012). There has been limited use of the AR in the oil and gas industry until very recently. Augmented reality in the subsea environment using an ROV was first used in 2015 in the Gulf of Mexico (Parente et al., 2019). In 2016, Augmented Reality was used by (Stewart, Ryden, & Cox, 2016) in which they presented an interactive interface for multi-pilot ROV intervention, their methods were successfully implemented in an augmented reality software with the capability of using multiple pilots.

3.4.2 Survey and Scanning Systems

Some surveys can only be done using ROVs as in the case of (Schubert, Lind, Eriksson, & Jacobsen, 2017) where their survey was extended to include the internal structure of the offshore steel structure, which was only accessible to observation by remotely operated vehicle (ROV). Sometimes 3D sonar is mounted on ROVs for monitoring efforts as in the case of the GOM-SCHEMA project where a 3D laser data from an Autonomous Underwater Vehicle (AUV) is joined with 3D sonar of the ROV to collect data that will inform the U.S. Bureau of Ocean Energy Management (BOEM) and Bureau of Safety and Environmental Enforcement (BSEE) of oil spill's long term impacts on the shipwreck preservation (Damour, Church, Warren, & Horrell, 2019).

Woods Hole Oceanographic Institute (WHOI) developed the hybrid ROV (HROV) known also as Nereus, it became the first ROV to explore the Mariana Trench since 1998. It can also be switched into an autonomous vehicle, this vehicle was ideally suited to explore the extremes of the ocean. This hybrid ROV has a lightweight fibre optic tether that allows for deep dives and high manoeuvrability (Yuh, Marani, & Blidberg, 2011).

Since 1995 the only full ocean depth survey system was the Kaiko (Momma, Watanabe, Hashimoto, & Tashiro, 2004). It was built in 1993 (Nakajoh, Miyazaki, Sawa, Sugimoto, & Murashima, 2016) and it has accomplished more than 20 dives to 11000m at challenging depth in the Mariana Trench. Unfortunately in 2003, its cable failed and the vehicle went been missing (Momma et al., 2004). Then Japan Agency for Marine-Earth Science and Technology (JAMSTEC) decided to remodel the vehicle in FY 2004 and called it Kaiko 7000, they improved its performance in 2006 and called it Kaiko 7000II and in 2016 a paper was presented for the development of the fourth Kaiko called Kaiko MK IV (Nakajoh et al., 2016).

3.4.3 Umbilical and Tether Management System

Observation class ROVs can be deployed directly by hand releasing the tether to deploy the vehicle, however, with larger ROVs, a TMS has to be employed to reduce the effect of the umbilical weight drag and vertical movement on the ROV. However having a TMS structure introduces more joints and connectors to the system making it more susceptible to mechanical and electrical failures (Fard et al., 2018).

The standard architecture for ROV power umbilical does not permit ROV power to be distributed to additional equipment such as a second ROV, dredges, pumps, or subsea hydraulic power units which currently require dedicated power and control lines and topside equipment but a technology roadmap has been created to plan the development and commercialization of a complete solution for expanding distribution of ROV umbilical power to drive additional subsea devices (Restivo, Glenn, & Williams, 2017).

3.4.4 Communication

An untethered ROV centred on supervised autonomy wherein a "person in the loop" can have real-time visual feedback of the operation (same as ROV operations). This person or supervisor can be located on the field host platform or on-shore, allowing for greater flexibility in autonomous missions and with more robust operational integrity. It is not only for efficiency but also for industry acceptance of new intervention framework. This offers a pragmatic and effective operational architecture for the deployment of autonomous vehicles in IMR (Vincent, Sevinc, & Herbst, 2019).

A point to point satellite connection communication link has also been used in the control of ROVs such as in the case of the experiment carried out by the NASA Ames Research Center in

1993, austral spring where a telepresence-controlled underwater vehicle (TROV) was remotely operated from USA Ames labs and used to study seafloor ecology in Antarctica (Stocker et al., 1995).

Experiments have also been carried out trying to use the world wide web as support for teleoperation, if successful, this idea will make available the robots to a vast number of people and will allow the possibility to develop cheap, flexible, expandable and a truly distributed system. The first two web telerobots systems that came into existence in late 1994 were the Mercury Project (Koldberg et al., 1995) developed at University of California at Berkeley and the Australia's telerobot (Taylor and Treveylan, 1995), developed at University of Western Australia (Bruzzone et al., 2004) demonstrated that the current technological state-of-the-art enables the development of internet teleoperated robotics systems that scientific users can be easily utilized for remotely operating underwater vehicles in unknown unstructured environments from the comfort of their labs utilizing a simple connection to the worldwide web (Bruzzone et al., 2004).

Satellite connections and semiautomatic control system can also be used for full control of ROVs such as in the support centre of Stavanger harbour that allows the operators to send commands without the need of guiding it in real-time. According to (Rassenfoss, 2016) the first onshore-controlled repair job for Statoil will entail helping to control an ROV that will be replacing anodes used for corrosion control on an offshore jack-up rig. In 2015, Oceaneering demonstrated that a land-based controller in the Gulf of Mexico could pilot a work-class ROV using a satellite link. In 2016 offshore Norway, a controller in Oceaneering's Mission Support Center in Stavanger used a multipurpose tool to clean marine growth off a subsea structure. Others developing ROV technology are working on combining robotics and distant control capabilities to reduce crews offshore. One such project by the Idiap Research Institute in Switzerland is focused on reducing offshore crews, which often require three professionals per shift, with enough workers on hand for round-the-clock staffing. When another large ROV maker, FMC Technologies, was asked about distant control, it said it has included "the framework for distance independent control and monitoring in its ROVs for several years."(Rassenfoss, 2016)

3.4.5 ROV Interfacing

(Granhaug & Brewster, 1995) ROVs are used in the development of oil and gas reserves as in the case of Garden Banks Block 388 (GB 388) in the U.S Gulf of Mexico where a new purpose-built ROV system was built with fully integrated ROV interface system to be able to handle the specific work requirements of the project that needed ROV support.

(States, Hernandez, & Hickok, 1996) Discussed the ROV interface with the Popeye Project Subsea System where there was an efficient installation of an innovative subsea production system. The success of Popeye´s project has allowed for several technology advancements which depended on effective ROV intervention to be implemented with no significant difficulties. ´´The Popeye Project helped advance the technology and standardization of ROV interfaces for deepwater subsea production systems`` (States et al., 1996).

ROV interfaces were discussed in (Hernandez, McCalla, McCoy, & Clark, 1998) were two new tools; seal removal and replacement tool and auxiliary high-pressure tool were designed, fabricated and tested in the Mensa project subsea system were some of the subsea equipment were installed by ROV and all the subsea equipment were designed for ROV intervention. During ROV interfacing with subsea equipment in deepwater projects, it is essential to identify the type of ROV intervention task in the early design phase because the success of the ROV activities depends on it. This has been demonstrated by the Mensa project which has also shown that configuring the ROV to perform multiple tasks during in a single dive which saves both time and money (Hernandez et al., 1998).

In (Carpenter, 2017) a Passive Heave Compensator (PHC) was designed to provide two settings, one based on landing-speed requirements and the other based on providing an average efficiency in reducing dynamics at structure liftoff and dynamics in the splash zone, and eliminating resonance effects throughout the water column. Each 700-t PHC was designed and equipped with an ROV interface panel to control and monitor valves that, when opened, released charged gas from three accumulators into four accumulators to increase the volume and therefore reduce stiffness (Carpenter, 2017).

In 2015, Aquabotix released the hybrid ARV, the first ROV/AUV hybrid for shallow water tasks. The Modus Seabed, which was made commercially available in early 2017 can be operated as a fully autonomous vehicle or as an ROV with tether it can operate fully autonomously or as a tethered ROV, the thruster patter allows it to hover and operate with 6° of freedom, which allows inspection and intervention capabilities different from other hybrids. Developed with Saab, the system will be used for survey and inspection, supporting pre-engineering, construction support, and life-of-field condition monitoring. Before, ROVs had to be flown into place to manipulate valves, inject fluids and other related works but with the control systems available today all of this can be automated even without the people flying it. According to White (Whitfield, 2017), the industry needs innovation and telepresence. Even if it's an AUV, you still can have a camera on it and maybe you can inspect something using the cameras. According to him, they tried to address that by not trying to talk about what ROVs do and what AUVs do. It's a subsea vehicle so it doesn't matter as much however what matters now are the interfaces." (Whitfield, 2017)

4 DISCUSSION AND CONCLUSION

This paper reported a review of some applications, technologies and recent developments of the ROVs in the oil and gas industry. It highlights the incorporating of NDT tools to ROV and the benefit of developing a single vehicle that can perform IRM tasks. In the last 60 years, ROV technology had faced an aggressive advancement from an absolute military application to many other applications with the oil and gas industry as the main driving force and will remain so for years to come. Most NDT techniques are carried out by human divers. Switching to an entirely ROV based inspections by incorporating these technologies in the tooling of the ROV can greatly increase efficiency, reduce cost and eliminate risking of human lives or health.

The market forecast has shown that ROVs will continue to grow in demand from the oil and gas industry and hence new requirements will continue to come up which will, in turn, shape the evolution of this technology. Light and Heavy duty work class ROVs have a problem of long tether management and requires support vessels and crews which in turn makes them costly. There have been developments of an ASV/ROV platforms that aims at solving this problem but they are of the Inspection class ROVs and despite the fact they this can reduce the cost of inspection there are still two vehicles involved and there is no a single vehicle to date that can serve to complete IRM tasks. Besides, there are cheap Inspection vehicles that can be kept on the platform and be utilized for time to time GVI. A better solution to solve this problem would be to develop a single vehicle that runs both as an ASV and ROV, a vehicle that can be deployed from onshore to go offshore and execute an IRM task, a vehicle that is in the Lightwork class range. With non-viability of using large hydraulic ROVs in inspections, cleaning activities and the development of new inspection and cleaning tools, with the increased necessity of inspecting subsea assets, a development of a single vehicle that will execute these tasks without the need of a support vessel will greatly reduce cost of operation and increased efficiency for the industry.

5 ACKNOWLEDMENTS

The authors would like to acknowledge the Nigerian Institution Petroleum Technology Development Fund (PTDF) and the Brazilian institution Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), for supporting the present study.

6 REFERENCES

Al-Taie, I., Alsaiari, H., Amer, A., Abdellatif, F., Outa, A., Trigui, H., … Abedan, A. (2015). *Survey of Underwater NDT Technologies for Offshore Assets*.

Bjelland, I., Brådland, T., Rundsag, J., Ingvar, A., & Rygg, J. (2019). *Cost-Effective Subsea Rock Removal Tool for Deepwater Applications*. 1011–1016.

Brown, M. G., Hall, T. D., Marr, D. G., English, M., & Snell, R. O. (2005). Floating Production Mooring Integrity JIP - Key Findings. *Offshore Technology Conference*, p. 12. https://doi.org/10.4043/17499-MS

Bruzzone, G., Bruzzone, G., Bono, R., Caccia, M., Spirandelli, E., & Veruggio, G. (2004). Internet-based Teleoperation of the Romeo ROV In Polar Environments. *The Fourteenth International Offshore and Polar Engineering Conference*, p. 6. Retrieved from https://doi.org/

Capocci, R., Dooly, G., Omerdić, E., Coleman, J., Newe, T., & Toal, D. (2017). Inspection-Class Remotely Operated Vehicles—A Review. *Journal of Marine Science and Engineering*, Vol. 5. https://doi.org/10.3390/jmse5010013

Carpenter, C. (2017). Deepwater-Structure-Installation Challenges Offshore Australia. *Journal of Petroleum Technology*, *69*(05), 50–52. https://doi.org/10.2118/0517-0050-JPT

Centenaro, E., Lany, M., Meyer, T., & Gasparin, E. (2019). Structural Health Monitoring Solutions for Offshore Platforms. *Offshore Mediterranean Conference and Exhibition*, p. 14. Retrieved from https://doi.org/

Christ, R. D., & Wernli, R. L. (2013). The ROV manual: a user's guide to remotely operated vehicles. In *Elsevier*.

Constantinis, D., & Davies, P. (2016). In-service hull inspections for avoiding dry-docking safely. *Offshore Technology Conference Asia 2016, OTCA 2016*, (February), 2290–2301. https://doi.org/10.2118/0217-0058-jpt

Damour, M., Church, R., Warren, D., & Horrell, C. (2019). Utilizing 3D Optical and Acoustic Scanning Systems to Investigate Impacts from the Oil Spill on Historic Shipwrecks. *Offshore Technology Conference*, p. 13. https://doi.org/10.4043/29508-MS

Danovaro, R., Barone, G., Carugati, L., Lo Martire, M., Dell'Anno, A., & Corinaldesi, C. (2017). Implementing the Monitoring and Restoration of Marine Ecosystems Impacted by Offshore Platform. *Offshore Mediterranean Conference and Exhibition*, p. 13. Retrieved from https://doi.org/

Fard, R., Eidsvik, O., Tedeschi, E., & Schjølberg, I. (2018). *Cable Selection Considerations for Subsea Vehicles*. https://doi.org/10.1109/OCEANSKOBE.2018.8559225

Ghorbel, F. H., Kapusta, S., & Allen, J. (2019). An ideation and road mapping workshop on the development of AUVs for oil & gas subsea applications. *Proceedings of the Annual Offshore Technology Conference*, *2019-May*. https://doi.org/10.4043/29671-ms

Gintautas, T., & Sørensen, J. D. (2018). Reliability-Based Inspection Planning of 20 MW Offshore Wind Turbine Jacket. *International Journal of Offshore and Polar Engineering*, *28*(03), 272–279. Retrieved from https://doi.org/

Global Remotely Operated Vehicle (ROV) Market 2017-2025 : Top Key Players are Andrews Survey, C-Innovation, DOF Subsea AS, Forum Energy Technologies, Fugro Subsea Services Ltd - MarketWatch. (n.d.). Retrieved October 25, 2019, from https://www.marketwatch.com/press-release/global-remotely-operated-vehicle-rov-market-2017-2025-top-key-players-are-andrews-survey-c-innovation-dof-subsea-as-forum-energy-technologies-fugro-subsea-services-ltd-2019-04-18-111971312

Granhaug, O., & Brewster, D. (1995). Garden Banks 388 ROV Interface Systems. *Offshore Technology Conference*, p. 10. https://doi.org/10.4043/7856-MS

Hartley, D. W. (1998). Rov Capabilities. *Subsea Controls and Data Acquisition '98: Cost-Effective Challenges for a Geographically Expanding Industry*, p. 28. Retrieved from https://doi.org/

Hartley, D. W., & Prince, M. A. (1989). The Future of ROV Technology. *Diverless and Deepwater Technology: Proceedings of an International Conference*, p. 8. Retrieved from https://doi.org/

Hernandez, D. A., McCalla, J. M., McCoy, R. W., & Clark, T. C. (1998). Mensa Project: ROV Interfaces. *Offshore Technology Conference*, p. 6. https://doi.org/10.4043/8631-MS

Kelner, E. (2012). An ROV-Deployed Deepwater Subsea Sampling System. *Offshore Technology Conference*, p. 9. https://doi.org/10.4043/23412-MS

Martini, M., Johnston, J., & Morello, F. (2007). Marine Growth Cleaning Tool. *Offshore Mediterranean Conference and Exhibition*, p. 7. Retrieved from https://doi.org/

McFarlane, J. R. (2002). Will ROV-AUV Hybrids Be the Next Generation of Work Vehicles? *The Fifth ISOPE Pacific/Asia Offshore Mechanics Symposium*, p. 8. Retrieved from https://doi.org/

Melilo, A. C., da Costa, C. H. O., Armani Delalibera, C. A., Schwingel Dias, M. A., de Oliveira, T. M. P., & Pereira, R. M. (2019). Pre-laying of flexible lines flowline and riser and floaters in ultra-deepwater. *Society of Petroleum Engineers - SPE Oil and Gas India Conference and Exhibition 2019, OGIC 2019*, 1–11. https://doi.org/10.2118/194614-ms

Momma, H., Watanabe, M., Hashimoto, K., & Tashiro, S. (2004). Loss of the Full Ocean Depth ROV Kaiko - Part 1: ROV Kaiko - A Review. *The Fourteenth International Offshore and Polar Engineering Conference*, p. 3. Retrieved from https://doi.org/

Nakajoh, H., Miyazaki, T., Sawa, T., Sugimoto, F., & Murashima, T. (2016). Development of 7000m work class ROV "KAIKO Mk-IV." *OCEANS 2016 MTS/IEEE Monterey*, 1–6. https://doi.org/10.1109/OCEANS.2016.7761063

Omerdic, E., Toal, D., Nolan, S., & Ahmad, H. (2012). ROV LATIS: Next-generation smart underwater vehicle. *Further Advances in Unmanned Marine Vehicles* (pp. 9–44). https://doi.org/10.1049/PBCE077E_ch2

Parente, M., Stevens, M., Ferreira, J., Simao, R., & Dionisio, M. (2019). Subsea Digitalization: From the Virtual World into the Real World—Using Augmented Reality in Offshore Operations. *Offshore Technology Conference*, p. 8. https://doi.org/10.4043/29312-MS

Rahimuddin, R., Hasan, H., Rivai, H., Iskandar, Y., & Pirri Hermanses, C. (2018). Design of Omni Directional Remotely Operated Vehicle (ROV). *Journal of Physics: Conference Series*, *962*, 12017. https://doi.org/10.1088/1742-6596/962/1/012017

Ramsey, R. D., & Vuyk, D. (2003). A Novel Method: MSV / ROV Installation of VIV Suppression on Existing TLP's. *Offshore Technology Conference*, p. 10. https://doi.org/10.4043/15287-MS

Rassenfoss, S. (2016). Norway Faces Up to Harsh Conditions. *Journal of Petroleum Technology*, *68*(06), 32–39. https://doi.org/10.2118/0616-0032-JPT

Restivo, A., Glenn, C., & Williams, L. (2017). Supplying Additional Power Subsea through Intervention ROV Systems. *Offshore Technology Conference*, p. 8. https://doi.org/10.4043/27652-MS

Robert, B. (2015). Underwater robots: a review of technologies and applications. *Industrial Robot: An International Journal*, *42*(3), 186–191. https://doi.org/10.1108/IR-01-2015-0010

Robertson, G. S. (1991). The Application Of Work Class ROV's. *Subtech '91*, p. 8. Retrieved from https://doi.org/

Rodrigues, V., Delgado, E., & Frotte, A. (2019). Deepwater pipeline pre-commissioning operation using large-diameter coiled tubing instead of standard downline: State of the art of this technology. *Society of Petroleum Engineers - SPE/ICoTA Well Intervention Conference and Exhibition 2019*. https://doi.org/10.2118/194280-ms

ROV Systems | Oceaneering. (n.d.). Retrieved October 25, 2019, from https://www.oceaneering.com/rov-services/rov-systems/

Schubert, M., Lind, M. T., Eriksson, M., & Jacobsen, F. (2017). Reliability Assessment of an Existing Offshore Steel Structure with Hot Spots. *International Journal of Offshore and Polar Engineering*, *27*(04), 433–441. Retrieved from https://doi.org/

States, C. R., Hernandez, D. A., & Hickok, D. D. (1996). Popeye Project: ROV Interface. *Offshore Technology Conference*, p. 15. https://doi.org/10.4043/8169-MS

Stewart, A., Ryden, F., & Cox, R. (2016). An interactive interface for multi-pilot ROV intervention. *OCEANS 2016 - Shanghai*, 1–6. https://doi.org/10.1109/OCEANSAP.2016.7485397

Stroud, D. (1997). *Deepwater ROV's- beyond 2,000m*.

Usui, A., & Suzuki, K. (2019). Small-Scale Distribution Patterns of Hydrogenetic Ferromanganese Crusts in the NW Pacific Seamounts : A Reconnaissance Survey Using ROVs and a Manned Submersible. *The 29th International Ocean and Polar Engineering Conference*, p. 7. Retrieved from https://doi.org/

Vincent, J. H., Sevinc, N. D., & Herbst, N. A. (2019). uROV – The Next Generation IMR Platform Utilizing Supervised Autonomy. *Offshore Technology Conference*, p. 7. https://doi.org/10.4043/29586-MS

Vukić, Z., & Mišković, N. (2016). State and Perspectives of Underwater Robotics - Role of Laboratory for Underwater Systems and Technologies. *Journal of Maritime & Transportation Science*, *Special ed*(1), 15–27. https://doi.org/10.18048/2016-00.15

Wang, H., Zhang, Q., Liu, Y., Mao, J., Zhu, W., & Shen, H. (2019). Liuhua 11-1 FPSO & FPS mooring system life extension evaluation and challenging issues. *Proceedings of the Annual Offshore Technology Conference*, *2019-May*, 1–20. https://doi.org/10.4043/29338-ms

Wen, F., Pray, J., McSweeney, K., & Gu, H. (2019). Emerging Inspection Technologies – Enabling Remote Surveys/Inspections. *Offshore Technology Conference*, p. 16. https://doi.org/10.4043/29450-MS

Whitfield, S. (2017). The Industry of the Future: What Does It Look Like? *Journal of Petroleum Technology*, *69*(12), 43–46. https://doi.org/10.2118/1217-0043-JPT

World ROV Operations Market Forecast 2019-2023 - Westwood. (n.d.). Retrieved October 25, 2019, from https://www.westwoodenergy.com/product/world-rov-operations-market-forecast-2019-2023/

Yuh, J., Marani, G., & Blidberg, D. R. (2011). Applications of marine robotic vehicles. *Intelligent Service Robotics*, *4*(4), 221. https://doi.org/10.1007/s11370-011-0096-5

Zhang, Y., Zheng, M., An, C., Seo, J. K., Pasqualino, I. P., Lim, F., & Duan, M. (2019). A review of the integrity management of subsea production systems: inspection and monitoring methods. *Ships and Offshore Structures*, *5302*. https://doi.org/10.1080/17445302.2019.1565071

COMO CITAR ESTE ARTIGO:

Dalhatu, A. A., De Azevedo, R. C., Udebhulu, O. D., De Tomi, G. (2021). Recent developments of remotely operated vehicle in the oil and gas industry. *Holos.* 37 (3), 1-18.

SOBRE OS AUTORES

A. A. DALHATU

Received B.Eng. electrical and electronics with a specialization in communication from Linton University College, in the city of Mantin in the state of Negeri Sembilan, Malaysia in 2012. Currently doing his Masters at the University of Sao Paulo (USP), Department of Mining and Petroleum Engineering, Polytechnic School. His research area is offshore inspections using Remotely Operated Vehicle.
E-mail: abdullahiabba@usp.br
ORCID ID: https://orcid.org/0000-0002-0105-7338

R. AZEVEDO

Ph.D. Professor at the Mining and Petroleum Engineering Department (PMI) of the University of Sao Paulo, Brazil (USP), with Post-Doctorate in Petroleum Engineering at the University of Stavanger, Norway (2014), specialization in Occupational Safety Engineering (2013), PhD (2007) and MSc (2002) in Mineral Engineering, all from USP, he is also a mining engineer from PMI/USP. He has experience in Mining Engineering, with an emphasis on Petroleum Exploration and Production. He works mainly with petroleum reservoir engineering, well-reservoir integration, petroleum and mining information management, and mine planning. He has participated in the USP Petroleum Engineering Program creation, and now he teaches at this Program, and, less frequently, in the Mining Engineering and other Programs from USP.
E-mail: rcazevedo@usp.br
ORCID ID: http://orcid.org/0000-0001-6772-5549

O. D. UDEBHULU

Received B.Eng. Chemical Engineering 2008 at Ahmadu Bello University in Kaduna State, Nigeria. He received M.Sc. Petroleum Engineering in 2014 at the African University of Science and Technology in Abuja, Federal Capital Territory, Nigeria. He is currently doing a doctorate at the University of São Paulo (USP) in the Department of Mining and Petroleum Engineering, Escola Politécnica.
E-mail: odudebhulu@usp.br
ORCID ID: https://orcid.org/0000-0002-4572-2862

G. DE TOMI

Dr. De Tomi has a degree in mining engineering from the University of Sao Paulo, PhD from Imperial College, London and MSc from Southern Illinois University, USA. Has experience in mining, digital transformation and innovation management. The areas of expertise include mine planning and scheduling, technical mining software, mine automation, management of the mine value chain, mining governance, lean mining and mineral production management, with special emphasis on practices to the mining industry. Currently, he is the Director of the Center for Responsible Mining, at the University of São Paulo (USP) in Brazil, which is a research center, dedicated to innovation and applied research focused on responsible practices in mining. He was the Head of the Department of Mining and Petroleum Engineering at USP from 2015 to 2019. He is an International Consultant with the Global Mercury Program of the UNIDO (United Nations Industrial Development Organization), member of SME (USA), Fellow of The Institute of Materials, Minerals & Mining (IOM3, UK) and Chartered Engineer CEng (Engineering Council, UK), as well as acting QP (Qualified Person, NI-43101) and CP (Competent Person, JORC and CRIRSCO) for numerous mining enterprises worldwide. Currently, he is a member of the Technical Board of CBBR (Brazilian Commission for Mineral Resources and Reserves), a member of the Executive Board of EMBRAPII's Unit Tecnogreen, a Research Scholar with FAPESP and CNPq (Brazil) and a member of the Editorial Board of the Mining Technology journal and the Brasil Mineral journal. member of SME (USA),

Fellow of The Institute of Materials, Minerals & Mining (IOM3, UK) and Chartered Engineer CEng (Engineering Council, UK), as well as acting QP (Qualified Person, NI-4310) and CP (Competent Person, JORC and CRIRSCO) for numerous mining enterprises worldwide. Currently, he is a member of the Technical Board of CBBR (Brazilian Commission for Mineral Resources and Reserves), a member of the Executive Board of EMBRAPII's Unit Tecnogreen, a Research Scholar with FAPESP and CNPq (Brazil) and a member of the Editorial Board of the Mining Technology journal and the Brasil Mineral journal. member of SME (USA), Fellow of The Institute of Materials, Minerals & Mining (IOM3, UK) and Chartered Engineer CEng (Engineering Council, UK), as well as acting QP (Qualified Person, NI-4310) and CP (Competent Person, JORC and CRIRSCO) for numerous mining enterprises worldwide. Currently, he is a member of the Technical Board of CBBR (Brazilian Commission for Mineral Resources and Reserves), a member of the Executive Board of EMBRAPII's Unit Tecnogreen, a Research Scholar with FAPESP and CNPq (Brazil) and a member of the Editorial Board of the Mining Technology journal and the Brasil Mineral journal. JORC and CRIRSCO) for numerous mining enterprises worldwide. Currently, he is a member of the Technical Board of CBBR (Brazilian Commission for Mineral Resources and Reserves), a member of the Executive Board of EMBRAPII's Unit Tecnogreen, a Research Scholar with FAPESP and CNPq (Brazil) and a member of the Editorial Board of the Mining Technology journal and the Brasil Mineral journal. JORC and CRIRSCO) for numerous mining enterprises worldwide. Currently, he is a member of the Technical Board of CBBR (Brazilian Commission for Mineral Resources and Reserves), a member of the Executive Board of EMBRAPII's Unit Tecnogreen, a Research Scholar with FAPESP and CNPq (Brazil) and a member of the Editorial Board of the Mining Technology journal and the Brasil Mineral journal.
E-mail: gdetomi@usp.br
ORCID ID: https://orcid.org/0000-0002-7836-1389

Editor(a) Responsável: Francinaide de Lima Silva Nascimento