Role of Geoinformatics for Ghana oil and gas industry

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Abstract—**The Geoinformatics Engineer (GE), who uses mathematical theory and precise measurements for the collection and distribution of geospatial data, plays a significant role in the oil and gas industry. The paper reviews the role the GE would play in the recent oil and gas discovery in Ghana. This is because the GE is required in the planning and execution of nearly every form of activities at the upstream, midstream and downstream; for example offshore and onshore construction, exploration and engineering for the production and dissemination of oil and gas. Ghana is at the initial stages in the commercial production of oil and gas; and thus needs research institutions with excellent practical and research skills, such as the Department of Geomatic Engineering (DGE), Kwame Nkrumah University of Science and Technology (KNUST), Ghana and School of Earth Sciences and Engineering (SESE), Hohai University, China, in employing Geoinformatics theories, applications and principles for geospatial decision making for sustainable production of oil and gas for Ghana and the Sub-Saharan Africa. SESE expertise in 3S Technology would greatly assist in the construction and monitoring of oil and gas infrastructures at the upstream, midstream and downstream. The paper recommends useful suggestions for smooth management of the oil and gas industry focusing on GEs and research institutions.**

Keywords-Oil and Gas Industry; Geoinformatics Engineer; Academia; Ghana

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I. INTRODUCTION

The Surveying profession is very broad embracing General Practice Surveying, Planning and Development Surveying, Building Surveying, Quantity Surveying, Rural and Urban Practice Surveying, Minerals Surveying and Land Surveying [1, 2]. In Ghana, the General Practice Surveyors are mostly concerned with valuation and investment. The Planning and Development Surveyors analyses existing level of residential accommodation against population forecast for the preparation of valuations to accrue profits. The Building Surveyors advises on the construction, maintenance, repair and refurbishment of residential and commercial properties. The Quantity Surveyor evaluates costs and advices on alternative proposals, and assesses the implications of changes in design, site conditions and working arrangements. Minerals Surveyors plan the development and future of mineral findings and workings; and manages and values mineral estates and surveys mineral workings in open cast or deep underground mines. The Rural and Urban Surveying practice advices landowners, farmers, etc. with interests in the rural and urban areas. Land Surveying is the technique and science of accurately determining the 2D or 3D position of points and the distances and angles between them; these points which describes the Earth surface are used to create maps and boundaries for ownership, governmental purposes and decision making [1-6].

In this review detailed explanation and definition of Geoinformatics, which in modern times embraces the Land Surveying profession, is adopted from [7, 8]. Geomatics is also a similar term that encompasses Geoinformatics; it is a field of activity that integrates the acquisition, processing, analysis, display and management of spatial information. Geoinformatics combines geospatial analysis and modeling, development of geospatial databases, information systems design, human-computer interaction and both wired and wireless networking technologies; and uses geo-computation and geovisualization for analyzing geoinformation [9-16]. In Ghana, Geomatic (formerly Geodetic) Engineering embraces the disciplines of Photogrammetry and Remote Sensing (RS), Land and Engineering Surveying, Geographic Information System (GIS), Cartography, Geodesy, Hydrography, Cadastral Surveying and Land Information Management. It is an exciting grouping of subjects in the spatial and environmental information sciences with a broad range of employment opportunities as well as challenging pure and applied research problems in a vast range of interdisciplinary fields. The Geodetic is recognized as Geomatic due to the role Information and Communication Technology (ICT) plays in surveying instrumentation and practices. This has enable Geomatic Engineers to use sophisticated measurement and data collection techniques (e.g. satellite positioning and digital imaging systems) and modern computer-based data management and visualization

tools to play a key role in a wide range of important practical projects in fields such as design, construction and management of complex civil engineering projects; acquisition of data for the production of maps and charts; management of assets, such as land, property, and transportation infrastructure especially through the use of GIS; monitoring of our changing environment using satellite and airborne remote sensing management of natural resources [e.g. 17, 18], both on land and offshore; planning urban environments (e.g. location of schools, hospitals and supermarkets); understanding and predicting earthquakes by measuring very small land movements; ensuring the safety of man-made structures, such as bridges, dams and large buildings, by monitoring their deformation; exploration and engineering for the production of oil and gas; dimensional control of industrial components; measurement in hazardous environments such as in the nuclear power industry and on oil platforms; and provision of measurement information in medicine [19], architecture, etc. In this paper the Geoinformatics Engineer (GE) will be used in place of Geomatic or Geodetic Engineer.

It is based on the above potentials of Geoinformatics that the review was conducted to inform the decision makers in Ghana, in the firsthand experience in the oil and gas industry, about the Geoinformatics discipline and to involve the GE in all endeavours and planning of the oil and gas industry. The review is collectively based on what is been done globally which can effectively and efficiently be introduced in the Ghanaian oil and gas industry. Thus, the review serves as a proposal for the oil and gas industry in Ghana.

A. *Academia*

The academia supports in solving problems through funded research in relation to the oil and gas industry. The Department of Geomatic Engineering (DGE) since its establishment in the 1960's in Ghana has been a producer of graduate GEs at the bachelor, masters and more recently doctoral levels. Also, University of Mines and Technology (UMAT), Tarkwah and Survey and Mapping Division (SMD) respectively produces Geomatic Engineers and Land Surveyors. The DGE offers tailored programmes for institutions ready to take particular courses in Geoinformatics; consultancies; and allowing students visit industries for industrial attachment. The very practical nature of the course as recognized by DGE has led to considerable number of subjects to be taught, together with an uncommonly lengthy field practical hours, with the view of producing sufficiently professionally skilled graduate GE. Due to the broad nature of Land Surveying, the DGE has been sectioned into the following sections: Land Surveying; Geodesy and Hydrography; Photogrammetry and RS; and GIS, ICT and Cartography. The DGE as a research body cannot be left out in the decisions and activities of the oil and gas industries; since it has staff with excellent teaching and research skills. The staffs are professional members and fellows of the Ghana Institution of Surveyors (GhIS).

B. *Committee of Geoinformatics Engineers*

Advanced industrial limitations and problems in the oil and gas industry are source of motivation and ideas for the academia. KNUST, a five-star University, located in the Garden City of the Ashanti Region is endowed with panorama of beautiful and modern buildings interspersed with verdant lawns and tropical flora which provide a cool and refreshing atmosphere congenial to academic studies. It has, within the short period of its existence, become an important centre for the training of scientists and technologists not only for Ghana but also for Sub-Saharan Africa. It is intermixed with international students. KNUST strong collaboration with other Universities, such as Hohai University, China can be helpful in enhancing the quality of petroleum products, efficiency of industrial processes and teaching-learning processes. The University of Hohai's experienced staffs equipped with Geoinformatics theories, principles and applications as well as hydrological practical and research experience in partnership with DGE will play a significant role in the Ghanaian oil and gas industry.

II. MATERIALS AND METHODS USED BY GEOINFORMATICS ENGINEERS

The GE uses sophisticated equipment, techniques and software in the collection and distribution of geo-spatial data in the oil and gas industry. The GE measures distances and angles as raw data from the field which are later converted into meaningful information for mapping. With technological advancement, coordinates are directly measured on field with the Global Navigation Satellite Systems (GNSS) [20-22] of which Global Positioning System (GPS) is an example [23, 24]; however, cautioned needs to be made to transform [25, 26] the satellite observations based on the International Terrestrial Reference Frame (ITRF) World Global System 1984 (WGS84) to the national coordinate system of Ghana. The integration of GPS and RS into a GIS platform [27], the 3S Technology, plays a significant role in geospatial analysis when it comes to the oils and gas industry. The term, 3S Technology, is coined from the letter 'S' of the last words in the terms of GPS, RS and GIS. Researches done by [28-31] etc. demonstrates how the 3S Technology plays a significant role in the oil and gas industry. The GE applies the principles of Survey Adjustment to adjust measurements and correct for errors before the results are mapped [32-36]. Adjustment of results is important since precise measurements are required in the oil and gas industry. This is due to the fact that the initial investment costs are high and precise measurements are needed to erect long-lasting structures in the oil and gas industry.

Precise survey equipment is used for the acquisition of distances, angles and coordinates for design and mapping.

For example, the GE uses the Total Station (for both angle and distance measurements), Electronic Theodolite (for angle measurements), Automatic/Digital Leveling instrument (for measuring difference in elevation), and GPS (for horizontal and vertical rectangular coordinate observations). Modern Total Stations requires no reflector or prism to return distance measurements; they are now robotic and can even e-mail point data to the office computer and connect to GNSS. One-person robotic-guided total stations allow surveyors to gather precise measurements without extra workers to look through and turn the telescope or record data. A faster but expensive way to measure large areas is with a helicopter or airplanes, equipped with a laser scanner, combined with GPS to determine the position and elevation of the helicopter or airplanes. The GE maps large areas with cameras mounted onboard airplanes or satellites. For cameras mounted on airplanes, overlapping which form stereoscopic images taken over the earth surface are used to produce maps.

The GE employs many techniques for the determination of horizontal and vertical coordinates. Examples of the former are traversing, triangulation and trilateration; and that of the latter are precise levelling. With the GNSS, horizontal and vertical rectangular coordinates can also be derived with sophisticated satellite receivers. Usually the GPS results of the vertical rectangular coordinates are somewhat less accurate than with traditional precise leveling. However, the accuracies may be similar if the traditional leveling would have to be run over a long distance. Real Time Kinematic (RTK), a technique for precision satellite navigation, could be resorted to improve upon the accuracy of the GPS. The Terrestrial Laser Scanning which employs contact-free measuring devices that can collect dense point-clouds of objects is also becoming important for surveying applications such as construction and monitoring of structures. After processing each point is assigned with X, Y, Z coordinates, colour and reflectance value; the relative precision, that is the ratio between absolute precision and measurement range, is better than 10^{-4} [37].

The GE employs varieties of software for report writing and presentation, post-processing of field observation and cartographic presentations. Some of these include: Microsoft Office Suite, Spectrum Survey, AutoCAD, Microstation, ArcView GIS, ArcGIS, MapInfo, Quantum GIS Enceladus, MapMaker, AutoDesk,Ilwis, ENVI, Erdas,Global Mapper, Smartimage, EQuIS,Encom Discover, Didger, DeltaGraph,WhiteStar,WMS (Watershed Modeling System), GMT, Star, Grass, Manifold, Geomedia, GeoConcept, Idrisi, Informix, SQL Server, Oracle, Sybase IQ, ERDAS, ENVI, IDL, etc. The GE also uses programming software such as Matlab, Java, Visual Basics, Python, C^{++}, $C^{\#}$ etc. to develop customised Graphical User Interface (GUI) applications [e.g. 38] to automate data entry, processes and presentation of geospatial results for the end user.

III. Role of the GE in the Upstream, Midstream and Downstream

Geoinformatics has many applications in the activities of the petroleum industry. Activities includes the global processes of exploration, extraction, refining, transporting (currently executed in Ghana through oil tanker with pipelines yet to be fully employed), and marketing petroleum products. The industry is usually divided into three major components: upstream, midstream and downstream. References on the explanations, products, functions, etc. of the upstream, midstream and downstream are documented in literature [e.g. 38-45].

The GE plays a key role in the searching for and the recovery and production of crude oil and natural gas upstream; in acquiring lands, demarcation and boundary disputes (e.g. a pending issue between Ghana and Cote d'Ivoire due to oil discovery) and building storage facilities, marketing and transporting crude oil, natural gas, Natural Gas Liquid (NGL) and Liquefied Natural Gas (LNG) and finally involved in reaching the final consumer with processed products at the downstream. The GE plays a significant role in constructing access roads. The construction of pipes offshore and onshore either underground or on the surface cannot be executed without the GE. The roles the GE plays in the petroleum industry are inexhaustible and few are outlined in the subsequent sections. In the fast growing oil and gas industry mistakes are costly hence reliable and robust measurement system is prerequisite for most applications. The GE continuously operates on "high-end" survey projects and is renowned for applying its multi-skilled experience in any field where fast and precise dimensional measurement are required. Complex and hazardous structures such as offshore oil rigs, refineries, and industrial plants are easily and quickly surveyed by the GE. The GE surveying experience, cost-effectiveness and safety track record in the oil and gas industry are involved in subsea structures, pipelines work, vessel units and oil rigs [46]. The GE offer services like well site surveys, location surveys, layout, design and survey of multi-pad leases for extraction of heavy oil, provision of as-built site plans for existing facilities, and project management [47]. Data coupled with GPS and high quality photography and RS images provides very highly detailed and precise 2D CAD drawings and 3D models which is utilized as an as-built record for retrofitting and front end engineering design. The GE provides deliverables on a web-based interface which simplifies asset visualization and management. The oil and gas industry relies on the time sensitive data relating to X, Y, and Z positions of terrain data for explorations strategies. The GE assist in determining the best source for of the Digital Elevation Model (DEM) data required for the oil and gas industry.

A. Application of GIS in oil and gas industry

GIS is used to decide where to drill a well, route a pipeline, build a refinery, and reclaim a site [48]. GIS provides oil and gas industry solutions throughout the petroleum life cycle. GIS is a tool for conducting variety of quantitative analysis; to conduct area measurements, to test theoretical hypotheses, and also develop useful models to attempt to locate new resources based on statistical analysis [49]. Major oil companies in the world use GIS technology to manage their location-based information, from leases, wells, and pipelines to environmental sites, facilities, and retail outlets [48]. The GIS integrated with GNSS and RS can effectively and efficiently handle the upstream, midstream and downstream activities of the oil and gas industry (Fig. 1a). Some of these activities include: infrastructure, data management, exploration, production, transportation, distribution, facility management, retailing, environmental, businesses and Information Communication and Technology (ICT) (Fig. 1b).

[Figure 1]

Petroleum companies manage wide range of information across areas of varied business groups; and GIS is an integrating technology that can help meet this challenge, resulting to improved communication, greater efficiency, and better decision making [48]. GIS has the capability of displaying and manipulating maps on the computer and the use of GPS makes the acquisition and updating of spatial data very fast [50]. For example, Houston, Texas-based Plains All American Pipeline handles more than 3 million barrels per day of crude oil, refined products, and LPG through 20,000 miles of pipelines using [51]. The natural gas discovery in southern New York led to a boom in hydrocarbon exploration by employing the model leverages of ArcGIS and the ArcGIS 3D Analyst extension to structurally analyze surface and subsurface data and target promising areas for exploration [51].

Developing a map for visual representation of data helps solve problems and make decisions. The GIS field is growing quickly, mostly due to high-tech computer software and hardware that stores, displays, analyzes, and maps information. Mobile GIS and Participatory GIS has also taken an important role in the activities of the GE, due to the computer power of the handheld devices. Mobile GIS collects geo-data using GNSS positioning, GIS functionality, wireless connection and mapping, all integrated in one compact device [52]. Mobile GIS is employed by the GE to conduct pipeline inspection in the oil and gas industry.

B. Application of Cartographic Visualization in oil and gas industry

Cartography is an important branch of graphics, since it is an extremely efficient way of manipulating, analysing, and displaying data, thus expressing ideas, forms and relationships that occur in 2D, 2½D, 3D or 4D space. Cartography includes any activity in which the presentation and use of maps is a matter of basic concern [53, 54]. Maps serve as means to make visible or present spatial phenomena to the end user. The use of computers in map making is an integral part of Cartographic Visualization [55, 56]. Simulations of the activities oil and gas industry in the upstream, midstream and downstream can be visualized in 2D, 2½D, 3D and 4D models for more in depth data exploration, analysis and presentation. 3D GIS solves complex analysis tasks in urban areas and oil explorations, offering comprehensive thematic descriptions [57]. Reference [57] added that, utilizing 3D topographically structured data to analyse spatial relationships promotes realistic visualization by storing textures which can be interfaced with virtual reality systems through the internet. The use of visualization methods in the analysis of geo-referenced data is based on static models, which restricts the visual analysis capabilities [58, 59] . Thus, the use of virtual reality, which gives the user the ability to change viewpoints and models dynamically, can overcome the static limitations of analysing and visualizing geo-referenced data [60]. 3D GIS visualization is a promising way of visualizing digital descriptions of a wide range of application from environmental to oil and gas. With recent developments in computers we experience a switch in architectural visualizations from still images and pre-rendered animations to interactive 3D model and virtual reality [61]. The visualization of land in a visual environment helps users develop and share insights into thinking and creativity of analysing data for decision making [62]. Virtual Reality is one of the techniques for representing 3D spatial data. It enables complex details of the real world to be visualized by utilizing the human ability to navigate through familiar environments and fully interact with spatial information of various types [63]. Visualization of the data and model outputs needs to be comprehensible not to only experts but also users who are increasingly becoming important in decision making about the future [64]. Reference [65] idea on mapping of information onto graphs or images as a means of visualization can be identified as a powerful tool for data investigation. Integrating panoramic scenes into GIS platforms produces realism, which enables the user to view a multi-dimensional map with significantly more geographic information as a model to explore the environment in the design and planning processes [66]. The output of GIS is directly linked to Cartography where both the spatial and non-spatial datasets are visualized on a map.

C. Application of Remote Sensing in oil and gas industry

Oil spills, an inevitable occurrence in the oil and gas industry, can destroy marine life as well as damage habitat for land animals and humans. Remote Sensing (RS) has the ability to produce accurate and timely information regarding mapping out spatial phenomenon of interest [49] . Majority

of marine oil spills result from ships emptying their haulage tanks before or after entering port in the oil and gas industry. Large area oil spills result from tanker ruptures or collisions with reefs, rocky shoals, or other ships. Following a spill, government regulatory agencies are responsible for disaster mitigation by getting involved and overseeing the activity. The GE employs RS to determine spill location, size and extent of the spill, direction and magnitude of oil movement, and wind, current and wave information for predicting future oil movement. RS offers the advantage of being able to observe events in remote and often inaccessible areas. University of Hohai has practical expertise in RS in monitoring infrastructures pertaining to oil and gas at the upstream, midstream and downstream.

RS devices employed are infrared video and photography from airborne platforms, thermal infrared imaging as well as airborne and space borne Synthetic Aperture Radar (SAR). SAR sensors have an advantage over optical sensors as it can provide data under poor weather conditions and during darkness. Remote Control Vehicles (RCV) operating on land or in the air fitted with radio control device, cable between control and vehicle, or an infrared controller; and Remotely Operated Vehicles (ROV) fitted with thrusters, video and still cameras, lights, and sensors can be employed for research and exploration. ROV aids in conducting undersea surveys, searching for mineral deposits and monitoring installed oil rigs and dams; data is amalgamated with GIS.

D. Application of Photogrammetry in oil and gas industry

Photogrammetrists take aerial photos and use them to create detailed maps of large areas in a very short time and for land inaccessible by foot [67]. A more sophisticated technique, called stereophotogrammetry, involves estimating the 3D coordinates of points on an image [68]. In addition to mapping a waterway's coastline for the activities of the oil and gas industry, Photogrammetrists can learn more about topography, vegetation, and existing structures. Photogrammetrists use images to detect the contours of the land and the height of objects on the surface. Photogrammetry is used in different fields, such as topographic mapping and design of onshore and offshore facilities, engineering, quality control, police investigation, and geology and archaeology explorations to quickly produce plans of large or complex sites; and by the meteorologists as a way to determine the actual wind speed. To mention a few, [69-71] employed RS and photogrammetric techniques in making varied types of topographic maps.

E. Application of Hydrogrraphic Surveying in oil and gas industry

Hydrographic information facilitates delineation, establishment, administration and sustainable development of national maritime, coastal zones and resources. The GE provides hydrographic charts for the transport infrastructure in the oil and gas industry; suitable anchoring zones close to port; competitive nature of the international trade routes with ports at their hubs. Reference [72] statement on hydrographic survey explains the significance of survey in offshore activity benefited by policy makers, industries, engineering, geologists, biologists, research groups, heritage and protection. FIG (2011) reports on the economic benefits of Hydrography

F. Application of Engineering Surveying in oil and gas industry

The GE analyses and solves surveying engineering problems related to the oil and gas industry by applying basic principles of mathematics, science and engineering. The GE uses modern surveying engineering techniques, skills, and tools to identify, formulate and solve surveying engineering problems. The GE is able to solve surveying engineering problems, particularly the planning, design, establishing horizontal and vertical control, land use design, boundary determination, mapping and field layout that meet standards of accuracy and precision; keeping in mind cost, time, safety and quality needs, and objectives. Demand is increasing for deformation monitoring to ensure the stability of aging infrastructure and structures pertaining to the oil and gas industry. With expensive construction and natural occurrences, it is critical that the technology and solutions is available for the Ghanaian oil and gas industry. The GE with expertise in Engineering Surveying ensures precision carried at all levels in construction and monitoring. During pipeline maintenance checks, the GE employ can employ Trimble solutions for deformation monitoring provide powerful analysis tools to detect and review motion over time for evaluating the health of pipelines. More detailed pipeline condition information can be rapidly collected using 3D Scanning and modeling tools.

G. Application of Cadastral Surveying in oil and gas industry

Cadastres play a key role in society and lie at the basis of economic growth, poverty reduction and mitigation of climate change effects [73]. Reference [73] added that property rights, land registration and cadastral mapping are the foundations for tenure security, land and credit markets, land-use planning, and taxation. Cadastral surveying will promote these activities at the upstream, midstream and downstream categories. Research carried out by Transparency International confirms that the land sector is among the most corrupt sectors worldwide; the payment of bribes for land allocation and registration is commonplace in many countries, while in others 'grand corruption', in the sense of large-scale theft of private and state land [73]. Thus, employing the expertise of the GE in cadastral surveying can improve transparency in land administration making corruption visible for the public at large and less

easy for offenders in the oil and gas industry. Land registrars and GE together with professional ethics promotes sustainable management of onshore and offshore facilities. The GE who is involved in land administration with sound knowledge of technical subjects like data acquisition, database technology and data distribution, and adopting other business subjects such as process design and workflow management, planning and control; all covered with a good sense of politics; can go a long way to promote the activities of the oil and gas industry [73]. As reported in CHINAFRICA magazine by [74] on the Cote d'Ivoire and Ghana controversial dispute over maritime border after oil discovery necessitated the late Ghana President John Evans Atta Mills to pass Ghana Boundary Commission Bill to establish a commission to negotiate proper demarcation of Ghana's land and maritime boundaries with neighbouring countries; which inevitably calls for GE practical ethical expertise.

H. Application of Geodetic Surveying (Satellite Geodesy) in oil and gas industry

The GE employs Geodetic Surveying to determine the size and shape of the Earth, and the precise location of points on its surface. Geodesy is closely connected to astronomy and has been used to guide the great sailing ships and water traffic in the oil and gas industry. With the GPS, the GE (or Geodesists) can tell the exact position of an object on the Earth's surface usually within a centimeter. GPS is also used for guiding space satellites and airplanes, to track the movement of ships, planes, oil rigs, trucks, trains, etc. and to help locate people who need assistance [75]. The satellite navigation (or satnav) system provides autonomous geo-spatial positioning with global coverage. GE study geodynamical phenomena such as crustal motion (movements of the continental plates), tides, and polar motion. GE provides the basic coordinate control networks for surveying through very precise surveying techniques such as precise leveling, satellite altimetry, GNSS positioning, gravity measurements and so on.

IV. CONCLUSIONS

The roles of the GE in the oil and gas industry are enormous. The GE plays a role in the upstream, midstream and downstream activities of the oil and gas industry; either at the start, during or end of exploration and construction. The GE enters the projects area first to make survey; the GE continues to be on site during construction; and finally the GE re-surveys and maps the existing area after construction. The DGE also plays a role by providing qualified graduates for the oil and gas industry; offering consultancies; and solving problems through researches with the skillful research and teaching staffs. The DGE offers courses at levels within the Geoinformatics discipline for Ghana and Sub-Saharan Africa, and ready to provide tailored made courses and as well as researching into problems in the oil and gas industry. The DGE in collaboration with SESE, expert in Geoinformatics and 3S Technology, can help solve problems related to the oil and gas industry; since about 80-90% of the datasets in the oil and gas industry has spatial component. There is the need to implement a Committee of GE and Land Surveyors in Ghana to maintain and publish a dataset of parameters for coordinate reference system and coordinate transformation description for the oil and gas industry as it is been done in other countries. In addition, GEs are needed in resolving the controversial dispute over maritime border after oil discovery in proper demarcation of Ghana's land and maritime boundaries with neighbouring countries.

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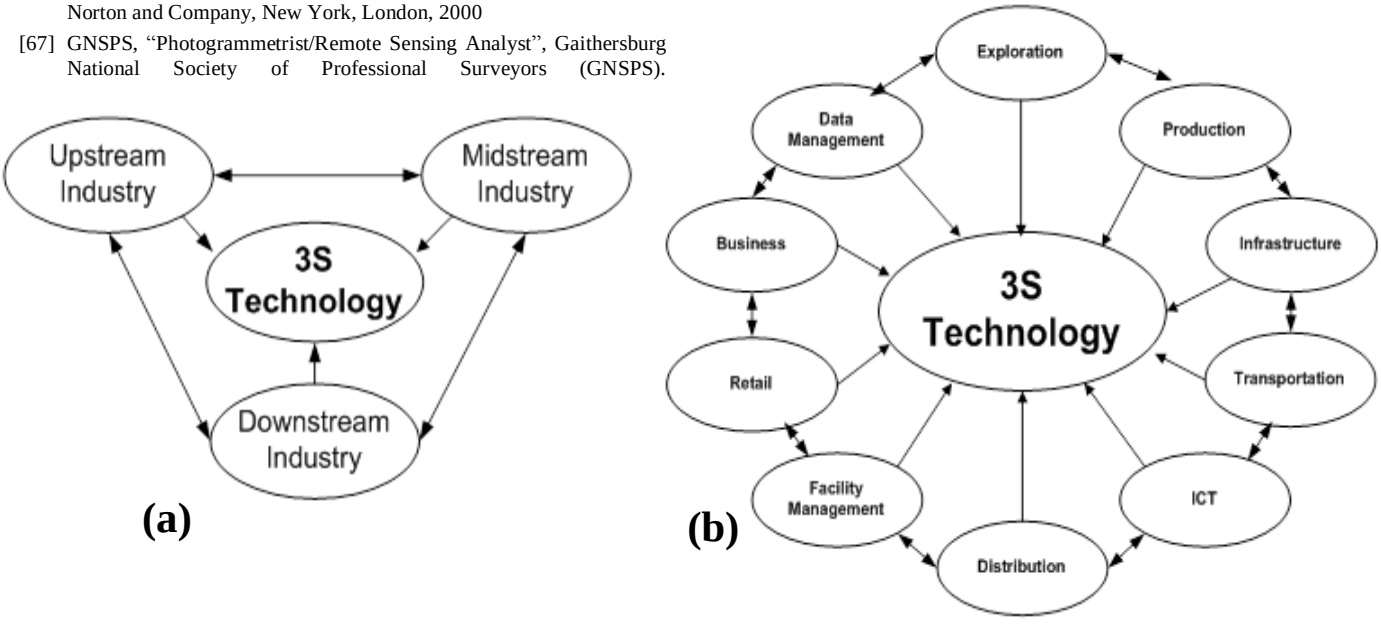

Figure 1. GIS integrated with GIS and RS for activities of the oil and gas industry; 1(b) Capabilities of 3S Technology handling detailed activities in the oil and gas industry (Adopted from ESRI, 2012)