STREAMLINING DIGITAL MODELING AND BUILDING INFORMATION MODELLING (BIM) USES FOR THE OIL AND GAS PROJECTS

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Abstract

The oil and gas industry is a technology-driven industry. Over the last two (2) decades, it has heavily made use of digital modeling and associated technologies (DMAT) to enhance its commercial capability. Meanwhile, the Building Information Modelling (BIM) has grown at an exponential rate in the built environment sector. It is not only a digital representation of physical and functional characteristics of a facility, but it has also made an impact on the management processes of building project lifecycle. It is apparent that there are many similarities between BIM and DMAT usability in the aspect of physical modeling and functionality. The aim of this study is to streamline the usage of both DMAT and BIM whilst discovering valuable practices for performance improvement in the oil and gas projects. To achieve this, twenty-eight (28) BIM guidelines, eighty-three (83) DMAT academic publications and one hundred and one (101) DMAT vendor case studies were selected for review. The findings uncover (a) thirty-eight (38) BIM uses; (b) thirty-two (32) DMAT uses and; (c) thirty-six (36) both DMAT and BIM uses. The synergy between DMAT and BIM uses would render insightful references into managing efficient oil and gas's projects. It also helps project stakeholders to recognise future investment or potential development areas of BIM and DMAT uses in their projects.

Keywords: Digital Modeling, Associated Technologies, Building Information Modeling, Streamline, Oil and Gas

1. Introduction

Oil and gas sector contributes significantly to more than half of humanity's primary energy supply (BHP, 2015). However, out of the total of 365 oil and gas megaprojects in the world, 73% of projects were reported schedule delays and 64% of projects experienced cost overruns (EY, 2014). One of the main factors contributed to project failures is management, contracting and project delivery strategies (Credit Suisse, 2014). It is envisaged that the technological prowess and advances should be incorporated into future oil and gas projects to embrace new thinking for performance improvement (Reid and Cann, 2016).

In the built environment sector, Building Information Modelling (BIM) is recognised as an emerging digital tool which enables information sharing of resources for a facility to form a reliable source for decision making throughout the project lifecycle (National BIM Standards, 2015). It is not only the digital representations of physical and characteristics of a facility but it is also a philosophy which transforms the way facilities are designed and managed by encouraging collaboration of all stakeholders' roles in a project (Azhar, 2011). Due to its potential values and benefits, BIM has been strongly advocated by many governments in the world. For instance, the Singapore government has mandated the implementation of BIM since 2013 (Teo et. al., 2015). The UK government also required all centrally procured public projects deploy BIM at level 2 by 2016 (HM Government, 2014). In Australia, the Federal Government's Infrastructure, Transport and Cities Parliamentary Committee has recommended that all major government infrastructure projects (over the value of $50 million) to implement BIM (Infrastructure Australia, 2016). BIM is commonly viewed in 3D, but the model includes information used by other building analysis applications, such as energy simulation, computational fluid dynamics (CFD), day lighting, cost estimating and building code checking (GSA, 2015). BIM adoption goes beyond design and construction, and it extends to the project management and facility management as the files of BIM can be extracted and exchanged to support decision making in connection with a facility.

On the other hand, it has been a few decades that the oil and gas projects deployed DMAT to enhance data management and collaboration process among the interdisciplinary team. DMAT refers to 3D geometric models and/or geometric bedding models and it's associated technologies which are usually adopted by the oil and gas industry to realise its facility. DMAT in the context of this study represents a simple 3D geometric model which contains very little intelligence or it may consist of high-level intelligence that is usually organised as a prototype of the facility to perform various functions. For exploration and production, geometry 3D bedding modeling such as the reservoir modeling has been developed to improve estimation of reserves (Abdideh and Bargahi, 2012); prediction of future production (Beeson et. al., 2014); and evaluating alternative reservoir management scenarios (Tavallali and Karimi, 2016). For design, construction and operation of the oil and gas facilities, plant lifecycle management (PLM) were deployed to allow multi-disciplinary teams like piping, electrical, mechanical, civil, structural and architectural design work concurrently under a collaboration platform (Intergraph, 2016). Information extracted from a plant model can be used for procurement such as material management, strategic sourcing and contract management (Xue, 2015). Apart from geometry bedding modelling and PLM, other DMAT uses which also have similar functionality and physical attributes with the BIM such as a unified information model of oil loading station was created in Samara Oblast, Russia, which used a mobile device on site for accessing information of model and project planning (Bentley, 2015, p. 123). Both BIM and DMAT are observed to have common attributes such as both technologies create 3D virtual models and they could interoperate with other technologies to achieve the project outcomes.

Some BIM uses could be potentially applied in the oil and gas industry to enhance their project performance. BIM and Augmented Realty (AR) could be used for project visualisation as it allows designers and owners to gain an immersive and interactive experience (Wang et al., 2014) prior to oil and gas plant fabrication and installation. BIM and Firefly Algorithm (FA) could be integrated to automatically develop an optimal tower crane layout plan (Wang et al., 2015) for the oil and gas project construction. Besides, BIM and Light Detection and Ranging (LiDAR) could be developed to provide real-time information for on-site quality control (Wang et al., 2015a). Mechanical, plumbing and electrical (MEP) are essential facility elements that formed a majority components of the oil and gas plant fabrication and installation. A practical BIM framework which integrated the MEP layout from preliminary design to construction stage was formulated to resolve the design and constructability issues (Wang et al., 2016). To improve defect management practices in the oil and gas projects, BIM information could be linked with defects data effectively by converting it to RDF format and implementing SPARQL queries (Lee et al., 2016). Past oil and gas projects failed to deliver their desired outcomes due to many re-works, design errors, inefficiency in construction and life cycle performance failures. A total constraint management (TCM) framework which incorporated BIM and other related technologies was developed to improve oil and gas construction workflow and productivity (Wang et al., 2016a).

There were reviews on the BIM uses in building and infrastructure projects but none of the studies were carried out to identify BIM uses in the oil and gas industry. Twenty-four (24) industrial reports and more than forty (40) case studies in academic publications were collected and assessed to determine current BIM uses and the emerging BIM applications among the building, airports, bridges and roadworks (Shou et al., 2014). The BIM and its associated technologies applications of the road projects in Australia and China were also be compared to analyse the differences in the cultural and managerial practices between the projects in two countries (Chong et al., 2016).

Infrastructure Australia (2016) asserted that the best practices require a focus on the harmonisation which means the practices and standards have to be aligned to reduce duplication and improve delivery. To identify potential BIM applications and its associated technologies for improving oil and gas project performance, it is important to streamline both DMAT and BIM uses. The synergy between DMAT and BIM uses could create a better understanding for the oil and gas industry to plan, design, develop and operate its facilities whilst distinguish valuable key process areas be brought into the oil and gas industry for performance improvement.

To achieve the aim, this paper outlines three objectives as follows: - (1) to synthesis BIM uses from BIM guidelines; (2) to determine DMAT uses in the oil and gas industry; and (3) to streamline BIM and DMAT uses for the oil and gas industry.

2. BIM and DMAT Uses

The term "uses" is originated to classify the BIM uses so that project participants who will deploy the BIM in their projects could communicate and collaborate the specific value of a particular BIM application prior to the BIM implementation. The motivation behind the identification of BIM uses is that there is no common language existed for project participants to precisely communicate the purposes among each other for implementing BIM (Kreider, 2013).

While some BIM guidelines expressed the term of BIM uses as "BIM deliverables", other guidelines used the term of "BIM applications" which in fact carry the similar meaning as the former. If we view all these terms as the synonyms of BIM uses, there are many BIM guidelines that outlined the BIM uses. However, only a few guidelines that defined the meaning of the BIM uses clearly. NATSPEC (2016) asserted that BIM uses should not link intrinsically to project phases but they should be selected to support project goals at the beginning of the project and be planned how to deploy during different project phases. The nature of BIM technology allows different stakeholders use the BIM in multiple ways depending on the specific needs they may have (NYCDDC, 2012). Hence, BIM uses could be defined as the BIM tools that are deployed to coordinate the specific purposes for realising the project objectives.

A similar rationale is applied to the DMAT uses as the ultimate goal of the oil and gas owners and/or operators are to realise a facility which would be delivered on time, within their budgets, safely, complied with the strict environmental regulations, satisfied other stakeholders and to optimise their production during operation. To achieve project outcomes, BIM and DMAT uses should be classified based on the purposes and objectives as in table 1.

Table 1: BIM and DMAT Uses Purposes

BIM use purpose	BIM use objective	Synonyms
Gather	It captures current status of a facility, quantifies the amount of a facility element, monitors the information and qualifies the status of facility elements.	administer, collect, manage, acquire, quantity take-off, observe, measure, follow, track, identify
Generate	It prescribes the need for and specify facility elements, arrange the placement of facility elements and determines the magnitude and size of facility elements.	create, author, model, program, specify, configure, lay out, locate, place, scale, engineer
Analyse	It coordinates the relationship of facility elements, forecasts the future performance of the facility and validates the accuracy of the facility information.	examine, evaluate, detect, avoid, simulate, predict, check, confirm
Communicate	It allows visualisation of a facility, transforms the information to be received by another process, draws a symbolic representation of the facility and documents the specification of the facility elements.	exchange, review, translate, draft, annotate, detail, specify, submit, schedule, report
Realise	It facilitates the facility information for fabrication, assembles the separate facility elements, controls the operation of executing equipment and regulates the operation of a facility element.	implement, perform, execute, manufacture, prefabricate, manipulate, direct

Note: This table is extracted from the National BIM Standard (2015)

3. Review Methodology

Figure 1 demonstrated a five-stage review framework which was used in this study.

Figure 1 Five-Stage Review Framework

Step 1: Problem Identification

There is an inconsistent language of BIM and DMAT uses between the Built Environment sector and the oil and gas industry. Hence, there is a need to bridge the semantic gap of BIM and DMAT uses between these two industries to provide a better understanding for the oil and gas industry to communicate precise purpose and context of implementing these technologies for improving project performance.

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Step 2 Search for Evidence

Stages	Sources	Actions	Evidences
Stage 1 Literature Search	BIM guidelines	Select	• Keyword: BIM guidelines
	DMAT uses: • Peer-reviewed Journal Articles and Conference Papers • DMAT Vendor Case Studies	Select	• Years: 2012-2016 • Keyword: 3D model oil gas
Stage 2 Literature Filtration	• BIM guidelines	Select	Discussed the BIM uses
	• DMAT academic publications (Peer-Reviewed) • DMT Vendor case studies	Select	Discussed the DMAT uses

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Step 3 Evaluate Data (Findings)

Sources	Actions	Evidences
BIM guidelines	Synthesis and Tabulate	BIM Uses
• DMAT academic publications • DMAT Vendor case studies	Synthesis and Tabulate	DMAT Uses

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Step 4 Data Analysis and Discussion (Streamlining and Presentation)

Sources	Actions	Evidences
• BIM Uses • DMAT Uses	Streamline and Tabulate	• Streamlined BIM and DMAT Uses • Distinguished DMAT Uses

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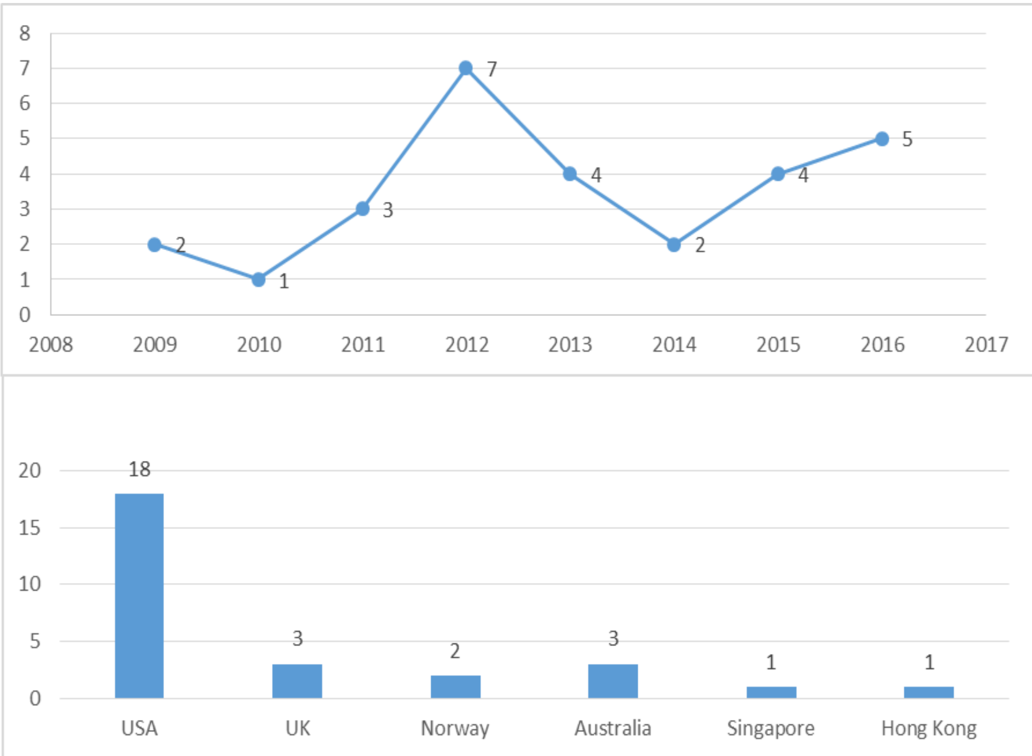
Step 5 Conclusion and Recommendations

The first step involved in this study was problem identification. Next, to identify the solution to the problem, an intensive literature search was carried out. The Google search engine was deployed to identify BIM guidelines. BIM guidelines were selected if they stated or sufficiently discussed BIM usability and its purpose. Figure 2 demonstrates the numbers of the BIM guidelines from 2012 to 2016 and also country by publications used in this study. The highest numbers of BIM guidelines were in the year of 2012.This may due to the rapid growth and use of BIM in the industry. The highest number of publications was recorded by the United States which consisted eighteen (18) articles. The significant high number of BIM guidelines in this country mainly due to the greater adoption and use of BIM in the country.

Figure 2: Years, numbers and country by publication of BIM guidelines



On the other hand, the usability of DMAT was determined through; (1) peer-reviewed journal articles and conference papers; and (2) DMAT vendor case studies. The Google scholar was used to identify the academic publication whereas the Google search engine was deployed to identify DMAT objective by DMAT vendors. Some of the common DMAT vendors selected in this study were as follows:-

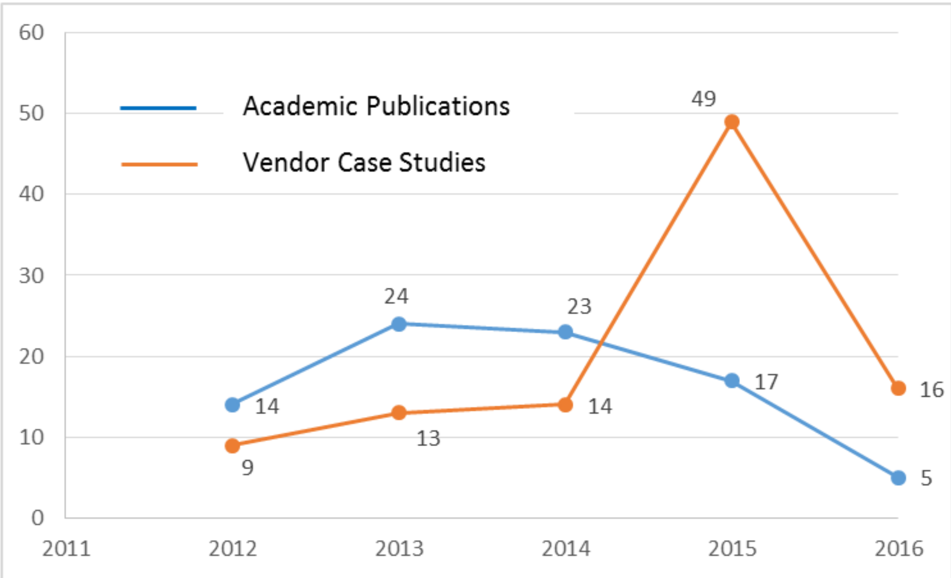
Table 2: List of Common DMAT vendors selected

Disciplines	**DMAT Vendors**
Exploration and Production	Schlumberger, Landmark, Paradigm, Petex
Design, Procure and Construct	Bentley, Autodesk, Synchro, AVEVA (formerly known as PDMS and Tribon), Intergraph, Tekla, Aspentech

Commissioning, Operation, and Maintenance	WinPCS, AVEVA, Intergraph, Bentley, Autodesk, Schlumberger

All data was retrieved from 2012 to 2016 to identify the recent trends of DMAT uses in the oil and gas industry. The keyword deployed for searching the academic publications were "3D model oil gas". The data was filtered through the elimination process. The academic publications and vendor case studies were selected if they sufficiently discussed the DMAT purpose. Figure 3 shows the numbers and years of academic publications and DMAT vendor case studies adopted in this study.

Figure 3: Years and numbers of DMAT Academic Publications and Vendor Case Studies



There were total eighty-three (83) DMAT academic publications and one hundred and one (101) DMAT vendor case studies selected in the study. Both types of sources projected a very dissimilar trend. Most of the DMAT academic publications that used in the study were in the year 2013 and 2014 which accounted for 24 and 23 respectively whereas the majority of the DMAT vendor case studies adopted in the study was in the year of 2015, which recorded forty-nine (49) number.

The data gained from the BIM guidelines, academic publications and vendor case studies were tabulated for analysis. To synthesise the BIM and DMAT uses, the term adopted in the references which had a similar connotation and similar definition were classified into the same theme. The BIM and DMAT uses extracted from the BIM guidelines, DMAT academic publications and DMAT vendor case studies were presented based on the project lifecycle as outlined in Table 4 to ease the understanding of the readers. The data of BIM and DMAT uses were also presented according to the purpose as outlined in Table 1.

Table 4 Project Lifecycle Used In the Study

No.	**Darko (2014)**	**Activity model of the process plant life-cycle (ISO 15926)**	**Oil and Gas Industry Life Cycle Tabulate in This Study (DMAT)**	**Description**	**Project Life Cycle Tabulate in This Study (BIM)**	**Description**
	The oil and gas industry life cycle stated in this study are referred to the phases described in the above two references.					
1	Exploration	-	Exploration	It includes seismic surveys to look for potential oil or/and gas sources (Darko 2014).	-	-
2	Appraisal	Conceptual Process Design, Conceptual Engineering Design (Front End)	Appraisal	This phase determines the projects should proceed or terminate based on the results of the potential of oil or/and gas reserves (Darko 2014). It also involves feasibility study, site planning and front-end engineering design (FEED) for production, transportation and processing oil and gas facilities projects.	Plan	This phase is the most important phase to determine the feasibility of the project. It includes site analysis, determination of the project location, conceptual design and preparation of initial estimate.
3	Development	-	Development	Wells and reservoirs are developed. Production operation	-	

				and maintenance strategies are also established (Darko 2014).		
3a	-	Detailed Process Design, Detailed Engineering Design	Design	It includes detailed engineering design.	Design	This phase includes the schematic design of a facility to the selection of contractor (Chong, 2016a).
3b	-	Procure and Control Equipment, Material and Services, Suppliers and Fabricators	Procure	It describes the ordering, purchasing and control of materials, equipment and services from fabricators and suppliers.	Procure	Same as the description of the oil and gas industry procurement stage.
3c	-	Construct Plant, Pre-Commission	Construct	This stage involves construction and fabrication of oil and gas facilities.	Construct	Same as the description of the oil and gas industry construction stage.
4	Production and Operation	Commission Plant, Operate Plant, Maintain Plant and Equipment	Production, Operate and Maintain	Oil or/and gas reserves are being extracted and transported for processing/ exported. It also involves commission, operates, modifications and maintains plant and equipment during the life of oil and gas facilities.	Operate and Maintain	This stage includes the operation and maintenance of a facility (Chong and Wang, 2016).
5	Abandonment	Decommission, Demolition Plant and Restore Site	Demolition	This phase involves well abandonment, dismantle the plants and restore the site to its original condition.	-	This section is not available as none of this phase mentioned in the BIM guidelines.

Thereafter, a streamlining process was conducted. If a BIM and DMAT use share the common function, they would be aligned with the same theme which represents its use. For the DMAT uses which did not have common functions as the BIM uses, it would be classified as the distinguished DMAT uses. Throughout the streamlining process, the BIM uses which were not commonly applied in the oil and gas projects could also be identified. The results were discussed. Limitations, conclusions and recommendations were then formulated and concluded at the end of this review.

4. Findings

4.1 BIM Uses

Table 5 demonstrates thirty-eight (38) BIM uses which were extracted from twenty-eight (28) BIM guidelines.

Table 5 List of BIM Uses

No.	BIM Uses/ Description	Project Phases: Plan	Design	Procure	Construct	Operate	References (BIM Guidelines)	BIM Use Purposes
1	Existing Conditions Modeling *A process in which a 3D model of the existing conditions for a site, facilities on a site or a specific area within a facility is developed (PSU, 2011). It includes modelling of the existing ground surface of the structures, the adjacent area and the infrastructure for project master planning, existing facilities and assets, existing spaces, building components and equipment, geotechnical elements and horizontal construction such as roadways, raised bridges, walkways and transportation is developed so that the total environment of the facilities can be modeled effectively (MPA, 2015).*	x	x		x	x	(BCA, 2013); (COD, 2011); (COSA, 2011): (CRC, 2009): (DOA/DSF, 2012); (FMS, 2012); (GISFIC, 2013); (GTFM, 2013); (Harvard, 2016); (HKCIC, 2015); (IU, 2015); (LACCD, 2016); (MPA, 2015); (NATSPEC, 2016); (NHBA, 2012); (NRC, 2014); (NYCSCA, 2014); (NYDDC, 2012); (OFCC, 2012); (PSU, 2011); (SDCCD, 2012); (Statsbygg, 2013); (TPA, 2016); (USACE, 2012)	Gather; Generate
2.	Site Analysis *A process in which BIM or GIS tools are used to evaluate the site location to determine :(1) an appropriate location for a future project (NYCDDC, 2012); and (2) analyse the volumes, location (placement, orientation) of the facility(s) on site (Statsbygg, 2013).*	x					(BCA, 2013); (COD, 2011);(HKCIC, 2015); (NATSPEC, 2016); (NRC, 2014); (NYDDC, 2012); (OFCC, 2012); (PSU, 2011); (TPA, 2016); (USACE, 2012)	Analyse
3	Cost Estimation *A process in which BIM can be used to establish accurate cost estimate and cost effects of changes made to the design can be traced from the BIM which enables designers to curb excessive cost overruns due to project modifications (NYCDDC, 2012). It includes cost planning, quantity take-off and cost tracking.*	x	x	x	x	x	(AGC, 2009); (BCA, 2013); (CFM, 2010); (COD, 2011); (COSA, 2011): (CRC, 2009): (DOA/DSF, 2012); (HKCIC, 2015); (IU, 2015); (LACCD, 2016); (MPA, 2015); (NATSPEC, 2016); (NRC, 2014); (NYSCA, 2014); (NYDDC, 2012); (PSU, 2011); (SDCCD, 2012); (SEC, 2013); (TPA, 2016); (USACE, 2012); (GTFM, 2016)	Gather; Generate, Analyse
a	Cost analysis (5D)/Cost and Schedule Forecast *A process in which a 5D BIM is deployed to link the cost data to 4D BIM (NATSPEC, 2016) for cost analysis and generating cash flow forecast report.*	x	x	x	x	x	(AGC, 2009); (CFM, 2010); (CRC, 2009); (LACCD, 2016);; (NATSPEC, 2016); (NRC, 2014); (SEC, 2013); (Statsbygg, 2013); (TPA, 2016); (USACE, 2012)	Analyse, Communicate
4	Phase Planning (4D Modeling)/ Scheduling *A process in which phased occupancy is planned effectively through utilisation of 4D model so that a project team can visualise and communicate for a better understanding of project milestones and construction plans (PSU, 2011). It involves early project phasing to allow for comparison of different strategies, detail phasing to sequence multi-trade installation and scheduling for project control (Harvard, 2016).*	x	x	x	x		(AGC, 2009); (BCA, 2013); (CFM, 2010); (COD, 2011); (COSA, 2011); (CRC, 2009); (DOA/DSF, 2012); (GISFIC, 2013); (GTFM, 2016); (Harvard, 2016); (HKCIC, 2015); (LACCD, 2016); (MPA, 2015); (NATSPEC, 2016); (NRC, 2014); (NYCSCA, 2014); (NYDDC, 2012); (PSU, 2011); (SDCCD, 2012); (SEC, 2013); (Statsbygg, 2013); (TPA, 2016); (USACE, 2012)	Communicate
5	Programming/ Are and Space Program Validation *A process in which area and program information is extracted from BIM to assess the space design as the design develops. It allows tracking rentable area, gross area and usable area (Harvard, 2016.).*	x					(BCA, 2013); (CFM, 2010); (COD, 2011); (COSA, 2011); (CRC, 2009); (DOA/DSF, 2012); (FMS, 2012); (GISFIC, 2013); (GTFM, 2016); (Harvard, 2016); (HKCIC, 2015); (IU, 2015); (LACCD, 2016); (MPA, 2015); (NATSPEC, 2016); (NYCSCA, 2014); (NYDDC, 2012); (OFCC, 2012); (PSU, 2011); (SDCCD, 2012); (Statsbygg, 2013); (TPA, 2016); (UCASE, 2012)	Generate
6	Design Authoring *A process in which authoring tools are deployed by multi-disciplinary teams to add richness of information to a facility (HKCIC, 2015).*	x	x	x	x		(CFM, 2010); (COD, 2011); (COSA, 2011); (FMS, 2012); (Harvard, 2016); (HKCIC, 2015); (LACCD, 2016); (NRC, 2014); (NYDDC, 2012); (PSU, 2011); (SDCCD, 2012); (Statsbygg, 2013); (TPA, 2016); (USACE, 2012)	Generate
7	Design Reviews and Constructability Reviews *A process in which a 3D model is viewed by stakeholders through different forms of presentations to provide their feedbacks for multiple design aspects validation (PSU, 2011.). It involves design selection from various options provided by the BIM, design communication through visualisation and digital mock-ups (Harvard, 2016).*	x	x				(AECUK, 2015); (AGC, 2009); (BCA, 2013); (CFM, 2010); (COD, 2011); (COSA, 2011); (DOA/DSF, 2011); (FMS, 2012); (GISFIC, 2013); (Harvard, 2016); (HKCIC, 2015); (LACCD, 2016); (MPA, 2015); (NATSPEC, 2016); (NRC, 2014); (NYCSCA,	Communicate

							2014); (NYDDC, 2012); (OFCC, 2012); (PSU, 2011); (SDCCD, 2012); (Statsbygg, 2013); (TPA, 2016); (USACE, 2012)	
8	Modeling *Each facility system shall be organised as a separate model linked to a common origin point for efficient coordination purposes. (LACCD, 2016).It includes an architectural model which consists of material and spatial design, structural, MEPF, interiors and any other common models for building a facility.*	x	x				(AECUK, 2015); (AGC, 2009); (CFM, 2010); (BCA, 2013); (COSA, 2011); (COD, 2011); (CRC, 2009); (FMS, 2012); (GISFIC, 2013); (GTFM, 2016); (IU, 2015); (LACCD, 2016); (MPA, 2015); (NATSPEC, 2016); (NHBA, 2012); (NYSCA, 2014); (OFCC, 2012); (SDCCD, 2012); (Statsbygg, 2013);	Generate
a	Civil Engineering/ Infrastructure Model *A process in which civil engineering model is created to represent civil engineering or infrastructure elements which shall distinguish with building models. The civil engineering or infrastructure elements may include site topography model, landscaping elements and site utilities models (FMS, 2012) with the aids of associated technologies such as GIS (Statsbygg, 2013, LiDAR and etc. Bridge, main road, highway, railway and tunnel models (NRC, 2014) are the examples of civil engineering models.*	x	x				(CFM, 2010); (COD, 2011); (COSA, 2011); (CRC, 2009); (FMS, 2012); (GTFM, 2016); (HKCIC, 2015); (LACCD, 2016); (OFCC, 2012); (SDCCD, 2012); (Statsbygg, 2013)	Generate
b	Equipment Modeling and Maintenance Clearance Space Modeling *A process in which equipment models are created to indicate its location, sizes and details (FMS, 2012). It also includes modeling for maintenance space and consideration of typical maintenance cycles, replacement paths continuity of operations so that adjacent equipment can be serviced at the same time (MPA, 2015).*	x	x				(FMS, 2012); (MPA, 2015); (SDCCD, 2012)	Generate
c	Energy Modeling *Due to the timing of analysis and potential model clean-up, energy analysis is often performed separately from the BIM (Harvard, 2016). It streamlines the simulation process quickly with minimal data from existing building conditions to develop an energy analysis (MPA, 2015).*	x	x				(BCA, 2013); (CFM, 2010); (COD, 2011); (GTFM, 2015); (Harvard, 2016); (IU, 2015); (MPA, 2015); (NHBA, 2012); (OFCC, 2012)	Generate
9	Design Analysis/ Engineering Analysis *A process in which the models are simulated with typical analysis software or used for structural analysis, lighting analysis, fire safety analysis etc.*		x				(BCA, 2013); (COD, 2011); (CRC, 2009); (DOA/DSF, 2009); (GISFIC, 2013); (Harvard, 2016); (HKCIC, 2015); (MPA, 2015); (NATSPEC, 2016); (NYDDC, 2012); (PSU, 2011); (SDCCD, 2012); (Statsbygg, 2013); (TPA, 2013); (USACE, 2012)	Analyse
a	Energy Analysis *A process in which energy simulation and lifecycle cost are analysed with the information extracted from BIM (CFM, 2010). The scope includes renewable energy analysis (SDCCD, 2012).*		x				(BCA, 2013); (CFM, 2010); (COD, 2011); (CRC, 2009); (DOA/DSF 2009); (GISFIC, 2013); (GTFM, 2016); (Harvard, 2016); (HKCIC, 2015); (IU, 2015); (LACCD, 2016); (MPA, 2015); (NATSPEC, 2016); (NHBA, 2012); (PSU, 2011); (SDCCD, 2012); (Statsbygg, 2013); (TPA, 2016); (USACE, 2012)	Analyse
b	Accessibility Analysis *A process of using colours, lighting conditions, acoustics and etc. which are not so straightforward to check as geometry requirements to assess the practicability and accessibility for all people which include people with disabilities (Statsbygg, 2013).*		x				(Statsbygg, 2013)	Analyse
c	Proximity Analysis *A process of deploying BIM to conduct proximity analysis for determining the appropriate travel distance between areas to another area (Statsbygg, 2013).*		x				(Statsbygg, 2013)	Analyse
d	Security and Circulation Analysis *A process in which a BIM is simulated with a security and circulation analysis software to analyse the circulation areas where the building has define security zones (Statsbygg, 2013).*		x				(Statsbygg, 2013)	Analyse
e	Acoustics Analysis *A process in which BIM is simulated with an acoustical analysis tool to perform room acoustical analysis and sound insulation calculations (Statsbygg, 2013).*		x				(CRC, 2009); (Harvard, 2016); (Statsbygg, 2013)	Analyse
f	Mechanical Analysis/ Virtual Testing and Balancing/ System Analysis/ Building Disposal Analysis *A process to compare a facility performance with the design specifications. It includes assessments of how a mechanical system operates, how much energy a project uses, conducting lighting analysis, solar gain analysis and airflow analysis using CFD (HKCIC, 2015).*		x			x	(BCA, 2013); (CFM, 2010); (COD, 2011); (COSA, 2011); (CRC, 2009); (Harvard, 2016); (HKCIC, 2015); (MPA, 2015); (NATSPEC, 2016); (NRC, 2014); (NYDDC, 2012); (PSU, 2011); (Statsbygg, 2013); (TPA, 2016); (USACE, 2012)	Analyse

g	Sustainability Evaluation/Environmental Analysis/ Environmental Hazardous Products Analysis *A process in which models are used to simulate and validate facility properties such as thermal performance, energy use, structural calculations, acoustics, heat flows, Life Cycle Costing (LCC), Life Cycle Analysis (LCA) and environmental sustainability (CRC, 2009) based on the requirement of standard sustainability assessment.*	x	x	x	x	x	(BCA, 2013); (COD, 2011); (CRC, 2009); (DOA/DSF, 2012); (GISFIC, 2013); (GTFM, 2016); (Harvard, 2016); (HKCIC, 2015); (LACCD, 2016); (NATSPEC, 2016); (NYDDC, 2012); (PSU, 2011); (Statsbygg, 2013); (TPA, 2016); (USACE, 2012)	Analyse
h	Civil Engineering Analysis *A process in which the models of civil engineering elements can be analysed with the aids GPS, LiDAR and any other forms of technologies such as for the hydraulic design of water supply, sewerage, storm water drainage systems (HKCIC, 2015), surface analysis and traffic simulation (NRC, 2014).*		x				(CFM, 2010); (COD, 2011); (HKCIC, 2015); (LACCD, 2016); (SDCCD, 2012); (NRC, 2014)	Analyse
i	Signal Sighting *A process in which BIM can be deployed to design and test the new signaling proposals before fixing (NRC, 2014).*		x				(NRC, 2014)	Analyse
j	Code Validation/ Building Code Analysis/ Model Checking Program/ Compliance Checking/ Design Validation *A process in which code validation software is utilised to check the model parameters against project specific codes (PSU, 2011). Apart from compliance validation, it includes prescription and functionality validation (NRC, 2014).*		x				(AECUK, 2015); (CFM, 200); (COD, 2011); (CRC, 2009); (GTFM, 2016); (Harvard, 2016); (IU, 2015); (LACCD, 2016); (MPA, 2015); (NATSPEC, 2016); (NRC, 2014); (NYDDC, 2012); (OFCC, 2012); (PSU, 2011); (Statsbygg, 2013); (TPA, 2016); (USACE, 2012)	Analyse
10	Design Coordination / 3D Coordination/ Interference Management/Clash Avoidance and Detection *A process in which clash detection software is deployed to analyse the BIM for physical interferences between building systems and components, clashes are manually sorted and reported (Harvard, 2016). Automated clash detection analysis for drainage and utility networks is made possible with BIM tools (NRC, 2014).*		x				(ARC, 2009); (BCA, 2013); (CFM, 2010); (COD, 2011); (COSA, 2011); (CRC, 2009); (DOA/DSF, 2012); (FMS, 2012); (GISFIC, 2013);(GTFM, 2016); (Harvard, 2016); (HKCIC, 2015); (IU, 2016); (LACCD, 2016); (MPA, 2015); NATSPEC, 2016); (NRC, 2014); (NYCSA, 2014); (NYDDC, 2012); (OFCC, 2012); (PSU, 2011); (SDCCD, 2012); (SEC, 2013); (Statsbygg, 2013); (TPA, 2016); (USACE, 2012)	Analyse
11	Design Documents/ Drawing Generation *A process in which design documents such as schematic, design development, construction and shop drawings are extracted directly from the BIM repositories or object libraries (PSU, 2011).*		x				(BCA, 2013); (CFM, 2010); (COD, 2011); (CRC, 2009); (Harvard, 2016); (LACCD, 2016); (PSU, 2011); (SDCCD, 2012)	Communicate
12	Digital Fabrication *A process in which geometry from the BIM is extracted for shop drawings and can be sent to computer numerical control equipment for prefabrication and erected efficiently on site (Harvard, 2016).*			x	x		(AGC, 2009); (BCA, 2013); (CFM, 200); (COD, 2011); (CRC, 2009); (GTFM, 2016); (Harvard, 2016); (HKCIC, 2015); (LACCD, 2016); (MPA, 2015); (NATSPEC, 2016); (NRC, 2014); (NYCSCA, 2014); (NYDDC, 2012); (OFCC, 2012); (PSU, 2011); (TPA, 2016); (USACE, 2012)	Realise
13	Subcontractor/ Trade Coordination *A process in which a coordinated model is deployed for the contractor to coordinate with the subcontractors for review the design, optimise scheduling and field installation prior to installation (NATSPEC, 2016).*			x	x		(AGC, 2009); (CFM, 2010); (COD, 2011); (NATSPEC, 2016); NYCSCA, 2014)	Realise
14	Material Management *A process in BIM is used to support multiple-user access, receive, track and control all project deliverables such as prefabrication components and other small construction support materials to ensure the materials deliver on schedule and meet the quality expectations (NRC, 2014).*			x	x		(NRC, 2014)	Gather; Generate
15	Equipment Management *A process in which BIM is deployed to support construction equipment management such as scheduling the downtime to fit project workload, produce maintenance schedules, complete service history and work arrangement (NRC, 2014).*			x	x		(NRC, 2014)	Gather; Generate
16	Site Utilisation Planning/ Site and Logistic Planning *A process in which detailed logistic objects are modeled in the BIM (Harvard, 2016) and link to construction schedule (4D) (HKCIC, 2015) for permanent and temporary facilities on site (PSU, 2011).*				x		(AGC, 2009); (COD, 2011); (CRC, 2009); (Harvard, 2016); (HKCIC, 2015); (NATSPEC, 2016); (NRC, 2014); (PSU, 2011); (TPA, 2016); (USACE, 2012)	Communicate
17	3D Control and Planning (Digital Layout)/ In field Construction Layout *A process in which layout points are taken from the BIM and loaded into robotic total stations for layout. Conversely, layout points are captured in the field during construction and round-tripped back to the model for proactive quality control (MPA, 2015).*				x		(COD, 2011)); (Harvard, 2016); (HKCIC, 2015); (MPA, 2015); (NRC, 2014); (PSU, 2011); (USACE, 2012)	Communicate

18	Lift Planning *A process in which lift plan models are created through collaboration between the structure engineers and experienced site personnel such as lift supervisor to communicate the lift plan for execution (NATSPEC, 2016).*				x		(NATSPEC, 2016)	Communicate
19	Safety/ Safety Planning/Site Safety Review *A process in which BIM is deployed to develop safety plans for communication on site and off site such as information for emergency routes of public safety measures can be extracted from the BIM (Harvard, 2016) and BIM-based orientation can be used to provide safety training (MPA, 2015).*				x		(GISFIC, 2013); (Harvard, 2016); (MPA, 2015); (NRC, 2014); (TPA, 2016)	Communicate
20	Construction System Design *A process in which complex building systems such as modular construction components, formwork and scaffolding can be modeled to improve planning, construction productivity and safety (NATSPEC, 2016).*				x		(COD, 2011); (NATSPEC, 2016); (NYDDC, 2012); (PSU, 2011); (TPA, 2016); (USACE, 2012)	Generate; Communicate
21	Progress Tracking *A process in which 4D BIM is integrated with laser scanning and mobile computing to assist project managers in assessing construction progress effectively and make a timely decision if schedule delay appeared.*				x		(NRC, 2014)	Gather
22	Field and Management Tracking/ Quality Tracking and Reporting *A process in which Field Management software is used during the construction, commissioning, and handover process to manage, track, task, and report on quality, safety, documents to the field, commissioning, and handover programs, connected to BIM for project compliance (PSU,n.d.).*				x		(PSU, 2011); (Statsbygg, 2013); (USACE, 2012); (NRC, 2014)	Gather; Generate; Communicate
23	Field Supplements *Data extracted from BIM can be used to support field supplements (Harvard, 2016) such as construction drawings and schedules, as-built documents and sustainability certification documentation to be submitted as part of the project deliverables.*				x		(AGC, 2009); (Harvard, 2016); (LACCD, 2016); (MPA, 2015); (SDCCD, 2012); (Statsbygg, 2013); (TPA, 2016)	Communicate
24	Record Model/ As-built Model *Record Modeling is the process used to depict an accurate representation of the physical conditions, environment, and assets of a facility. It is the culmination of all the BIM Modeling throughout the project, including linking Operation, Maintenance, and Asset data to the As-Built model (created from the Design, Construction, 4D Coordination Models, and Subcontractor Fabrication Models) to deliver a record model to the owner or facility manager (PSU,2011).*				x		(AECUK, 2015); (AGC, 2009); (BCA, 2013); (COD, 2011); (COSA 2011); (CRC, 2009); (GTFM, 2016); (Harvard, 2016); (HKCIC, 2015); (IU, 2015); (LACCD, 2016); (MPA, 2015); (NATSPEC, 2016); (NRC, 2014); (NYDDC, 2012); (OFCC, 2012); (PSU, 2011); (SDCCD, 2012); (Statsbygg, 2013); (TPA, 2016); (USACE, 2012)	Generate
25	COBie/ Commissioning *A systematic process of verifying that all building systems perform interactively according to the design intent and the owner's operational needs (MPA, 2015).*	x	x	x	x	x	(CFM, 2010); (COD, 2011); (FMS, 2012); (GTFM, 2016); (IU, 2015); (LACCD, 2016); (MPA, 2015); (NATSPEC, 2016); (NRC, 2014); (SDCCD, 2012); (SEC, 2013); (Statsbygg, 2013); (TPA, 2016); (USACE, 2012)	Communicate; Realise
26	Other FM information handover *A process in which where the client and BIM Team determine that use of the COBie system is not appropriate for the project, other specific information required for facility management and the strategy for delivering it are purposed (NATSPEC, 2016).*					x	(NATSPEC, 2016)	Communicate; Realise
27	Operation and Maintenance Scheduling/ Preventive Maintenance Analysis *A process of record model/ as-built model is deployed with building management system such as building automation system, computerised maintenance management system to plan, manage and track operation and maintenance activities (PSU, 2011).*					x	(BCA, 2013); (COD, 2011); (CRC, 2009); (HKCIC, 2015); (MPA, 2015); (NATSPEC, 2016); (NRC, 2014); (PSU, 2011); (SDCCD, 2012); (Statsbygg, 2013); (TPA, 2016); (USACE, 2012)	Communicate
28	Asset Management/Facility Management *A process of bi-directionally linking an as-built model database to an organised building management system which can be used to maintain and operate a facility and its assets (HKCIC,2015).The assets include physical components, systems, surrounding environment and equipment (NRC, 2014).*					x	(BCA, 2013); (COD, 2011); (CRC, 2009); (Harvard, 2016); (HKCIC, 2015); (MPA, 2015); (NATSPEC, 2016); (NRC, 2014); (NYDDC, 2012); (OFCC, 2012); (PSU, 2011); (SDCCD, 2012); (Statsbygg, 2013); (TPA, 2016); (USACE, 2012)	Gather; Generate; Communicate
29	Maintenance Training *BIM can be used during commissioning, preoccupation, and post-occupation to train staff on asset location, maintenance access and maintenance procedures. This information can be developed into a mobile accessible package (MPA, 2015).*					x	(MPA, 2015)	Realise

30	Space Management and Tracking *A process in which BIM may integrate with spatial tracking software to assess, manage and track the existing use space and associated resources within a project (HKCIC, 2015)*					x	(BCA, 2013); (COD, 2011); (CRC, 2009); Harvard, 2016); (HKCIC, 2016); (MPA, 2015); (NATSPEC, 2016); (PSU, 2011); (SDCCD, 2012); (TPA, 2016); (USACE, 2012)	Gather; Communicate
31	Disaster Planning/Contingency Planning Analysis *A process in which BIM is used in conjunction with building management system for emergency response planning (NATSPEC, 2016).*					x	(COD, 2011); (CRC, 2009); (Harvard, 2016); (MPA, 2015); (NATSPEC, 2016); (NRC, 2014); (PSU, 2011); (SDCCD, 2012); (Statsbygg, 2013); (TPA, 2016); (USACE, 2012)	Generate; Analyse; Communicate
32	Assessment Models *BIM can be used in the field for efficient data collection. Mobile software supporting BIM shall be considered by the assessment team (MPA, 2015).*					x	(MPA, 2015)	Gather
33	Resiliency Modeling *BIM can be used to create resiliency modeling particular for the projects where their assets and properties are located in areas subject to environmental change (MPA, 2015).*					x	(MPA, 2015)	Generate
34	Road/Rail Management *A process in which BIM is utilised to provide solutions to build and manage infrastructure models, analyse current working conditions of infrastructure, plan for infrastructure improvement and future growth with the aids of various forms of technologies such as geospatial tracking and graphical representation of the networks (NRC, 2014).*					x	(NRC, 2014)	Realise
35	Transportation/ Logistic Management System *A process in which BIM transportation management tools are deployed to support entire transportation lifecycle ranging from creating the least cost shipment plans and maximising loading capacity to streamlining freight financial administration for match- and auto-pay or self-invoicing processes, as well as leverage end-to-end visibility for proactive monitoring and intelligent exception management for whole distribution network (NRC, 2014).*					x	(NRC, 2014)	Realise
36	Traffic Volume Simulation *A process in which performance measures generated by BIM models and BIM visualization capabilities enable detailed operational analyses of travel corridors in the area and assist in determining the potential effectiveness of transportation projects and access management practices (NRC, 2014).*					x	(NRC, 2014)	Analyse
37	GIS Asset Tracking *A process in which BIM is deployed to monitor location and movement of objects in real time. Objects that can transmit their geographic location via Global Positioning Systems (GPS) or similar technologies can be dynamically tracked on a display map that can be shared via the Internet or intranet (NRC, 2014).*					x	(NRC, 2014)	Gather
38	Water Mitigation and Planning *A process in which BIM operation tools can be deployed to support appropriate legislation for flood plain zoning, implementation and collection of data essential for the assessment of the community's flood risk (NRC, 2014).*					x	(NRC, 2014)	Communicate

4.2 DMAT Uses in the Oil and Gas Industry

Table 6 demonstrates thirty-two (32) DMAT uses extracted from a total of eighty-three (83) academic publications and one hundred and one (101) DMAT vendor case studies.

No.	DMAT Uses/ Description	Project Phase							References		DMAT Use Purposes
				Development					Academic Publications (most of the papers discussed the potential DMAT uses in the oil and gas projects or examined the DMAT uses in research, except for those with * indicates the DMAT uses were applied in the practice)	DMAT Vendor Case Studies	
		Exploration	Appraisal /Plan	Design	Procure	Construct	Production, Operate & Maintain	Abandonment/ Demolition			
1	Geological Modeling *A process in which a 3D geological model is generated through repeated seismic surveys and predictions about its properties and structures (Abideh and Bargahi, 2012).*	x	x				x		(Abideh and Bargahi, 2012); (Amanippor et al., 2013); (Besson et. al., 2014)*; (Cuba et. al., 2012);(Do Couto et.al., 2015); (Duran et al., 2013); (Fayemi and Di, 2016); (Lindsay et al., 2013); (Liu et al., 2012); (Tiruneh et al., 2013); (Turrini et al., 2014)*; (Zhu et al., 2013)	(Paradigm, 2013)	Generate
2	Reservoir Modeling *A process in which a geological model can be up-scaled to simulate with fluid behaviours under different sets of circumstances to identify the optimal production techniques. It is mainly used for charge risk assessments, locate new prospects, identify drilling targets, optimise completions and accelerate developments (Paradigm, 2016).*	x	x				x		(Amoyedo et al., 2016); (Brigaud et al., 2014); (Bruns et al., 2013); (Cacace and Blocher, 205); (Dong et al., 2014); (Fegh et al., 2013); (Geiger et.al., 2012); (Glegola, 2013); (Kamali et al., 2013); (Katterbauer et al., 2014); (King et al., 2012)*; (Morongjiu-Porcu et al., 2016); (de Oliveira Miranda et al., 2015); (Naji and Khalil, 2012); (Norden et al., 2012); (Panfili et al., 2012); (Park and Datta-Gupta, 2013); (Senel et al., 2014)*; (Soleimani and Shokri, 2015); (Zeinalzadeh et al., 2015)	(Paradigm, 2016); (Paradigm, 2016b); (Paradigm, 2016c); Schlumberger, 2015b); (Schlumberger, 2016b)	Analyse
3	Data or Information Management *A process in which a data or information management tool is deployed to collaborate multi-disciplinary teams in a common visualisation environment. It includes the deployment of other advanced IT tools such as big data (Perrons and Jensen, 2015), cloud computing (Perrons and Hems, 2013) and etc.*	x	x	x	x	x	x	x	(Baaziz and Quoniam, 2013); (Chelmis et al., 2013); (Han et al.,2014); (He and Wang, 2015); (Kim et al., 2014); (Perrons and Hems, 2013); (Perrons and Jensen, 2015); (Popa and Cassidy, 2012)*; (Sawaryn et al., 2014); (Veyber et al., 2012); (Ward et al., 2014)*; (Zhu et al., 2015)	(Aveva, 2015a); (Aveva, 2015c); (Aveva, 2015, p.26-30); (Aveva, 2015, p.31-33); (Aveva, 2015, p.34-37); (Aveva, 2015, p.42-45); (Aveva, 2015, p.46-47); (Aveva, 2015, p.48-51); (Bentley, 2012, p.105); (Bentley, 2012, p.27); (Bentley, 2013, p.20); (Bentley, 2013, p.26); (Bentley, 2014, p.11 and p.73); (Bentley, 2014, p.110);(Bentley, 2014, p.115); (Bentley, 2015, p.105); (Bentley, 2015, p.122); (Bentley, 2015, p.122a); (Bentley, 2015, p.123a); (Bentley, 2015, p.124a); (Bentley, 2015, p.135); (Bentley, 2015,p.192); (Bentley, 2015, p. 201); (Intergraph, 2012); (Intergraph, 2013); (Intergraph, 2013a); (Intergraph, 2015a); (Intergraph, 2016); (Intergraph, 2016a); (Tekla, 2016a); (Tekla, 2016c); (Aspentech, 2015b)	Communicate
4	Well Planning *A process in which a well is interpreted and it is assessed with well-planning software and reservoir modeling through various scenarios to quantify wellbore position and precision (Paradigm, 2016) for safe operation and at*		x	x	x	x	x		(Chemali et al., 2014); (Jain et al., 2013); (Ask et al., 2015); (Odunowo et al., 2013); (Tavallali and Karimi, 2016); (Zhu et al., 2014)	(Landmark, 2016); (Paradigm, 2016a); (Schlumberger, 2013b); (Schlumberger, 2014); (Schlumberger, 2015a); (Schumberger, 2016); (Schlumberger, 2016a);	Generate

	the lowest cost. A 3D drillable trajectory is designed inside a subsurface model with well control simulation software to understand and mitigate operational risks and meet drilling regulations (Schlumberger, 2016). As drilling operation is progress, reservoir model is updated and coupled with simulation software to situate the good structure and provide a more realistic drilling (Chemali et al., 2014).										
5	Subsurface Model Review *A process in which a 3D subsurface model and other necessary data are reviewed by stakeholders through different forms of presentations to assist in decision making for well planning, drilling and production optimisation (Schlumberger, 2013).*	x	x	x			x		-	(Schlumberger, 2013); (Schlumberger, 2014a)	Communication
6	Drilling Operation *Drilling operations include utilisation of drilling operations software and other services for drilling engineers and the rig site to continuously monitor and analyse drilling operations for drilling performance optimisation, wellbore assurance, risk mitigation, and operational efficiency (Schlumberger, 2016). The result of the drilling data analysing data grid could be visualised through 3D model (Zhang and Zhang, 2012).*		x	x	x	x	x		(Downtown, 2015); (Iversen et al., 2013); (Nikolaou, 2013); (Tavallali and Karimi, 2016);(Zhang and Zhang, 2012)	(Schlumberger, 2012); (Schlumberger, 2013a)	Realise
7	Existing Conditions Modeling		x	x		x	x	x	(Ward et al., 2014)*	-	Gather, Generate
a	As-Built Model *A process in which an as-built model of an existing facility or a new built fabrication model is created through laser scanning technology (Aveva, 2015, p.16-19).*		x	x		x	x	x	-	(Aveva, 2015a); (Aveva, 2015, p.10-12); (Aveva, 2015, p.13-15); (Aveva, 2015, p.16-19); (Aveva, 2015, p.26-30); (Aveva, 2015, p.3-5); (Bentley, 2012, p. 109); (Bentley, 2014, p.98); (Intergraph, 2014a)	Gather, Generate
8	Programming		x						(Ward et al., 2014)*	-	Generate
9	Phase Planning (4D Modeling)/ Scheduling		x	x		x	x	x	(Kim et. al., 2013); (Ward et al., 2014)*; (Zhou et al., 2015a)	(Aveva, 2015,p.31-33); (Bentley, 2013,p.62); (Bentley, 2015,p.13); (Synchro, 2014); (Synchro, 2015)	Communicate
10	Cost Estimation		x	x	x	x	x		-	(Aspentech, 2015); (Asptentech, 2016)	Gather; Generate; Analyse
a	Quantity Extraction *It is a process in which a 3D model is used to extract quantity for cost estimation (Aveva, 2015, p.13-15).*		x	x	x	x	x		(Ward et al., 2014)*	(Aveva, 2015,p.13-15); (Aveva, 2015,p.26-30); (Aveva, 2015,p.34-37); (Bentley, 2012, p. 125); (Bentley, 2013,p.143); (Bentley, 2013,p.146); (Bentley, 2013,p.20); (Bentley,2015,p.103); (Bentley, 2015,p.122); (Bentley, 2015,p.192); (Intergraph, 2013); (Intergraph, 2014a); (Intergraph, 2015); (Intergraph, 2015a); (Intergraph, 2016a); (Tekla, 2016); (Tekla, 2016a)	Gather
b	Cost Analysis (5D)/Cost and Schedule Forecast		x	x	x	x	x		(Wang et al., 2014a)	-	Analyse
11	Design Authoring		x	x	x	x			(Ward et al., 2014)*; (Xie and Ma, 2015)	(Autodesk, 2012); (Autodesk, 2012a); (Aveva, 2015, p.48-51); (Bentley, 2012, p.105); (Bentley, 2012, p.109); (Bentley, 2012, p.27); (Bentley, 2013,p.143);	Generate

										(Bentley, 2013, p.143); (Bentley, 2013,p.146); (Bentley, 2014,p.110); (Bentley, 2014, p.115);(Bentley, 2015, p.103); (Bentley, 2015, p.122); (Bentley, 2015, p.122a); (Bentley, 2015, p.135); (Bentley, 2015, p.201); (Intergraph, 2013); (Intergraph, 2013a); (Intergraph, 2014); (Intergraph, 2014a); (Intergraph, 2015a); (Intergraph, 2016); (Tekla, 2016); (Tekla, 2016a); (Tekla, 2016c)	
12	Design Reviews		x	x					(Carvalho et al., 2012); (Kim et al., 2014); (Muley et al., 2014); (Ward et al., 2014)*	(Aveva, 2015a); (Aveva, 2015,p.20-22); (Aveva, 2015,p.26-30); (Aveva, 2012,p.27); (Bentley, 2013, p. 20); (Bentley, 2014,p.110); (Bentley, 2014,p.115); (Bentley, 2015,p.103); (Bentley, 2015,p.122); (Bentley, 2015,p.124); (Bentley, 2015,p.124a); (Bentley, 2015,p.135); (Bentley, 2015,p.201); (Intergraph, 2013); (Intergraph, 2015a); (Intergraph, 2016a); (Tekla, 2016a)	Communicate
13	Modeling , Instrumentation and Diagram *It includes mechanical, structural, piping, equipment, electrical, civil engineering and any other engineering modeling necessary for a facility. Concurrent design of different disciplines may exist under a collaboration platform (Intergraph, 2016; Aveva, 2016). It also includes the process of facilitating the instrumentation and diagram from various disciplines to support operational tasks such as generating new as-built data, offer interface for calibration and SAP (one of the ERP providers) for maintenance scheduling (Intergraph, 2016).All tools discussed are necessary to support the changes made to ensure the information are always up-to-date.*		x	x	x	x	x		(Li et al., 2013); (Savazzi et al., 2013); (Ward et al., 2014)*; (Zhou et al., 2015); (Norton et al., 2013); (Ma, 2014)*	(Autodesk, 2012); (Autodesk, 2012a); (Autodesk, 2013); (Autodesk, 2013a) (Aveva, 2015a); (Aveva, 2015c); (Aveva, 2015,p.10-12); (Aveva, 2015,p.13-15); (Aveva, 2015,p.20-22); (Aveva, 2015,p.26-30); (Aveva, 2015,p.31-33); (Aveva, 2015,p.34-37); (Aveva, 2015,p.3-5); (Aveva, 2015,p.46-47); (Aveva, 2015,p.48-51);(Bentley, 2012,p.105); (Bentley, 2012,p.125); (Bentley, 2012,p.27); (Bentley, 2013,p.143); (Bentley, 2013,p.146); (Bentley, 2013,p.26); (Bentley, 2014,p.110); (Bentley, 2014,p.115); (Bentley, 2015,p.101); (Bentley, 2015,p.103); (Bentley, 2015,p.104); (Bentley, 2015,p.105);(Bentley 2015,p.105a); (Bentley, 2015,p.122); (Bentley, 2015,p.122a); (Bentley, 2015,p.123); (Bentley, 2015,p.124); (Bentley, 2015,p.124a); (Bentley, 2015,p.135); (Bentley, 2015,p.192);(Intergraph, 2013); (Intergraph, 2013a); (Intergraph, 2014a); (Intergraph, 2015a); (Intergraph, 2016); (Intergraph, 2016b); (Tekla, 2016c)	Generate
14	**Design Analysis/Engineering Analysis**			x					-	-	Analyse
a	Structural Analysis			x					(Ward et al., 2014)*	(Bentley, 2012,p.105); (Bentley, 2014,p.110); (Bentley, 2014,p.95); (Bentley, 2015,p.101); (Bentley, 2015,p.102); (Bentley, 2015,p.103); (Tekla, 2016)	Analyse
b	Offshore Structural Analysis *A process in which a structure is simulated with offshore system response such as hydrostatic, hydrodynamic, mooring, and structural behaviour, for an example, blast and explosion analysis to assess the offshore structural integrity (Bentley, 2016).*								(Munoz-Garcia, 2013); (Paris and Cahay, 2015); (Ma, 2014)*	(Bentley, 2014,p.98); ; (Bentley, 2015,p.99); (Bentley, 2015,p.99a); (Bentley, 2015,p.101a); (Bentley, 2015,p.102); (Bentley, 2015,p.105); (Bentley, 2015,p.105a); (Bentley, 2015,p.106); (Bentley, 2015,p.106a); (Bentley, 2015,p.107);	
c	Spatial, Raceway and Cable System Analysis *A 3D model can simulate with raceway and cable system analysis software to identify the best path through raceways using different segregation criteria and routing methods for plant design (Bentley 2015, p.103).*			x					-	(Aveva, 2015,p.31-33); (Aveva, 2015,p.34-37);(Bentley, 2015,p.103)	Analyse
d	Process Analysis *A 3D model can also be simulated with process analysis software to address engineering challenges such as the*			X					(Pathak et al., 2013); (Walnum et al., 2013); (Kvesic et al. 2012)	(Aveva, 2015,p.34-37); (Intergraph, 2014); (Intergraph, 2015a); (Aspentech, 2015a)	Analyse

	multiphase flow modeling, gas processing, refining and LNG process (Aveva 2015, p.34-37).										
e	Material and/or Pipe Stress Analysis *A process in which material is analysed with simulation software. One of the examples is that the piping analysis was deployed to analyse the flexibility and stress of pipe. The model created could clearly indicate areas of concern via color-coded stress models and animated displacements for any stress load case (Intergraph 2015a; Intergraph 2016; Intergraph 2016a).*			x					(Hu et al., 2015); (Munoz-Garcia, 2013)	(Aveva, 2015, p. 31-33); (Bentley, 2014,p.110); (Bentley, 2015, p.101); (Bentley, 2015, p. 103); (Bentley, 2015,p.105a); (Bentley, 2015,p.122a); (Bentley, 2015,p.123); (Bentley, 2015,p.124); (Bentley, 2015,p.135);(Intergraph, 2013); (Intergraph, 2014); (Intergraph, 2014a); (Intergraph, 2015a)	Analyse
f	Acoustic Analysis			x					-	(Bentley, 2015,p.123)	Analyse
g	Civil Engineering Analysis			x					(Ward et. al., 2014)*	-	
h	Geospatial Analysis *The analysis is used to design and installation of the pipeline, field gathering stations, gas distribution manifolds, flow and trunklines, and water and gas re-injection facilities in El Merk (Intergraph, 2016b).*		x	x			x		-	(Intergraph, 2016b)	Analyse
i	Economic Evaluation *A process in which an economic model is embedded into process modeling to assess the viability of the capital, production, operation costs and any other associated costs arising from the planning until the demolition of the oil and gas facilities (Berk, 2011)s.*		x	x	x	x	x		-	(Aspentech, 2015); (Asptentech, 2016)	Analyse
15	Code Validation/ Building Code Analysis/ Model Checking Program/ Compliance Checking/ Design Validation			x					-	**Almost most of the common design software has code compliance checking feature.*	Analyse
16	Design Documents		x	x	x	x			(Ward et al., 2014)*	(Aveva, 2015a); (Aveva, 2015c); (Aveva, 2015,p.10-12); (Aveva, 2015, p. 13-15); (Aveva, 2015, p. 34-37); (Aveva, 2015, p. 46-47); (Aveva, 2015, p. 48-51);(Bentley, 2012, p.125); (Bentley, 2012,p.27); (Bentley, 2013,p.143); (Bentley, 2013,p.146); (Bentley, 2014,p.140); (Bentley, 2015,p.101); (Bentley, 2015,p.102); (Bentley, 2015,p.103); (Bentley, 2015,p.104); (Bentley, 2015,p.105); (Bentley, 2015,p.122); (Bentley, 2015,p.122a); (Bentley, 2015,p.124); (Bentley, 2015,p.124a); (Bentley, 2015,p.135); (Bentley, 2015,p.192); (Intergraph, 2013); (Intergraph, 2013a); (Intergraph, 2014a); (Intergraph, 2015a); (Intergraph, 2016); (Tekla, 2016); (Tekla, 2016a)	Communicate
17	Design Coordination / 3D Coordination/ Interference Management/Clash Avoidance and Detection			x	x	x			(Ward et al., 2014)*	(Aveva, 2015a); (Aveva, 2015c); (Aveva, 2015,p.10-12); (Aveva, 2015,p.13-15); (Aveva, 2015,p.26-30); (Aveva, 2015,p.31-33); (Aveva, 2015,p.34-37); (Aveva, 2015,p.46-47); (Aveva, 2015,p.48-51); (Bentley, 2012,p.27); (Bentley, 2013,p.143); (Bentley, 2014,p.110); (Bentley, 2014,p.115); (Bentley, 2015,p.101); (Bentley, 2015,p.103); (Bentley, 2015,p.105); (Bentley, 2015,p.105a); (Bentley, 2015,p.122); (Bentley, 2015,p.122a); (Bentley,	Analyse

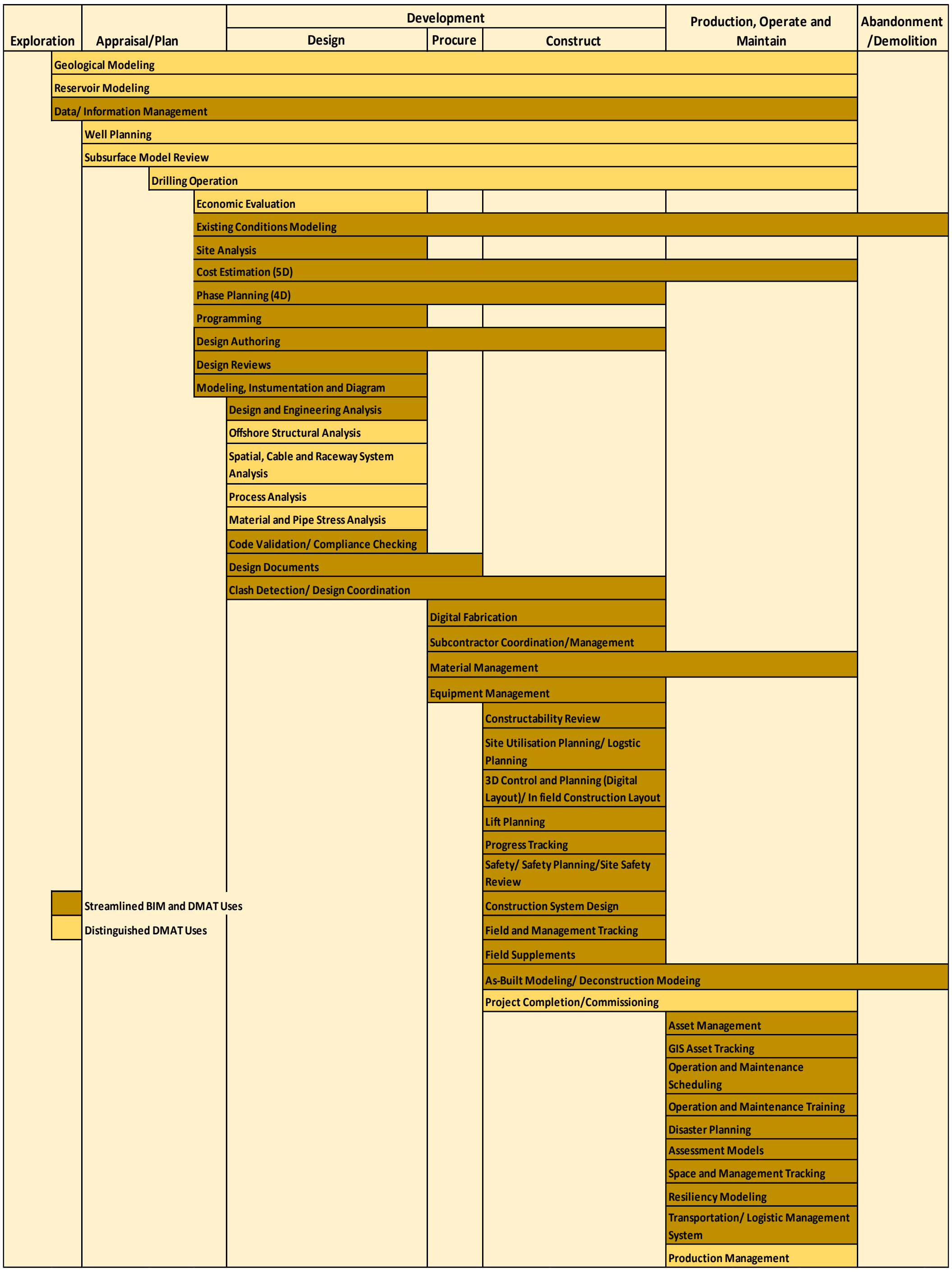
										2015,p.123); (Bentley, 2015,p.124); (Bentley, 2015,p.124a); (Bentley, 2015,p.135); (Intergraph, 2013); (Intergraph, 2014); (Intergraph, 2014a); (Intergraph, 2015a); (Intergraph, 2016a);(Synchro, 2015); (Tekla, 2016); (Tekla, 2016c)	
18	Digital Fabrication				x	x			(Bedair, 2014); (Kul'ga and Men'shikov, 2015); (Ward et al., 2014)*	(Aveva, 2015a); (Aveva, 2015,p.10-12); (Aveva, 2015,p.20-22); (Aveva, 2015,p.26-30); (Aveva, 2015,p.34-37);(Intergraph, 2014a); (Tekla, 2016c)	Realise
19	Supplier and Subcontractor Management				x	x			-	(Aveva, 2015,p.26-30); (Aveva, 2015,p.34-37); (Aveva, 2015,p.48-51); (Intergraph, 2013); (Intergraph, 2015)	Gather; Generate
20	Material management				x	x	x		(Chi et al., 2015); (Trujens et al., 2014); (Xu et al., 2012)	(Aveva, 2015,p.23-25); (Aveva, 2015,p.26-30); (Aveva, 2015,p.34-37); (Aveva, 2015,p.48-51); (Aveva, 2015,p.40-41); (Bentley, 2013,p.62); (Intergraph, 2013); (Intergraph, 2015)	Gather; Generate
21	Equipment management				x	x			-	(Bentley, 2015,p.13)	Gather; Generate
22	Constructability Review *The real-time data integration on project development allows clients and other team members review construction progress from time to time (Bentley, 2015, p.13) to curb the schedule overrun.*					x			(Carvalho et al., 2012); (Muley et al., 2014); Wang et al., 2014a)	(Bentley, 2015,p.13); (Synchro, 2015)	Communicate
23	Progress Tracking					x			(Wang et al., 2014b)	(Bentley, 2015,p.13)	Gather
24	Safety/ Safety Planning/Site Safety Review					x	x	x	(Albert et al., 2014); (Carvalho et al., 2012); (Chen et al., 2015); (Muley et al., 2014); (Norton, 2013); (Ward et. al., 2014)*	(Bentley, 2015,p.13)	Communicate
25	Deconstruction Model *A deconstruction model is developed to assist in the analysis of the future deconstruction and reinstatement work. The model provides a central location for quantitative technical, environmental and cost data (Ward et al., 2014).*						x	x	(Ward et al., 2014)*	-	Generate
26	Project Completion/ Certification Tracking System/ Commissioning *It is a process in which structured database management system is used to track the engineering data from all disciplines. It provides a portal to import, sort, analyses and quality control the data before the engineering data is accepted and move into the database. It also reports the completion and certification of design changes (WinPCS, 2014).*					x	x		-	(WinPCS, 2014); (WinPCS, 2014a); (WinPCS, 2014b)	Realise
27	Asset Management *It involves asset management for onshore and offshore production, and downstream facility. It includes the scope for enterprise asset management (Aveva, 2015,p.40-41),*						x		(Perrons and Richard, 2014); (Savazzi et al., 2013)	(Autodesk, 2012); (Autodesk, 2012a); (Autodesk, 2012a); (Aveva, 2015b); (Aveva, 2015,p.23-25); (Aveva, 2015,p.40-41); (Aveva, 2015, p.42-45); (Aveva, 2015,p.48-51); (Bentley, 2015,p.123a); (Bentley, 2015,p.135); (Intergraph, 2013a); (Schlumberger, 2015)	Gather; Generate; Communicate

	asset tracking (Autodesk, 2012, outage analysis (Autodesk, 2012a) and etc.										
a	Asset Visualisation *A process in which asset visualisation software is deployed to allow team members to assess to detail and up-to-date asset information for planning and controlling of the facility (Aveva, 2015b).*						x		-	(Aveva, 2015b); (Aveva, 2015,p.26-30); (Aveva, 2015,p.31-33); (Aveva, 2015,p.34-37); (Aveva, 2015,p.38-39); (Aveva, 2015,p.3-5); (Aveva, 2015,p.42-45); (Aveva, 2015,p.48-51); (Aveva, 2015,p.6-9);(Bentley, 2015, p.123a)	Communicate
28	GIS Asset Tracking						x		-	(Autodesk, 2012); (Autodesk, 2012a)	Gather
29	Operation and Maintenance Scheduling						x		-	(Aveva, 2015,p.23-25); (Aveva, 2015,p.40-41)	Communicate
30	Disaster Planning						x		(Huang et al., 2016)	-	Generate, Analyse, Communicate
31	Operation or Maintenance Training						x		(Colombo et al., 2014)	-	Realise
32	Production Management						x		(Allan et al., 2014); (Tavallali and Karimi, 2016); (Veyber et al., 2012); (Zhang and Zhang, 2012)	(Landmark, 2012); (Petex, 2014)	Generate, Analyse, Communicate; Realise

5. Analysis and Discussion

By streamlining the table 5 and 6, there is a total of thirty-six (36) BIM and DMAT application (as shown in figure 4) which could be applied in the oil and gas industry.

Figure 4: Streamlined BIM and DMAT Uses for the Oil and Gas Industry



5.1 Exploration/Appraisal/Plan

Distinguished DMAT application shown in Figure 4 indicates that the practices which are commonly applied in the oil and gas industry but are rarely adopted in the built environment such as for the building and infrastructure projects. These include geological modeling, reservoir modeling, well planning, subsurface model review, drilling operation in the exploration and appraisal phases. These DMAT applications are distinguished from the BIM uses as it is not adequate to be adopted by the building and infrastructure projects due to the natural work process. These DMAT practices are mainly used in (1) exploration and production, and (2) process and production facility. Besides, sustainability evaluation is important to most of the building construction as it is the significant process informing the life-cycle cost of a building (Gourlis and Kovacic, 2016). However, for the oil and gas industry, evaluating the life cycle cost such as the capital, operation and production costs of the projects is the ultimate aim. Accurate economic models embedded in the process modeling is essential in assessing the viability of the oil and gas facilities such as for the LNG projects (Beck, 2011).

BIM and DMAT application in the oil and gas industry for data and information management become prominent. Some evidence of this application include hybrid cloud computing system (Bentley, 2012, p.27, p. 105) was deployed to accelerate communication across the project teams; for energy refinery in Alberta, Canada, an innovated information plant management system was established to gather, store and connect the facility's technical data, engineering resource planning information, and documents in a single, reliable system supporting the day-to-day operations and maintenance decisions; and the system encompasses electronic documentation management system, lifecycle server, SAP asset management system and plant design tools (Bentley, 2013, p. 26). Also, a master tag registry and engineering data warehouse were developed in Queensland Curtis LNG project to supply the commissioning team with critical information related to various systems, tags, and documents (Bentley, 2014, p.11 and p.73).

During the feasibility stage, existing conditions modeling and site analysis are required to model the existing site and the facilities in the surrounding for project master planning. However, these uses are not apparent in the oil and gas industry. Only a case study demonstrated the development of 3D model using BIM tool to produce photomontages for inclusion in the environmental impact statement (Ward et. al., 2014). The majority of the existing conditions modeling are used for modeling the as-built oil and gas facilities. The adoption of the laser scanning for develop existing 3D models are gaining important in the oil and gas projects (Aveva, 2015a; Aveva, 2015, p.10-12; Aveva, 2015, p.13-15; Aveva, 2015, p.16-19; Aveva, 2015, p.26-30; Aveva, 2015, p.3-5; Bentley, 2012, p. 109; Bentley, 2014, p.98; Intergraph, 2014a) as there are getting more facilities required alterations and refurbishments. The laser scan data is easily imported into the design software and could be viewed effortlessly by the designers (Aveva, 2015, p.13-15). For process facility located in Bakersfield, California, laser scanning was utilised as verification tools at fabrication and construction process. Laser scan data in fabrication shop was imported to check against any deviations of the design model by informing decisions to reject or accept non-compliant piping components (Aveva, 2015, p. 16-19). Nevertheless, BIM uses such as cost estimating using model-based estimating software for 5D cost analysis and update the cost when there are changes made to the design (NYCDDC, 2012); and programming to track the design space (Harvard, 2016) which are important in planning a facility are not evident in the oil and gas projects.

5.2 Design

The practices of the oil and gas industry in modeling its facility is distinguished with that of the BIM in the built environment. The main focus of the oil and gas projects is to develop logic models so that the schematic design diagrams for piping and other MEP components are built according to the functional requirements of a facility and without any deviations among the facility elements. The plant life cycle management model used by the oil and gas projects enabled multi-disciplinary teams design simultaneously in a collaboration platform. The oil and gas industry is moving towards design integration. Diagram of engineering design could easily export information to other software and integrate with other engineering design tool (Aveva, 2015a; Aveva, 2015, p.10-12; Aveva, 2015, p. 13-15; Aveva, 2015, p. 26-30).

Apart from that, the use of 4D modeling for planning, scheduling and sequencing the works in the oil and gas industry is also noticeable. A real-time pipe tracking system which utilised the radio-frequency identification (RFID) and 3D digital models in a handheld mobile device was developed to allow more efficient task management (Kim et al., 2013). Also, a 4D model for scheduling activity and operation of mega LNG construction projects was proposed to improve process planning and control (Zhou et al., 2015a). The engineering data such as the 3D model, piping isometrics and structural steel data were exported to a scheduling tool to create field installation work packages from a virtual construction model (Bentley, 2013, p.62). Another two important functions of BIM are the design review and design authoring which are commonly used in the oil and gas industry. Design review tool was deployed to review the plant design so that installation errors could be reduced (Aveva, 2015a). Design authoring is also used heavily in the oil and gas projects as it is the tool which adds richness of information in the oil and gas facility model. One of the examples is that the tool was used to enable the structure and piping design information to be integrated into the model (Bentley, 2012, p. 105).

Some distinguished DMAT uses which are not commonly used in the built environment include offshore structural analysis; spatial, cable and raceway system analysis; and process analysis. Besides, code checking, design documents and clash detection are the important DMAT uses which are usually embedded into the design software as parts of their supplementary functions. It is important to note that BIM is not about the technology, but it improves project management and collaboration among multi-disciplinary teams. To optimise the functions of the BIM and DMAT such as the clash detection, the regular meeting may be necessary to discuss the collaboration process among different design disciplines.

5.3 Procure

Modular construction is very common in the oil and gas projects. Several examples of modularisation strategies for steel designs have been proposed to maximise project savings of the oil and gas projects (Bedair, 2014). It is evident that digital fabrication has become important in the oil and gas industry, particularly in the steel fabrication components. Corrib onshore gas pipeline project deployed digital fabrication software (Ward et. al., 2014) to provide rapid detailing automation, automatic fabrication shop drawings and computer numeric control (CNC) machinery production deliverables. The software allows effective collaboration between engineers, detailers and fabricators.

Also, the information of plant life cycle model could be exported to into the oil and gas enterprise software for resource management such as the subcontractor and/or supplier management, material management and equipment management. In the BIM context, subcontractor coordination means it is a process of coordination among subcontractor for reviewing the design and optimising the scheduling prior to installations (NATSPEC, 2016). However, this process is not observable neither in the DMAT academic publications nor DMAT vendor case studies. This may due to both sources are technology-oriented, therefore, it is hard to find the discussion on the technology management practices in the oil and gas projects.

In the research and development, a conceptual framework was proposed to assure modular construction quality through introducing a situation awareness construction environment with well-defined sensing and tracking technologies (Chi et. al., 2015). A study investigated the RFID solutions was also conducted to identify the positions of onsite materials and components (Trujens et al., 2014). In practice, various procurement software were adopted in the oil and gas projects such as VPRM procurement and logistics (Aveva, 2015, p.48-51), oracle primavera (Aveva, 2015, p.24-27) and smartplant materials. With the material and supplier/ subcontractor management tool, bills of materials are extracted from the plant design tool to verify its completeness in the tool; supplier past performance can be assessed, new suppliers can be selected based on the selection criteria and maintain their record in the tool; the tool can also allow material status to be tracked, record, updated and activities from inviting subcontractor to manage the sub-contracting are also the functions of the tool (Intergraph, 2013). An integrated supplier management system was set up to include an eSupplier portal, activities from a request for quotation (RFQ)s to award, all post-agreement workflows, and progress control for each subcontract. This allows teams to collaborate more effectively across the engineering, procurement, and construction disciplines (Intergraph

2015). The integrated supplier and subcontractor management were used in Thailand where the procurement office in Bangkok would have to handle suppliers in the Sattahip onshore base to support Bualuang wellhead project (Aveva 2015, p.40-41). 4D modeling and mobile tools were deployed to manage and schedule the equipment for the construction of a new facility to connect to the existing oil and gas facility (Bentley, 2015, p.13).

5.4 Construct

Constructability review is important to the design and construction of the oil and gas projects. 4D modeling was used by Abreu e Lima refinery (Synchro, 2015) to analyse the execution and concreting sequence of the ramp and the substation implementation. Wang et al. (2014a) proposed the use of AR and BIM to enable walk-through functionality for facilitating design and constructability review process on the site. Apart from constructability review, the integration of these tools allows on-site progress monitoring to detect real problems, such as low productivity and the tendency of committing an error in assembly. Nevertheless, other BIM uses are not apparent in the oil and gas projects. The BIM use in planning and controlling the construction layout, logistic planning, lift planning and construction system design are not observable in the study. Construction system design is particular significant to the oil and gas projects given the complexity of the design and construction of the facilities. With the adoption of the construction system design, complex facility system such as modular components, formwork and scaffolding can be modeled to improve productivity and safety (NATSPEC, 2016).

Safety element is one of the main concerns of the oil and gas industry. 4D modeling was deployed to sequence the work packages in the NAG Project at the ExxonMobil facility in Texas enabling planning for access and egress routes that contributed to maintaining safety and reducing risk (Bentley, 2015, p.13). The 3D model was also deployed innovatively to review the operational and safety aspects of the surrounding during the design phase (Ward et. al., 2014) and the model could be coupled with various tools such as AR (Albert et.al., 2014; Chen et al., 2015), and hybrid-desk in a semi-immersive environment (Carvalho et al., 2012).

For the completion and commissioning management system (CCMS), the common practices for the built environment sector is the Construction Operations Building Information Exchange (COBie), which is a non-proprietary platform for the exchange of life cycle data needed by facility managers (Kensek, 2015) and it was developed by a number of US public agencies to improve the handover process to building owner-operators (Buxton, 2015). For the oil and gas projects, the industry has their own commissioning system which differs from the building. The facilities and data format involve in the oil and gas projects are large and complex, hence, a real-time tracking system for project commissioning is more appropriate to ensure fast and accurate delivery. The tools carry similar functions of the BIM use such as the field and management tracking and prepare for project completion and commissioning. The examples of common CCMS system used in the oil and gas projects include WinPCS, ContinuumEdge (CE) and qedi.

5.5 Production, maintain and operate

Pertaining to the asset management, the oil and gas projects have a more complex facility management system. Enterprise asset management was deployed by the oil and gas exploration and production firm for (1) procurement and materials management; and (2) maintenance planning (Aveva, 2015, p.40-41). It also referred to Computerised Maintenance Management (CMM) system which was used to order materials from anywhere and track the delivery status enabled the operators to take informed actions to reduce the impact on operations. The system could also integrate with another system to ensure the reliable information provided for shutdown maintenance planning or any unplanned downtime. GIS asset tracking was deployed to enable safer and better gas pipeline management in Romania. An integrated 3D map, map server system, pipeline management system and sensors tracking system were established to manage the asset updates (Autodesk, 2012). Another similar system was used to analyse the outage which enabled better customer service (Autodesk, 2012a).

For operation and maintenance training, it is observed that the immersive virtual reality (IVR) which deployed the 3D plant model was proposed to enable the control-room operator (CROP) and field operator (FOP) to be trained simultaneously. Besides, the IVR enables the performance to be assessed by eliminating the subjectivity and the trainees were trained under an experimental approach instead of classical approach (Colombo et al., 2014). For disaster planning, a 3D visualisation model was integrated with other advanced technologies to monitor and forecast the disaster. By integrating sensor technologies, spatial information technologies, 3D visualisation technologies, and a landslide-forecasting model, it was used to monitor and forecast landslides in the Danjiangkou Reservoir area (Huang et. al., 2016). In the context of BIM, disaster planning is in connection with the BIM use with building management system for emergency response planning (NATSPEC, 2016) which is not apparent in the oil and gas projects. Other BIM uses such as assessment models, space and management tracking, resiliency modeling and logistics management system are not apparent in the oil and gas projects.

Production management is a distinguished DMAT use which is not commonly applied in the built environment. An integrated system which consisted of an up-to-date 3D geological model, production management software such as ERP system (Veyber et al., 2012), grid-based production management system (Zhang and Zhang, 2012) was proposed for the upstream oil and gas production management. Information extracted from well data was used to establish cost estimate of drilling and production via Cost Estimate Request (CER) database. The combination of Well Planner and FracScheduler was also proposed to streamline the production scheduling and value stream discipline so as to determine which well is ready for rig work (Allan et al 2014).

5.6 Demolition

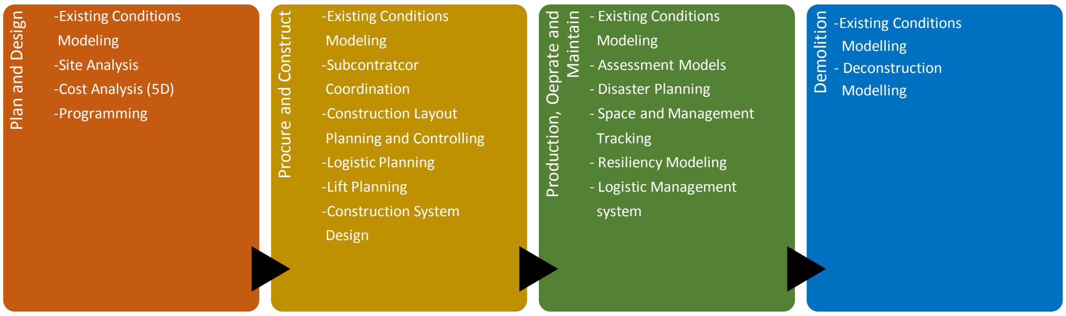
When the oil and gas field is near the end of its life cycle, it shall prepare for restoring the site to its original condition. The process and production plants would also have to be dismantled. Both the BIM and DMAT uses are not apparent at this stage. The existing conditions modeling and/or deconstruction modeling (Ward et al., 2014) could be used to present the existing as-built model and site conditions to plan for the demolition works. Other DMAT and BIM uses which were used for planning, designing and construction works could be possibly used in this stage to streamline the demolition process.

5.7 Summary

In the planning and design stage, while design reviews, 3D plant modeling, phase planning (4D), design coordination, design documents and code checking become prominent in the oil and gas projects, other BIM uses such as existing conditions modelling, site analysis, cost analysis (5D) and programming for assessing design space can also be deployed to provide more reliable information for the owners, designers and contractors (if they are involved during the early design stage) to make an informed decision on the oil and gas project development. Existing conditions modeling should not only use to model the as-built oil and gas facilities but it should extend to model the surrounding site conditions during the project planning stage and fabricated items before delivering them to a site. During the procure stage, digital fabrication is an essential element to speed up the oil and gas projects while reducing the deviations among the design, fabrications and installations. Subcontractor and supplier management, material and equipment management are also significant to smoothen the procurement process. However, subcontractor coordination is important too to ensure effective model coordination and resolve constructability issues between the different trades. In the construction stage, apart from constructability reviews, progress tracking, safety planning and field and management tracking which are commonly used by the oil and gas projects to improve project performance, other BIM uses such as planning and controlling the construction layout through creation of digital layout; logistic planning which involved detailed logistic objects that linked to construction schedule (4D model); lift planning model that allows the structure engineers and experienced site personnel to communicate the lift plan execution; and construction system design for modeling the complex construction could be implemented to improve the overall productivity of the construction process. In the production, operation and maintenance phase, it is noticed that asset management, GIS asset tracking, operation and maintenance training and production management are usually implemented in the oil and gas projects. Other uses such as assessment models for efficient field data collection; disaster planning for emergency response;

space and management tracking to evaluate, manage and track the existing use space and associated resources within an oil and gas facility; resiliency modelling for the remote areas subject to environmental change; and logistics management system to support entire transportation lifecycle from creating the least cost shipment plans to monitoring the whole distribution network proactively can also be adopted to improve overall operation efficiency. As in the final stage of a project life cycle, existing conditions modeling and de-construction model can be used to plan for the demolition works. Figure 5 shows the potential BIM and DMAT uses for performance improvement in the oil and gas projects.

Figure 5: Potential BIM and DMAT Uses for the Oil and Gas Projects



6. Conclusion and Recommendations

The conducted literature review of twenty-eight (28) BIM guidelines, eighty-three (83) DMAT academic publications and one hundred and one (101) DMAT vendor case studies have streamlined thirty-six (36) BIM and DMAT uses for oil and gas projects. The findings reveal that they are many potential applications of DMAT and BIM uses (figure 5) can be applied in the oil and gas projects for performance improvement. Data and information management system which are commonly implemented in the oil and gas projects could be deployed in the built environment sector to improve the collaboration among multi-disciplinary teams from planning until operation and maintenance phase.

Few limitations need to be considered in this research. This study does not take into account the effective measures of the BIM and DMAT uses. The highlighted technology practices are only applicable to the technologies, which have a similar taxonomy of (1) DMAT such as the geometry bedding used for oil and gas exploration and production and also PLM system used for design, construction and operation, and (2) BIM. The scope of this study is not extended to the common enterprise computational tools such as the enterprise resource planning (ERP) which is commonly used in the oil and gas firms. Also, the study may overlook some BIM and DMAT uses as per the BIM guidelines, DMAT academic publications and vendor case studies. Future studies may investigate the efficiency use of the BIM and DMAT technologies for the oil and gas project improvement; examine the potential DMAT applications in the built environment sector; and study the technical possibility of linking the PLM, BIM and ERP system for performance improvement in both the oil and gas and built environment sectors.

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Compliance with Ethical Standards

Human Participants Nor Animals

The research does not involve neither human participants nor animals

Informed Consent

All the authors are informed and provided their consent.

Conflict of Interest

The authors declare that they have no conflict of interest.

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