Promoting Early Collaboration, Communication and Leveraging the Use of BIM between Project Stakeholders for the Generation of Effective Knowledge in Information Protocols

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Knowledge is a major asset for every organisation in the construction industry because it forms the basis of effective decision-making, thereby providing them with a competitive advantage. Knowledge management (KM) in construction projects is important in facilitating improvements in decision-making, creating value and increasing productivity. The concept of BIM can facilitate KM by enabling project parties (appointing and appointed) to share information and access knowledge in a coordinated manner. It can also enhance communication and collaboration among project members by capturing, storing, representing, and sharing/transferring knowledge represented building models, as well as auditing it for retrieval data. Although BIM ensures knowledge represented building models in part of a fast-tracking system, collaboration and effective communication between project members is a critical strategy that can improve KM and delivers competitive advantages for information management (IM) in construction projects. The main aim of this research paper is to explore how collaboration and communication through the adoption of BIM contributes to KM in construction projects. The research strategy adopted is that of an integrative literature review. Drawing on relevant literature on the significance of BIM and early collaboration and communication between key project members in ensuring effective knowledge generation in information protocols, the paper presents insights into the status of current KM problems in construction projects and leveraging the use of BIM in knowledge represented building models management. The findings reveal that the capability of KM is enhanced by early collaboration, communication, and leveraging the use of BIM at the early project phases as this provides an interactive information flow in the knowledge generation management (i.e. research outcome) that is transparently accessible and workable in a collaborative environment for multi-disciplinary project members. The proposed knowledge generating workflow, which is the main contribution of the paper, consists of six steps and is based on the adoption of a BIM-enabled KM life-cycle approach. This paper concludes that this workflow can benefit all project stakeholders from the appointing, lead appointed, and appointed parties by introducing collaborative KM process throughout the project lifecycle under a BIM environment.

Keywords **-** Early Collaboration and Communication, Building Information Models/Building Information Modelling/Management (BIM), Knowledge Management, Knowledge Generating Model, Collaborative Knowledge Management.

I INTRODUCTION

The construction industry is both knowledge-intensive and knowledge-generating; however, challenges exist in terms of capturing and sharing knowledge of best practices and lessons learnt within and across projects [1]. This is primarily due to the multi-disciplinary, multi-organisational, and temporary nature of construction projects which cause valuable knowledge to remain with individuals and/or become lost with time [2]. Specifically, project teams are regrettably disbanded after each project without adequately capturing and storing important data of the project for future use. As a result, the fragmentary and transient nature of construction projects makes it difficult for information to be communicated among project members [3].

The nature of construction projects, including uncertainties, risks, interdependencies, and substantial complexity results in project delays and fragmentations in project activities [4]. Reviews on the problems associated with the information management (IM) of construction projects reveal that the principal sources of confusion and disagreements between project teams are communication breakdown and information bottlenecks between the client and the contractor, misunderstandings between engineers and architects due to the lack of collaboration and poor communication, as well as a lack of consistency in the information flow of the project as it progresses [5].

To improve these challenges, BIM acts as an innovative and centralised database that contains intelligent input information related to building models that are interconnected with information modelling through visualisation, simulation, and interactions in data/information management [2]. BIM enables project teams to easily access their required knowledge and information [6], thus reducing information asymmetry between project members, as well as reducing project uncertainty and risk.

Furthermore, BIM is a process for creating and managing information on a construction project across the project lifecycle [6] and the key output of this process is the Building Information Models (BIMs). These BIMs should be managed coordinatively at the early phase of the construction project where early collaboration, communication and the potential of building information models (BIM) management at the early project phases between project stakeholders are essential to generate effective knowledge in information protocols (i.e. the building information/ information models) via smooth information flows and data coordination [7]. Hence, in this article, it is focused on BIM at the early which can support the processes of designing, constructing and operating a building with the use of knowledge generating workflow that is detailed discussed in the research outcome and providing electronic object-orientated information, i.e. BIMs (including knowledge represented in the project/asset information models that are critically important to manage for smooth flows in information and data exchange throughout the project handover and facility operation management) of the project lifecycle [8]. Thus, in this research paper, the significance of BIMs management at the early project phases, early collaboration and communication between key project members are important to consider in order to develop via a new knowledge generation workflow ensuring enhanced KM processes in BIM based on exploratory research study.

On the other hand, Information is achieved from data in a specific context, and interpretation, abstraction or association of data leads to the generation of information. As a result, knowledge is obtained by experiencing and learning from this information and putting it into action [8]. Hence, knowledge is not directly available but is obtained by interpretation of information deduced from the analysis of data. Therefore, in this research study, it is also focused on the BIMs management based on the context of design process of construction projects as knowledge is an understanding of some pieces of information given by design consultants for the design contents [9]. Moreover, knowledge is valuable intellectual asset generally possessed by humans, which is the key understanding of how to use data and information and why to use them in a particular way [10]. In this article, it is concentrated on the designers' knowledge that is based on designers' experiences, design concepts, design's beliefs and as a result, these information from designers' knowledge are defined and codified as data in which ways of working that can be captured, stored, shared and communicated for the design information requirements using BIM technologies [8]. Based on the information requirements upon the client's requests, and defining this knowledge for information requirements in BIM, it is important to inscribe knowledge as data in this paper and represented as building information/models with the support of BIM tools [9]. Thus, KM in BIM includes generating, collecting, storing, exchanging, representing, and retrieving important data for the generation of information.

In comparison with the application of BIM at the information level, BIM at the knowledge level extends the sphere of its application [10]. Although BIM-supported KM is promising and has attracted increasing research attention in recent years, it is at an early stage in terms of both research and practice [8,9,10]; hence, further exploration is required. Therefore, the main aim of this paper is to explore how early collaboration and communication through BIM adoption early can contribute to the KM lifecycle in construction projects.

II KNOWLEDGE MANAGEMENT LIFECYCLE

Different actors among key project stakeholders did not focus on clearly defined organisational goals contributing to the construction project requirements and use different tools and managing systems. This type of complexity in generating data requires early collaboration on the part of all key actors (appointing and appointed parties) in order to form a mutual consensus that helps key decision-makers to perform their activities [11]. Typically, through early collaboration and communication among key stakeholders, different heterogeneous viewpoints converge into mutual objectives that involve establishing the same organisational goals so as to generate effective knowledge throughout asset management and project delivery [12].

Another problematic issue within the construction project is that an effective and practical system for capturing, storing, compiling, representing and retrieving important data may be absent, which does not achieve collaborative working practices among key project actors [7]. To solve this problem, KM can help improve communication and collaboration among project members in relation to the capturing, storing, representation and sharing/transfer of data, as well as the auditing of such data for reused information [13]. As a result, KM is seen as a fundamental process for organisations because it constitutes a systematic process of generating, gathering, capturing, sharing and analysing knowledge in terms of resources, documents, and people skills within and across an organisation [8, 13]. Therefore, KM has been defined as 'the identification, optimization, and active management of intellectual assets to create value, increase productivity and gain and sustain competitive advantage' [13].

The construction industry is a heavily knowledge-based environment that relies on the input of all participants in a project. This intensive KM process involves different stages of knowledge processing. The fact that KM helps project parties (i.e. appointing and appointed) to access valuable knowledge resources in order to accomplish project tasks could provide opportunities for substantially enhancing project performance. Furthermore, International Business Machines Corporation (IBM) has stated that KM is not about data, but about getting the right amount of information/data to the right people at the right time in order to control the overall bottom line [14, 15]. The KM process consists of six main stages: defining, codification, capturing, sharing/transfer, representation, and reuse of knowledge, which are summarised in Table1 [11, 15]. Based on these processes, the KM Lifecycle has been developed (see Figure 1).

Table 1: Relations between the Six Main Knowledge Management Processes [11, 15]

Generating Knowledge Process Lifecycle Relations					
Knowledge Defining ⟺	Knowledge Codification ⟺	Knowledge Capture ⟺	Knowledge Sharing/ Knowledge Transfer ⟺	Knowledge Representation ⟺	Knowledge Reuse/ Knowledge Maintenance
• Acquiring • Creating • Describing • Discovering • Identifying • Planning • Specifying	• Accessing • Locating • Organising • Setting	• Detaining • Gathering • Keeping • Placing • Recording • Storing • Seizing	• Collaborating • Distributing • Exchanging • Merging • Sharing • Transferring	• Acting • Applying • Presenting	• Archiving • Adjusting • Auditing • Assessing • Integrating • Modifying • Reapplying • Readapting • Removing • Validating

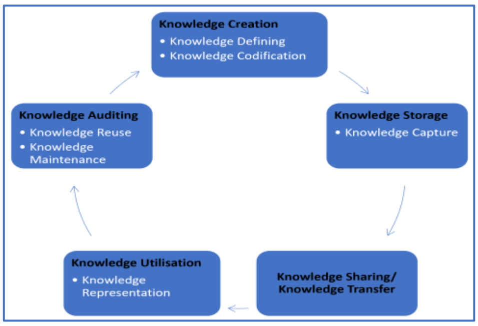

Figure 1: Generating Knowledge Lifecycle [16]

The KM lifecycle can assist in focusing on the generation, collection, capturing, storing, representation, and retrieval of data [15, 16] to support problem-solving, dynamic learning, strategic planning, decision-making, and the smooth flow of communication between project stakeholders [8]. The first stage in the KM life cycle, **Knowledge Creation**, refers to the process of constructing knowledge by defining and codifying it. It involves the formation of new ideas through interactions among project teams, and also includes the process of organising knowledge for storage and capture [17]. Once knowledge is captured, it needs to be stored in the form of a knowledge repository such as documents, reports, and databases, all of which form part of the **Knowledge Storage** process. The next most important stage of the KM life cycle is **Knowledge Sharing/Transfer**. Ensuring that knowledge can be accessed and shared by people allows them to exchange their views and ideas regarding a particular domain [18]. Transferring knowledge is a way of sharing information or ideas from one entity to another; it involves the dissemination of knowledge from point to point which could include a person, project information, data documents, and so on [20]. The fourth stage, **Knowledge Utilisation**, is where knowledge can be used for the representation of building models based on information requirements and information technology [21]. Knowledge represented in project/asset information models to provide decision support for organisational management, asset management, and project delivery. The final stage of the KM life cycle is that of **Knowledge Auditing for Reuse and Knowledge Maintenance** [22], which includes validation, modifying, and networking processes. Knowledge auditing for reuse refers to the amount of knowledge that can be reused for future innovations and new developments [21,22]. Therefore, Project Information Models (PIMs) are stored in a long-term archive so that knowledge can be re-applied in the future [23]. Finally, Knowledge Maintenance is an essential process that encompasses reviewing, correcting, and refining knowledge, as well as ensuring it is kept up-to-date by removing obsolete knowledge from the archive [24].

III RESEARCH METHODOLOGY

The main aim of this paper is to explore how early collaboration and communication through BIM adoption early can contribute to the KM lifecycle in construction projects. Among the numerous research approaches that might be adopted, the most appropriate was considered to be an integrative review of literature [25] on the significance of BIM, early collaboration, and communication between key project members in ensuring effective KM, including generating, collecting, storing, exchanging, representing, and retrieving important data for the generation of effective knowledge in information protocols. An integrative literature review based on the archival research is a research strategy that involves reviewing and synthesising the representative literature on an integrated topic in order to generate a new workflow of the knowledge generation management for information protocols in a particular context of work [26]. The research outcome is delivered as a workflow based on exploratory studies of KM processes and IM based on the BS EN ISO 19650-1:2018 Standard.

Initially, an exploratory research study was conducted of the state of the art in existing literature, standards, and websites in order to gather a sufficient basis for the secondary data derived from the work of other researchers. The exploratory phase was a three-step process: identify, collect and gather the literature; standards; and commentary websites. Focusing the literatures, BS & PAS Standards and UKBIM Framework series upon the UK guides are comprehensively reviewed, not considered upon the guides outside of the UK because the UK Government encouraged the building industry to implement BIM Level 2 in all projects as part of its Digital Built Britain drive which seeks to improve data management process and smooth information flows make the enhanced KM in BIM more efficient [21]. Furthermore, the UK is one of the leading countries in BIM adoption based on the UKBIM framework and BIM standards (ISO 19650 series and BS standard series) acting as a pivotal for IM throughout the lifecycle of construction projects towards BIM Level 3 by 2025.

Firstly, several representative keywords and phrases, namely "the use of building information management in building information models of construction projects" AND "knowledge management problems" OR "the potential of BIM benefits in information management of construction projects" AND "improving knowledge management processes" were searched. Here, the focus was on acquiring and identifying specific current information about the potential of BIM for improving KM practice and the KM lifecycle. Next, valuable standards and accompanying guidance associated with ISO 19650 standard series and UKBIM Framework Guidance were searched; these were sorted separately, as well as being collected from the UKBIM Alliance and BSI Group Standards websites. Secondly, academic papers containing a combination of the above terms focusing on the process for improving KM practice through BIM were looking into the Web of Science and Scopus. Thirdly, after reviewing the papers, relevant papers were added into references, and standards and guidance were selected and gathered in order to build the inclusion criteria for the generation of the new workflow. By using the search databases (Web of Science & Scopus focusing on literatures from 2018 to 2022, the 37 articles, and 3 ISO BIM series and 3 BS/PAS BIM standards are reviewed from among BIM framework and BS Standard Series. In order to ensure the review is on the most relevant and qualified literature, 318 papers are identified from the search databases and based on screening articles, total 159 papers are relevant to include (due to the focusing on the journal articles from 2018 to 2022). Among 159 papers, only 85 papers were collected (articles limited to construction management and English, papers for only "open access", not concerned to the IM in BIM construction projects) and from the collected 85 papers, 48 papers were excluded focusing on the duplications (articles not fully focused on KM processes or KM lifecycle, not associated with "ISO 19650" or "BIM standard" acting as the strict inclusion criteria); hence, total 37 journal articles are critically reviewed.

IV RESEARCH OUTCOME

a) *Knowledge Management Lifecycle In Collaboration With BIM Standard (ISO 19650-1)*

There are different reasons for the disruption of information flows in the project/asset's life cycle in BIM, which include non-consistent terminologies and taxonomies, inadequate specification of requirements, confusion over the information needs in the information protocols [27]. Moreover, the barriers of KM are compounded by the following: a lack of standard work processes, time and money constraints, poor information technology infrastructure, limitations on oral and paper communication modes, complicated information flows among increasingly diversified stakeholders, and a lack of standard workflow to communicate information and knowledge [27]. To overcome the current KM problems in construction projects, the use of BIM is considered. The feature of BIM is to create and operate on a shared digital database for information exchange, as well as to capture and preserve information for reuse and to manage changes effectively [14]. As BIM is used as a knowledge carrier to support KM throughout the project life cycle [28], it enables object-oriented and parameter-driven modelling through 3D visualisation and the collaborative platform of a building information repository [29, 30, 31].

In addition, KM through BIM integrates all exchanged data and information associated with the project plan, design, construction, and operation [32, 33]. Moreover, the importance of KM in BIM enables a core repository to be established that restores project data and helps to project parties in order to collaboratively conduct BIM-enabled project tasks (e.g. reduce information waste, clash detection, site analysis, energy simulation, design optimisation, and cost estimation) [34]. Although BIM has the capability of managing multidisciplinary information [35], collaboration and effective communication between project members acts as a critical strategy that can improve the KM process in BIM [5] and deliver competitive advantages for project information management [13]. The introduction of collaborative KM can ease data coordination processes, provide more efficient information and reduce conflict among project teams [36, 37].

The information flow of ISO 19650 includes specifying details of building information in Table 2, where it also outlines the scope of responsibilities of project parties for IM processes in the project delivery.

Table 2: Scope of Information Management Responsibilities among Project Parties [19, 20, 23]

<table>
<tr><th>Information Requirements/ Models</th><th>ISO 19650 Term related to Project Parties</th><th>Different Project Stakeholders</th><th>Responsibilities</th></tr>
<tr><td rowspan="3">• Organisational information requirements (OIRs): to clarify organisational needs, requirements, and objectives
• Project information requirements (PIRs): to agree on what asset information should be delivered for each project
• Exchange information requirements (EIRs): to agree on how to transfer the information, in what format, what level of information, and establishing a clear agreement among project stakeholders on how and with what characteristics they need to exchange their digital information
• Asset information requirements (AIRs): to clarify the asset's requirements, their management, and operation and maintenance (O&M) procedures
↓
Scope of Work
↓
Contract
↓
• Project Information Model (PIM): the single source of digital information related to a project or projects, developed during the design and construction phase of a project and created for the construction of a new asset or the modification of an existing asset; PIM is an information model developed during the design and construction phase of a project. The requirements for the PIM are set out in EIR.
• Asset Information Model (AIM): the single source of digital information related to an asset or assets, which must be at a level required to support an organisation's asset management system during the O&M, including existing asset information systems, new information, or information on PIMs. AIM is a model that compiles the data and information necessary to support asset management required for the O&M phase of an asset.</td><td>Appointing Party</td><td>Employer, Client, Asset Owner, Operator, End-user</td><td>- Creating the PIRs and Project Standards
- Establishing procedures for creation and delivery of information
- Preparing correct information to the Delivery Team at handover
- Establishing Common Data Environment for the project
- Capturing lesson learnt with the lead appointed party.</td></tr>
<tr><td>Lead Appointed Party (Delivery Team)</td><td>General Contractor (directly assigned by the client, and takes the role of a coordinator)</td><td>- Establishing BIM Execution Plan (BEP)
- Creating Master Information Delivery Plan
- Preparing and assigning resources 'people, process and technology' within the Delivery Team
- Creating contract documents for each appointed party
- Adding its own information requirements for the Delivery Team into EIRs set by the appointed party.</td></tr>
<tr><td>Appointed Party (Task Team)</td><td>Suppliers and Vendors (responsible for creating and providing information according to the appointment by the Lead Appointed Party)</td><td>- Helping the Lead Appointed Party in BEP creation
- Establishing a task information delivery plan across the task team
- Collaborative creation of information according to the information standard and requirements
- Participating in the review of the information model.</td></tr>
</table>

Overall, ISO 19650 provides a common framework that all project parties – from the appointing party to the lead appointed party of the delivery team and appointed parties from the task team (see Figure 2) –

are required to follow in order to minimise rework by reducing information waste through an integrated approach to IM [38].

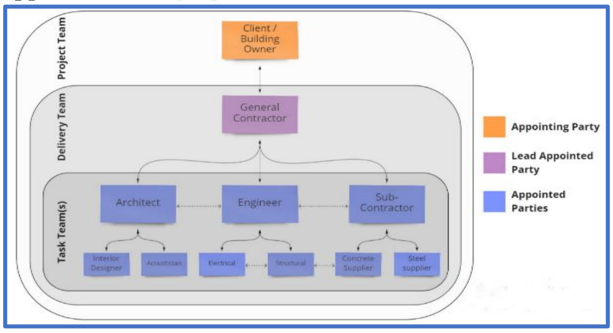

Figure 2: Different Project Stakeholders in the Design and Build procurement route [23]

There are different steps within the IM in BIM, but a gap is identified due to the current disruption of information flows in the project/asset's lifecycle in BIM. Information flowing from project management (PM) to asset management (AM) is often fragmented because temporary project organisations and project teams struggle to establish a common data environment (CDE) for data and information exchange between the appointing and appointed parties [31]. Other issues include imprecise information/data documentation for asset owners, deficiencies in sharing PIRs, an absence of information related to employer's information requirements, and poor software protocols and standards that result in poorly organised project data [39]. To bridge this gap, it leads to suggest that this new knowledge generation workflow can adopt in BIM (based on ISO 19650-1 standard) effectively to achieve a smooth flow in information protocols. All these challenges can be improved through BIM-enabled KM workflow which helps the realisation of data coordination and information quality in project delivery [14]. This is because it can facilitate the ability of project teams to generate, capture and share the data that is vital to the project and integrate these as project/asset information models, and this process is inscribed under the KM lifecycle and can collaborate with BIMs management so that project members can exploit this knowledge generation workflow effectively to add value to information protocols, business practices and decision-making for the overall benefit of the organisation [40]. The following steps should be adopted to build a new workflow for generating effective knowledge in information protocols:

1) Data Generating: Defining Knowledge for key decisions and codification of knowledge in terms of Organisational Information Requirements (OIRs)
2) Data Collecting: Setting knowledge for Project Information Requirements (PIRs) based on OIRs
3) Data Storing: Capturing knowledge for Asset Information Requirements (AIRs)
4) Data Exchange: Sharing knowledge/knowledge transfer for Exchange Information Requirements (EIRs)
5) Data Representation: Representation of Knowledge in AIM for Asset Information Products and PIM for Project Information Standards
6) Data Retrieval: Following knowledge auditing, knowledge reuse for PIM and knowledge of AIM that are maintained in a long-term archive.

1) Data Generating for OIRs: The collaborative production of information (i.e. building information) should start with clear and well-defined information requirements. Firstly, it is essential to define the data that are required to add value to clients and end-users, as well as to understand what data should be included depending on the context of the client's requirements. In this case, early collaboration and communication among key project members in the appointing party is the key driver for defining knowledge in terms of identifying the client requirements and initiating the plan for PIRs [31]. Following this, clear definitions of the project information are required by the appointing party; hence, the construction methods, project processes, project deadlines and methods of information deliverables will govern the project requirements in terms of defining knowledge based on project organisation requirements and the codification of that knowledge in OIRs [19]. Furthermore, such information in OIRs can explain the activities needed to achieve strategic objectives within the major stakeholder team. In OIRs, members from the appointing party state their project objectives for the required information deliverables which will inform or specify the responsibilities of their work [4]. As a result of early collaboration and communication between project members in the appointing party, the quantity and quality of defined knowledge in OIRs will become sufficient and aligned with the client's information requirements.

2) Data Collecting: Through early collaborative discussion between the project members of the appointing party, the subjective and objective goals of projects based on OIRs are identified and collected. For instance, the aim of collecting data for PIRs in the briefing process is to capture explicit knowledge (i.e. information on requirements) that aligns with the client's needs, as well as to transform this into a documented requirement brief to enable the designer to develop quality designs at the early procurement phases before construction work starts [39]. By setting knowledge for PIRs, strategic business operation procedures, a strategic AM process, project portfolio planning, and the policymaking for project progress and development can be implemented [19].

3) Data Storing: AIRs present the managerial, commercial, and technical aspects of producing asset requirements while taking into consideration early collaborative discussion among project stakeholders and knowledge of the managerial and technical aspects of AIRs that are specified [7]. Using BIM, a set of AIRs should be captured and recorded to quantify the detailed AIRs throughout the asset operation, and the knowledge captured can be incorporated into the AM process to support strategic decision-making [42]. In this case, data/information of AIRs should be accessible through the CDE in order to ensure the integrated flow of data between project members. Moreover, capturing knowledge of AIRs enables the important knowledge source for AIMs to be identified [43]. Therefore, for knowledge of AIMs, knowledge retained in a BIM model is linked to building objects while engineers who input knowledge in the model are also recorded. In doing so, it becomes possible to trace the source of knowledge. Thus, if any inaccurate or inappropriate knowledge is identified, it is easy to determine why such knowledge was captured and who was responsible for it [11, 38].

4) Data Exchange: The knowledge of EIRs is based on the collected data of PIRs. This knowledge should be shared in open and simple data formats such as Industry Foundation Classes (IFC) and Construction Operations Building Information Exchange (COBie) to facilitate the exchange of digital information in a structural way between different systems. This will assist project members to make productive decisions to ensure successful project delivery [40]. Likewise, the goal of knowledge sharing for EIRs is the creation of new knowledge through the combination of different forms of existing knowledge in AIRs & PIRs. In this case, motivation, team integration (based on effective communication and collaboration) and interest are delivered by team members sharing ideas and useful information for EIRs. This involves organising an open and simple 'Big-room' meeting where established AIRs and PIRs can be visualised by all project members, which will allow systematic decisions to be made. Consequently, information exchange between key project members encourages frequent communication between project parties, which reduces misunderstandings and conflicts, thus improving collaboration [43].

5) Data Representation: Knowledge of PIMs and AIMs is represented as BIM models by employing BIM technology in the knowledge representation process. BIM can improve information/data exchanges among project parties through a collaborative process. Typically, it includes the abundant parametric representation of objects and storage of abundant knowledge in the form of parameters that can be exported to external databases for project parties to share [33]. 3D models of BIM replace document-based communication approaches and strengthen the visualisation and accessibility of information [33]. As such, building information models (PIMs and AIMs) interpret the information and represent knowledge of project teams and help them to establish a mutual understanding during the project delivery process [13,35]. Furthermore, information in BIM models is useful in supporting the rapid analysis of different scenarios in relation to the building performance [40]. In fact, it can be used for a wide range of purposes including clash detection, construction planning, design simulation, and energy performance evaluation [15].

6) Data Retrieval: Knowledge auditing occurs through the adaption or integration of project information standards and PIMs of the delivery phase, with the purpose of reusing the data in the O&M phase. The updated PIMs should be stored in a long-term archive and aggregated into AIMs for the O&M of the asset [13,14]. Subsequently, knowledge maintenance in AIMs is implemented, which encompasses reviewing, correcting, updating, and refining AIMs to keep them up-to-date, as well as removing obsolete data from the archive. The updated AIMs are maintained securely for future innovations and to provide lessons learnt for the next similar project [30, 33].

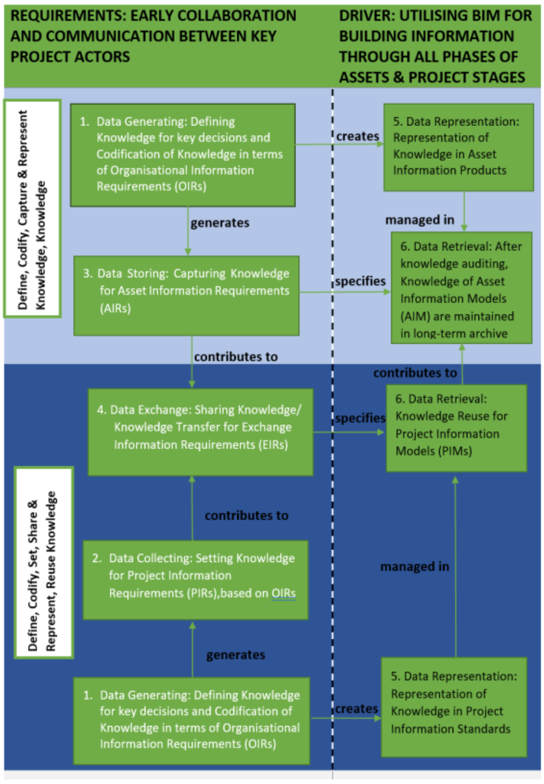

Figure 3: Information Flows in the Knowledge Generation Management (Source: Authors' own)

V CONCLUSIONS

This paper has reflected on the importance of early collaboration, communication, and leveraging the use of BIM in KM processes to facilitate the smooth delivery of information protocols in building information/models. The findings revealed that early collaboration and communication between the major project stakeholders of the appointing party is the key driver for defining knowledge in terms of identifying and setting effective information requirements (i.e. knowledge in OIR) that focus on client demands, providing vital support with regard to planning for project requirements [41]. However, the ability of BIM potentially enables a collaborative platform for the KM process to be initiated, and that focuses on capturing of AIR effectively, systematic sharing/transfer for EIR, clear knowledge representation of AIM and PIM, and reuse for PIM. Hence, this research identified that the capability of KM should be enhanced by early collaboration, communication, and leveraging the use of BIM as this can offer an interacting knowledge workflow (Figure 3) that is transparently accessible and workable in a collaborative environment for multidisciplinary project members.

Improvements in KM from early collaboration and communication through BIM adoption enable project stakeholders to collaboratively work on knowledge-intensive models, subsequently increasing project performance at the early procurement phases [36]. More importantly, this knowledge generating flow ensures that effective KM (i.e. data generating, collecting, storing, exchanging, representation, and retrieval) helps in data coordination and information exchange for data documentation throughout the project phases of the asset lifecycle. In conclusion, developing a knowledge generation workflow can benefit project stakeholders, including asset owners, consultants, project members of the appointing, lead appointed, and appointed parties, as well as end-users, in the following ways [19, 42]: 1) Ensuring the right information is delivered at the right time; 2) Facilitating greater collaboration and data coordination in the IM system, as well as ensuring information quality among project team members; 3) Reducing information wastage and rework through clearly specified information requirements; 4) Progressively generating knowledge through a managed process, improving the accuracy and validity of information; 5) Capturing an audit trail of information development and information exchange across the delivery and operation of a built asset.

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