A Building Information Modelling approach to the alignment of organisational objectives to asset information requirements

Abstract

It is critical that an asset-centric organisation understand the importance of their engineered assets to operate successfully. Despite this, organisations struggle to view assets within the context of whole-life management and ultimately struggle to harness the full potential value. A recurring theme is the challenges in capturing, storing and validating data across a diverse and complex asset portfolio. The primary reason for this is the fundamental lack of understanding of what information should be collected to support the efficient management of assets throughout their life. Asset-related information that is not collected in alignment to the organisational requirements will restrict the performance of capital investment decisions, risk management and operational performance throughout the whole life of the asset portfolio and ultimately have an impact on productivity. This paper presents a top-down methodology that utilises Building Information Modelling to support the development of asset Information Requirements, the novel aspect of this approach is the development of Functional Information Requirements to bridge the gap between organisational requirements and asset information requirements.

Keywords

Building Information Modelling, BIM, Engineering Asset Management, EAM, Information Requirements, Organisational Information Requirements, Asset Information Requirements, Requirements Engineering

1 Introduction

The importance of information management within the whole-life cycle of engineered assets is gaining momentum both in academic literature and industrial applications. Information management within the domain of Engineering Asset Management (EAM) is being guided by a set of industry specifications and standards that are solely focused on information management processes for the individual life-cycle phases (design, construction, Operations and Maintenance (O&M) and disposal / renewal) of engineered assets [1–3]. Most notable is the adoption of Building Information Modelling (BIM) that has seen a step change in how information is managed during the design and construction phases, with widespread evidence demonstrating a reduction in design and construction cost, increase in productivity and improved risk management [4–6]. Despite this, it can be seen that the adoption of BIM within the O&M phase is relatively limited [7]. The complexity of adopting BIM within the O&M is multi-pronged, common BIM information management challenges highlighted within the literature are summaries below:

1. *Fundamental lack in understanding how to demonstrate the value of BIM within the operational requirements.* [7].
2. *Historically the O&M industry has been hesitant to adopted new and emerging technology processes, resulting in a culture challenge that spans the whole industry. Indeed, the lack of BIM and general data management skills of personnel within the O&M industry strengthen this cultural challenge* [8].
3. *The interoperability between BIM related data (e.g. 3D models) and the existing O&M management systems such as Enterprise Resource Management (ERM) is limited* [9–11]. *Resulting in the often manual and ad-hoc approach of using BIM data and devaluing the business case for BIM within O&M* [12].
4. *O&M personnel are rarely consulted on their requirements for a BIM-enabled project, this results in a BIM model that is not optimised for O&M* [13].

A recurring theme is a fundamental challenge in demonstrating the value of BIM within the operational requirements of an organisation [7]. This is partly because asset owners, operators and maintainers fail to identify Asset Information Requirements (AIR) during the early BIM development stages, that leads the development of BIM processes that generate little value for the organisation. Organisational Information Requirements (OIR), if developed at all, are generally in the form of technical documentation and do not consider the organisational context within their development. Using these challenges as a foundation the following research questions has been developed to aid this research effort 1) how can the domains of BIM, Asset Management and Requirements Engineering be aligned to aid the development of organisation-lead Asset Information Requirements? This leads to a sub question of 2) How can the use of BIM-enabled asset classification system provide support to bridge the gap between organisational objectives, Organisational Information Requirements and Asset Information Requirements?

This paper investigates the development of organisational led AIR that supports BIM enabled processes within the O&M lifecycle phase of engineering assets. An extension of the current BIM information management relationship framework as defined within PAS 1192-3:2014 [14] is proposed. To support the development of AIR's that is generated from OIR's, an intermediate step that utilises the organisational point-of-view of engineering assets is required – the development of Functional Information Requirements (FIR).

The paper is organised as follows. Section 2 provides a review of academic literature and industry standards and specifications in the domain of BIM and EAM. Section 3 introduces the information requirements alignment methodology. Section 4 provides an overview of the methodology within two industry case studies. Finally, Section 5 summaries the key finds and challenges, proposing future research opportunities.

2 Background

With the rapid development of computing power in the 1950s and '60s, organisations found themselves with enormous and promised opportunities to streamline business processes and systems while also gaining greater insight and control. With this rapid development, there was a need to understand the user requirements of these new semi-automated Information Management Systems (IMS). It was quickly realised that you simply could not ask managers what information they require, as they operate in specific organisational functions and give bias to their priorities [15]. It is a mistake to assume that managers know what information they require and that this information will aid them in making better decisions, while evidence demonstrates the contrary [16]. Newly implemented IMS often require significant revisions to meet even the simplest of information requirements to support management decisions [17]. This often has a fiscal impact, with redesigning cost and time being significantly higher than the initial cost, in some cases as much as 50 to 100 times higher [15]. Information requirements do not arise naturally and therefore have to be engineered, highlighting the need for improving techniques in the development of information requirements to meet this significant challenge [18].

There is a growing set of methodologies, frameworks and tools to address the challenge of developing information requirements within an IMS. Some well documented techniques include Business System Planning (BSP), Critical Success Factors (CSF) and End/Means Analyse (E/M) [19–

21]. These techniques were the result of extensive research efforts in the early 1980s and ’90s that sought to solve the problems of developing information requirements.

2.1 Requirement Engineering

As IMS became increasingly popular, there has been a shift from process driven techniques to user-centric design that requires a thorough understanding of the needs and requirements of the users for designing an IMS [22]. The process of developing user requirements has manifested itself as a research and industry domain known as Requirement Engineering (RE).

RE is commonly referred to as a branch of software engineering that is concerned with the real-world wants and requirements for the design, development and implementation of information management solutions, e.g. software development [23]. The RE process consists of 5 main activities: eliciting requirements, modelling and analysing requirements, communicating / documenting requirements, agreeing on requirement and management of requirements [24]. There are many techniques available for the individual stages to ensure that the requirements are complete, relevant and consistent. These include stakeholder engagement [25], requirements prioritisation [26], storyboarding [27] and configuration management [28].

RE has predominantly been implemented within none asset-centric organisations such as financial firms, communication firms and marketing, with limited implementation in asset-heavy industries such as rail, highways and estate management. This is partly due to the late and poor adoption of IMS within the engineering industry.

2.2 Information Management Within Engineering Asset Management (EAM)

EAM involves the management of engineering assets throughout their whole-life, which involves the management of cost, risk and opportunities against the desired performance of the assets, to achieve the organisational requirements [1]. An asset (or engineered asset) within the domain of EAM is a physical asset (such as a bridge or rail signal) or an intangible assets (such as people or data its self) that has potential or actual value to an organisation [29,30]. The scope of this paper is focusing on the physical / engineered assets. EAM has an emerging domain of research within information management noted as one of the key challenges and enablers of supporting efficient development, implementation and operating of an EAM system [31]. Furthermore, a series of standards were developed by the ISO to outline a methodology for the design, development and implementation of an

EAM system [1–3]. This includes the development and documentation of EAM objectives, plans and requirements.

BIM has been widely cited as an enabler to supporting the development of information management processes within EAM, most notably supporting the exchange of information throughout the lifecycle of an asset and supporting the development of information requirements [32]. BIM is the process of designing, constructing or operating a building or infrastructure asset using object-oriented design [33]. The British Standards Institute (BSI) has developed an array of BIM related specifications and standards for an asset's lifecycle management including the exchange of information (geometry and non-geometry), information management processes, common data environment and level of detail [14,33–37]. Most notably, PAS 1192-3:2014 aims to provide a specification for information management within the operational phase of assets [14]. One of the critical components within the specification is defining the relationship between elements in the management of information. Figure 1 demonstrates the relationships by visualising the dependencies and hierarchy nature between information requirements developed within a BIM-enabled organisation.

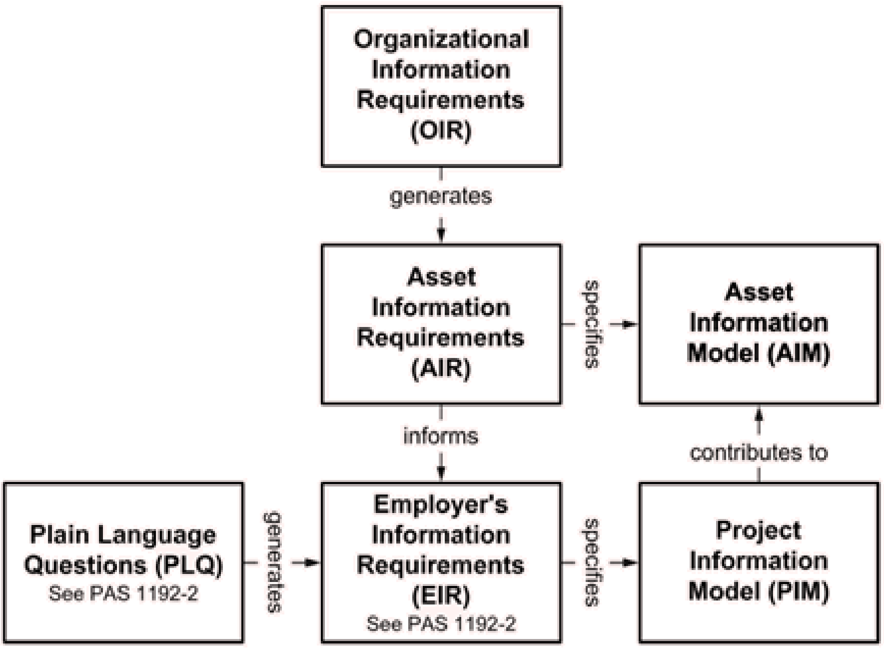

Figure 1 Relationship between elements of asset information management [14]

The purpose of the Asset Information Model (AIM) is to be a sole source of validated and approved information related to specific assets. The development of Organisational Information Requirements (OIR) which helps generate Asset Information Requirements (AIR) is a complex task, with very few examples of this being implemented in practice [38,39]. OIR and AIR development is led by technical guidelines, codes, regulations and specifications and will, therefore, struggle to meet the commercial, financial, managerial and customer management requirements of the organisation. Therefore it is critical that a systematic approach is used for developing the OIR from the stakeholders (e.g., clients, operators) requirements [40].

The Employers Information Requirements (EIR) is developed when the organisation requires information from the contractors of capital works projects. It supports the procurement of information as per the organisational requirements. There are limited examples in the academic literature that focus on the development of specific elements of this framework. Cavka [41] proposes a four-step methodology for the development of owners information requirements and how they related to BIM. This includes: (i) identify sources & collect data, (ii) classify landscape of owner requirements, (iii) identify the required information, and (iv) relate digital information with physical product requirements. While this is a comprehensive methodology, it does not create an alignment between the organisational requirements and specific AIR. Ashworth [39] argues that the OIR and AIR should be developed by facility managers and asset managers as they are uniquely placed to understand the organisational requirements of their assets. He further proposes an engagement model for their involvement. While nobody would argue that facility managers and asset managers should be consulted within developing the OIR and AIR, the bulk of their knowledge would be within the technical operational requirements. Using their perspective above others would risk missing alternative organisation requirements such as commercial, financial, managerial and customer. Finally, Patacas [42] proposes using the Information Delivery Manual (IDM) methodology developed by BuildingSMART [43] and developed into an ISO Standard [44,45]. IDM uses the concept of process maps defined in Business Process Modelling Notation (BPMN), highlighting the flow of information, models and data between different stakeholders over a set of lifecycle stages for a specific activity while the IDM methodology supports the required integration between stakeholders and lifecycle stages, being activity driven risks missing the organisational requirements that are not explicitly known for a given activity.

2.3 Standards to Support Information Management Processes within Engineering Asset Management

As stated above there are several specific standards related to BIM information management processes and EAM. Furthermore, there are several standards that are not directly related to BIM or EAM but indirectly support the design, development and governance of information management processes within EAM. ISO 12006-2 provides a classification system for both the construction and EAM industry [46]. This includes classification of activities such as painting and classification of engineering assets such as a window, beam or ventilation systems. This standard provides a consistent approach to the classification of construction and EAM related objects. Therefore, it supports the exchange of information between an asset's lifecycle and between the many stakeholders. ISO 12006-3 consists of a taxonomy model which can be used to develop dictionaries and relationships to store or provide information related to construction works [47]. BS 8536-1/2 gives recommendations for briefing the design and construction personnel to ensure that they consider the assets performance requirements throughout its operational life, e.g. considering the operational requirements at the very earliest design stages [48,49]. Finally, Government Soft Landings (GSL) is a framework for delivering pre-defined sets of information during the design and construction lifecycle, supporting a structured transfer into the operational phase [50].

2.4 Summary

From the earliest developments of IMS, developing the information requirements for those systems is a complex and puzzling task that is often neglected and result in reduced operational performance. Furthermore, the adoption of IMS within EAM is immature compared to other domains. While a branch of software engineering called Requirements Engineering (RE) has provided a framework for the development of information requirements, the conventional techniques used within the framework have limited use within EAM due to its multifaceted nature. Most notably, RE fails to address the whole-life management requirements of EAM. BIM has been described as a critical enabler for the adoption of an IMS within the construction and EAM sectors. While BIM has been actively implemented within the design and construction phases, it adoption within the operational phase has been limited. This is partly due to the complexity of capturing OIR within the initial stages of the BIM information management processes. While there are a few example methodologies in the literature, they use the current approach of assuming that the OIR can directly create the AIR, but it can be witnessed that the jump from OIR to AIR is a challenging step for most organisations. The reasons for this challenge are multifaceted and summarised below:

1. *Organisational management team often don't understand the technical aspects of the assets they maintain and operate.*
2. *Organisational requirements are often abstract and therefore poorly translate directly into AIR.*
3. *Due to management teams challenge to develop information requirements, AIR are developed from a technical perspective and lacking basic information for management processes such as financial management and risk management.*

These challenges are addressed by utilising the methodology proposed in this paper, adding the intermediate step of defining FIR's.

3. Information Requirements Development Methodology

As highlighted within section 2, there is a clear knowledge gap within the development of OIR within the domain of EAM. Furthermore, it can be observed that generating the AIR from the OIR is too much of a leap for most organisations and that a more comprehensive framework is required to aid in bridging this gap. This section proposes a systematic methodology to generate Asset Information Requirements ensuring alignment with organisational requirements. This is enabled by an intermediate step of Functional Information Requirements (FIR) which utilises the organisational point-of-view of the assets as the functional output that they support. Figure 2 illustrates the extension, and the dotted lines demonstrate a validation process that ensures the resulting Asset Information Model align with the OIR. This methodology takes a specific UK perspective of BIM due to the use of British developed standards and specifications, specifically the BS/PAS 1192 series. While this is currently true, there are several working groups within ISO that aims are to develop the British standards into international ISO standards, which would support the applicability of this methodology outside of the UK [51]. Furthermore, the ISO 55000 on Asset Management Systems is an international standard and the concepts of BIM and RE have been widely adopted to a degree within many countries that align their adoption in part or full to the proposed methodology.

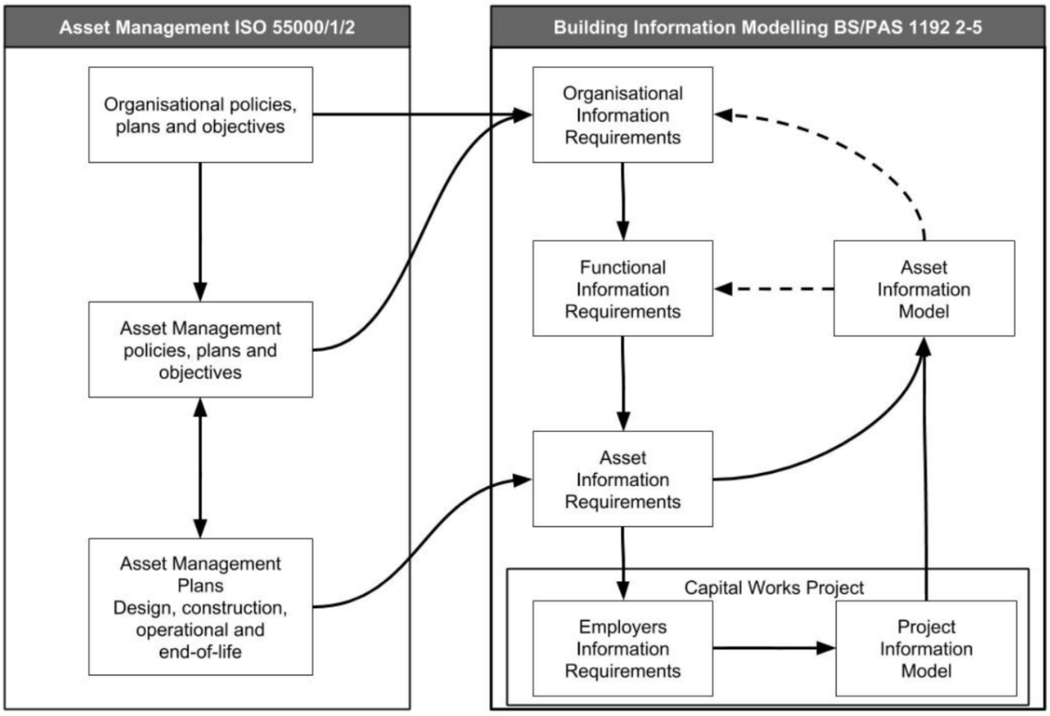

Figure 2 proposed extension to the BIM information management relationships adopted from [1,14]

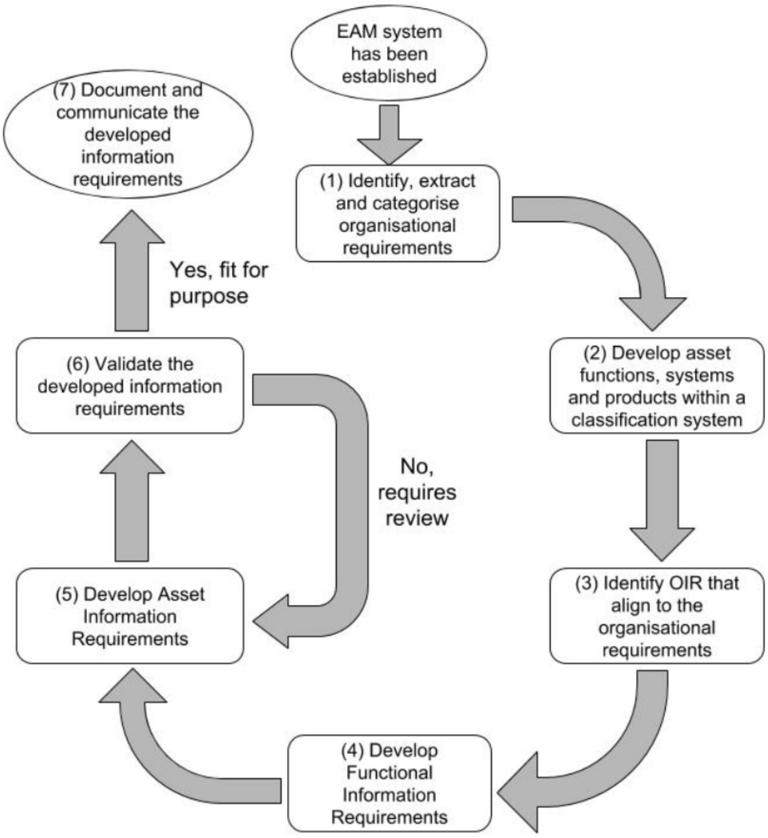

Figure 3 Information Requirements Development Framework

A seven-stage step methodology is proposed that aids in the development of information requirements, which is illustrated in Figure 3 and will now be described in detail.

Step 1 – Identify, extract and categorise organisational objectives

The first task is to identify the organisational and EAM objectives, Depending on the size and context of the organisation, these can be spread over several documents often developed in isolation within individual departments. The set of documentation that should be analysed includes annual reports, environmental impact strategy, customer strategy and financial growth reports. Analysing the documents involves comprehensibly reviewing the documents and extracting the objectives within them. Care should be taken to extract SMART[1] objectives, where available. Some documentation list objectives within a separate section, while other documents have objects embedded into the broader text, hence why the documents require a comprehensive review. Finally, if the text is not clearly stated as an objective, then it should be validated with the author / business owner to ensure that it is an objective. If the organisation has developed an EAM system as defined within the ISO 55000 standards [1], the documents produced to develop such a system including asset management policies, asset management plans and objectives should be prioritised for analysing. Furthermore, BIM related documentation such as Information Management Processes (IPM), Employers Information Requirements (EIR) and BIM data security strategy should also be analysed, to captures BIM related objectives. A common set of organisational documents that should be analysed are summarised in Table 1. If necessary, the objectives can also be identified through targeted interviews with key decision makers within the organisation. Where interviews are used to capture the objectives, care should be taken to ensure that personal biases of the interviewees are avoided through useful triangulation. If the organisation has developed a balanced scorecard, this can be a valuable tool to extract non-financial performance measures and objectives [52].

Source of Objectives	***Description***	***Objectives***
Strategic Asset Management Plan (SMAP)	*Key strategic documentation as part of ISO 55000, contains asset management objectives, goals and plans that align with organisational objectives.*	*Operational objectives* *Financial objectives* *Training objectives* *HR objectives* *Health & Safety objectives*

[1] specific, measurable, attainable, relevant, and time-bound (SMART)

Environmental Strategy	*Contains an organisational environmental framework and objectives to minus the impact of the organisation's requirements on the natural environment*	*Environmental objectives* *Air pollution reduction objectives*
Customer Engagement Strategy	*Provides a framework and objectives for engagement with customers and end-users. Often contains engagement targets and customer satisfaction targets*	*Reputational objectives* *Customer objectives*
Financial Growth Strategy (Business Plan)	*A strategic document that outlines the organisation finical growth plans and objectives.*	*Financial objectives* *Growth objectives*
Information/Technology Strategy	*Provides a framework and objectives for the implementation of technology and information management systems.*	*Data management objectives* *Digital adoption objecitves*
BIM Execution Plan	*contains BIM related requirements and objectives, most notably for the design and construction phase but could be utilised within the operational phase.*	*Data management objectives* *BIM target objectives*

Table 1 Key Documentation for identifying organisational requirements

After reviewing the documentation described within this section, it can be witnessed that there are six individual categories that all objectives can be categorised within, independent of the services or produces that the organisation provides. This is partly due to the board nature of the categories themselves and individual organisations following common management processes such as quality, risk and fiscal management and producing similar documentation as an outcome. Therefore, the objectives identified within this section should be categories within a single category of financial, environmental, operational, customer, health and safety and reputational. Categorising the objectives is especially important for four reasons:

(i) Large organisations could have over a hundred requirements, and analysing these requirements is made simpler by categorising them.
(ii) The categorisation can help identify any gaps within a specific category.
(iii) It allows for identifying conflicting or duplicate organisational requirements.
(iv) It helps to identify a baseline of universal information requirements that are required for different organisational requirements within the same category, therefore reducing duplication of work and provide a foundation for more specific information requirements.

The outcome of this first step is a comprehensive set of organisational objectives that form the foundation for consolidation into a clear set of OIR.

Step 2 – Develop asset functions, systems and products within a classification system

The second step requires the organisation to classify its asset portfolio using an asset classification system. An organisation classifying it engineering assets is a crucial element of the methodology as it supports the future development of information requirements. The parent-child Hierarchy relationship within the classification systems is utilised to support the developed multiple levels of information requirements, from high-level requirements (e.g. heating or ventilation requirements) to low-level granular requirements (e.g. radiator or air supply fan). The most comprehensive classification systems that support EAM are UNIClass and Omniclass [53,54]. They both follow the industry standard ISO 12006-2 [46] for classification of assets.

Traditionally classification systems are implemented by looking at the individual assets themselves and not the asset systems or functions that they support. This can be a daunting task, as even small organisations can have different individual assets that number in the thousands. Furthermore, these risks alienating the departments of the organisation that do not focus on the performance of individual assets but the functional output that they support, such as the financial or human resources departments. Figure 4 demonstrates the parent-child relationship as defined within ISO 12006-2 with examples of definitions from UNIClass, this section describes how such an approach can be utilised to aid in the development of information requirements.

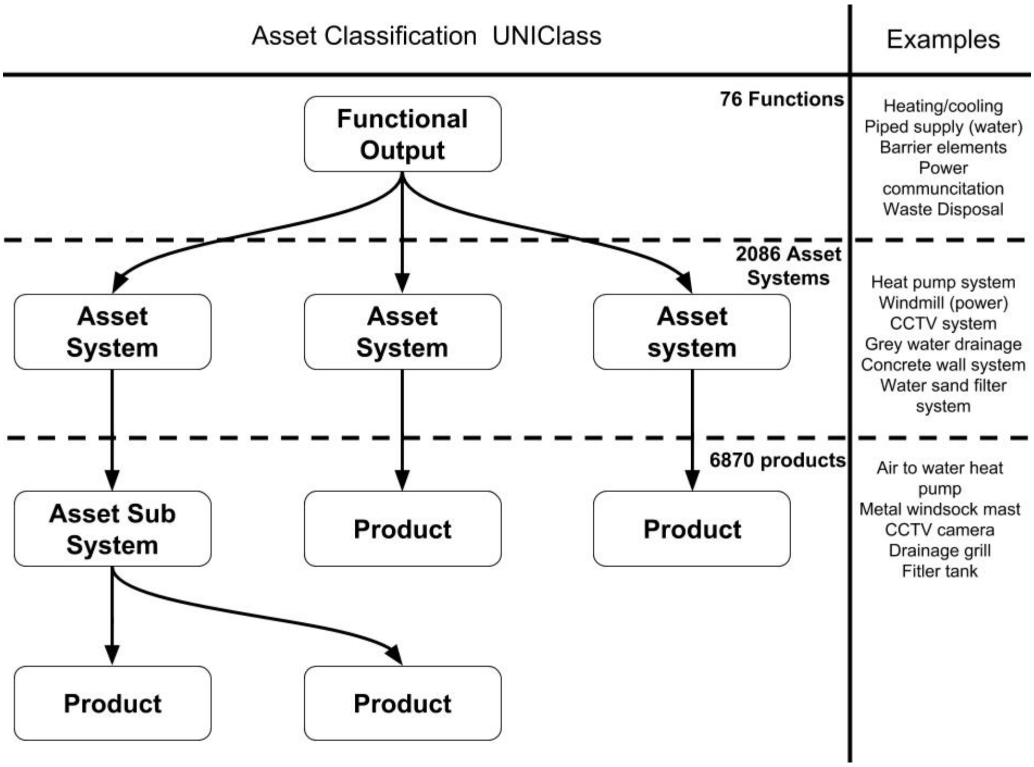

Figure 4 Asset Classification Hierarchy

It is proposed when implementing a classification system that the organisation first classify the functional output of their engineering assets. UNIClass Table EF provides a database of 76 functions that offers a comprehensive set of functional output covering all sectors including infrastructure, buildings and civil works. The key benefit of such a classification system is having a starting point for engineering asset classification that is understood through different organisational departments. As an example, the customer relationship department within an estate management company won’t have expert knowledge on the engineering asset systems or products that support the function of heating, but they will understand the performance requirements (e.g. temperature) that the tenants require. Furthermore, classifying the assets functional output enables the alignment of the functional output to the asset systems and the products that support that system, this creates a direct line-of-sight from the asset functional output to the asset systems and products. Moving down the classification hierarchy, it is then required to classify the asset systems that support the funcational output. UNIClass Table Ss provides a classification of 2085 asset system. Only asset systems that support the functional output should be classified. A sub-system might be required to be classified depending on the specific organisational requirements. Finally, the lowest level of the engineering asset classification system is the individual products that support the asset systems. UNIClass Table Pr provides a classification of 6870 products. Care should be taken when classifying products, as classifying all the products within the asset systems can be an extensive task, only products that are critical to the organisational objectives should be classified.

The critical outcome of this step is to have implemented a comprehensive classification system of the organisation's engineering assets. The classification should start at the highest level of the assets functional output, as this is how an organisation views the performance of its engineering assets. The classification system is used within the following steps to support the developing of the information requirements.

Step 3 – Develop Organisational Information Requirements (OIR) that Align to the organisational objectives

The third step is to translate the individual organisational objectives into an OIR. The primary goal of developing an OIR is to provide the information that is required to inform the performance of meeting (or not) the organisational objectives identified in step 1. The OIR should aim to meet all the requirements of an EAM system and organisational departments. The development of an OIR can be a daunting and complicated task due to its broad and cross-department nature. To provide a starting point in the OIR development, three categories are used to classify the captured information requirements within financial, managerial and technical, a summary of these is provided in Table 2.

Information Requirement Category	Summary
Financial information requirements	*Financial information requirements capture related financial information that supports the monitoring and validation of financial related performance and support such functions as whole-life costing, capital investment plans and strategic financial decision-making processes. Examples of financial information include operational cost, maintenance cost and initial cost.*
Managerial information requirements	*Managerial information requirements capture managerial information that an organisational requires to maintain their assets, including legal and commercial elements efficiently. Examples of managerial information include ownership, asset location and warranty / insurance information.*
Technical information requirements	*Technical information requirements capture information that an organisation requires to evaluate design, operational and maintenance performance limits of their assets. Example of technical information includes operational*

	performance data, design parameters and dependencies and interdependencies

Table 2 Summary of Information Requirements Categories

While the identified information categories support the management and classification of information requirements, they don't directly support their development. Supporting the development of information requirements, we utilise two methodologies firstly, Critical Success Factors (CSF) from the domain of requirements engineering and Plain Language Questions (PLQ's) from the domain of BIM. CSF has been Widely used within the domain of requirements engineering to highlight a customer and end-user requirements for the development of IMS. CSF forces managers to ask the question, what are the critical success factors of the business department I manage? And what information is required to ensure the critical success factors are acceptably managed? This approach is slightly modified to move focus away from individual organisational departments to organisational objectives by changing the question to, what are the critical success factors of achieving this objective? The CSF acts as guidance and provides a structured approach to the development of PLQ's. PLQ's form part of the BIM information requirements development process as outlined within PAS 1192-3 [14]. PLQ's are designed as a way for clients and end-user to communicate their broad and complex information requirements within a set of simple understandable questions. PLQ's within the contents of this approach is utilised to aid in the development of OIR, by developing high-level questions that an organisation need to be answered to confirm if they are meeting (or not) their objectives. The data to answer these questions will be found in the organisation's engineering assets, the questions are summarised into a set of information requirements. lastly, the data type (string, integer, date/time and Boolean) of the data required to answer the question is identified. Table 3, shows an example of organisational objectives and associated CSF, PLQ's and data type.

Reduce the Total Business Impact of Estate Facilities' Controllable Costs by 5%

Critical Success Factors	***Category***	***Question***	***Information Requirement***	***Data Type***
prompt response to maintenance requirements	*Operational*	*What is the current response time to maintenance request?*	*<current_responce_time>*	*Integer*
		What is the cost savings to a prompt response to maintenance requests?	*<promt_main_cost_saving>*	*Integer*

		what is the desired response time to maintenance request?	*<desired_responce_time>*	*Integer*
		who is reasonable for planning maintenance?	*<planning_maintenance_owner>*	*String*
reduction in operational cost	*Financial*	*What is the current total operational cost?*	*<total_operational_cost>*	*Integer*
		what is the difference between the planned operational cost and the current?	*<current_vs_planned_operational_cost>*	*Integer*
		who is reasonable for the operational cost?	*<operational_cost_owner>*	*String*
reduction in maintenance costs	*Financial*	*what does the total maintenance cost?*	*<total_main_cost>*	*Integer*
		what is the planned maintenance costs?	*<planned_main_cost>*	*Integer*
		what is the difference between the planned maintenance cost and the current?	*<planned_vs_current_main_cost>*	*Integer*
less reactive maintenance and more planned maintenance	*Operational*	*what is the total reactive maintenance requests to date?*	*<reactive_main_request>*	*Integer*
		what is the total planned maintenance to date?	*<planned_main_instances>*	*Date*
		what is the difference between reactive and planned maintenance?	*<planned_vs_reactive_main>*	*String*

Table 3 Organisational Information Requirements Summary

The final exercise in this step is to align the organisational objectives with the functional asset outputs defined within step 2. This is achieved by ranking the top three functions within the organisation's engineered assets that will have the most significant impact on achieving (or not) the organisational objective. For example, a financial objective will be the top functions which the most expenses or revenue generating functions to operate and maintain. While an environmental related objective would focus on the highest polluting functions, asset managers and asset maintainers should be consulted to ensure that the most relevant functions are selected and ranked correctly, as the ranking of the functions is a subjective task, it is critical to have the appropriate people in the room. These functions will be used within the following steps to translate the OIR into FIR and AIR.

The critical outcome of this step is a comprehensive set of OIR per organisational objective, this is supported by the development of CSF and PLQ. the OIR’s focus on the information required by the organisation to achieve (or not) its objectives. Simply put, the OIR’s developed should be a set of questions that an organisation asks of their engineering assets, the data received will aid in answering the questions. Furthermore, the top three asset functions that impact the objectives are captured and used in the following steps.

Step 4 – Develop Functional Information Requirements (FIR)

The fourth step is to define the FIR for the functional outputs as captured within step 3. The definition of an FIR is *"information requirements developed at an asset's functional output level of an organisations asset classification system that support the organisational requirements of their assets, including asset management, whole-life cycle costing and capital investment decisions"*.

This should aim to answer the questions asked in the OIR at a functional output level. When developing FIR's it is critical to not jump to the asset system or product level, as which is common within asset centric organisations. Care should be taken to enforce the point that we are capturing the impact of the asset functional output on the organisational objective. As an example, we want to understand how the functional output of heating can have an impact on the objective to reduce operational cost and what specific information is required from the function of heating to achieve this objective. As stated within step 1 the advantages of classifying engineering assets by their functional output is creating an alignment between the organisation and their assets they maintain and operate, the information captured within the FIR will aid in this alignment. As such the information captured within the FIR will be non-technical and mainly focus on managerial and financial related information.

The development of FIR is best achieved within a multi-discipline collaborative workshop environment. The workshop should be developed from such requirements engineering techniques including stakeholders' engagement, Joint Design Application (JDA), brainstorming and prototyping. Stakeholders' engagement should focus on highlighting the critical personnel required in the workshop. The FIR is vital in aligning the organisation with its engineered assets, as such the key personnel should understand the organisational management framework such as risk management, capital investment decisions and customer management processes. Typical personnel include asset managers, financial directors, risk managers and customer engagement managers. Due to the multi-discipline nature of this process using the user involvement nature of JDA to structure the workshop is a natural fit. While there is no hard structure for the development of JDA workshops, there are some fundamental building blocks that include facilitation, agenda setting/structure, documentation and group dynamics. Brainstorming is a group creativity technique that aims to find a dynamic conclusion to a set of problems. specifically, guided brainstorming is used as part of the group exercise within the JDA and therefore in the development of FIR. Depending on the complexity of the organisational objectives and the asset functions it could be beneficial to develop a set of prototypes, simulating the use of the information requirements within the FIR workshops to support the decision-making processes. The benefits are two-fold: firstly, it supports the validation that the development information requirements are fit for purpose. Secondly, it limits the risk of an IMS being developed that is not fit for purpose and requiring expensive upgrade and reworks. It is important to state that not all prototypes have to be software development related, it can emulate an event happening and the exchange of information within current business and software processes, therefore validating if the correct information requirements have been captured for the associated organisational objective.

The final task in this step is to align the asset systems that support the asset functional output. As an example, the function of heating can be supported by multiple asset systems such as a gas boiler system, underfloor heating system and electric heating system. Asset manager, maintainer and operators should be consulted to ensure that all the asset systems are captured. UNIClass classification system table Ss provides a classification of 2083 asset system. Similarly, Omniclass provides a classification of asset systems. These classification systems should be used as references to ensure consistency.

To support the capture of the information requirements developed during the workshop, an Information Requirements Matrix has been developed. The matric captures information within the categories of managerial, technical and financial, which replicas the categories of questions develop within the OIR (see step 3). Furthermore, the matric supports the alignment of the functional asset output to asset systems. The matrix should be collaboratively completed within the above-described workshop and used as a tool to document the developed information requirements. Figure 5, illustrates an example of a completed Information Requirements Matric.

Information Requirements	Heating Functional Output		Financial
Managerial Information	<maintainer> <operator> <client_owner>	<name> <function> <location>	<detailed_location> < description> <run_time>
Technical Information	<service_life> <Remaining_life> <current_performance>	<historical_performance> <optimise_performance> < criticality_rating>	<planned_maintenance> <reactive_maintenance >
Financial Information	<operational_cost> <total_maintenance_cost> <whole-life_cost>	<financial_owner> <target_cost> <reactive_maintenance_cost>	< proactive_maintenance_cost > <total_cost>
Asset Functions	Gas Heating System	Electric Heating System	Hot Water Heating System

Figure 5 Information Requirement example

the critical outcome of this step is a comprehensive set of FIR's that aligns to supporting asset systems. The information requirements are developed within a collaborative workshop environment, utilising elements of brainstorming and prototyping. While the information captured should be comprehensive, it is worth noting that it should only focus on the information required at the functional level of the asset and not the asset systems level, these will be captured in the following step. The FIR should aim to provide answers to the questions that were raised in the developed of the OIR (step 3).

Step 5 – Develop Asset Information Requirements (AIR)

The fifth step is to develop the AIR for the asset systems that have been defined within the functional information requirements matric. To avoid confusion with the associated BIM 1192 standards, this step will develop asset information requirements as defined within the 1192 standards, both asset systems and products information requirements are captured within the AIR. The definition of an AIR is *"any information that is captured at an assets system, sub-system or product level of an organisations asset classification system that supports the organisational requirements for their assets, including operational and maintenance management, spares management and risk assessments".* The AIR should aim to provide the data for the information requirements developed within the FIR.

Much like the development of FIR, the development of AIR is best achieved in a multi-discipline collaborative workshop environment. The workshop should utilise the same methodologies such as stakeholders' engagement, join design application and brainstorming. In addition to this, a new dynamic group exercise is introduced called the Information Delivery Manual (IDM) [44,45]. While the limitations of using the IDM methodology as a single solution for the development of information requirements was expressed within section 1, in the context on this framework and more specify this step it provides a structured approach to the capture of AIR. Regarding stakeholders' engagement at the AIR level, it is required to have the personnel that operate and maintain the asset portfolio at the asset system and product level. As such, it is required to have operational and maintainer engineers that have a strong technical understanding of how the assets within a system and as individual assets.

The IDM methodology utilises process maps that are defined using Business Process Modelling Notation (BPMN), specify the actions for a given activity and the supporting data and information requirements that support the given activity. The IDM methodology is divided into three discrete parts including process maps, exchange requirements and technical implementation. The IDM methodology is used to capture the current (as-is) flow of information between the defined actors of an asset-system for a given EAM activity. This process will capture the specific information that is exchanged to support activities such as maintenance, commissioning of new assets and risk assessments. While not all these activities will directly relate to an organisational objective, they will support in achieving the objectives. As an example, the information captures the activity of maintenance will have an impact on the objective to reduce business costs by 5%. The information highlighted is analysed within a workshop environment and If demanded appropriate to help answer a question or questions developed within the OIR, it is captured within the information requirements matrix (see Figure 5) and forms part of the AIR. The process map should be completed in a collaborative workshop environment with stakeholder from the above stakeholders' engagement exercise. Firstly, an EAM activity is selected, care should be taken to prioritise the key activities that will impact the organisational objectives. Secondly, the actors are identified. These are actors that within some point within the activity they send or receive information as part of the process, manually such as an email or a phone call and automatically such as an automatic work order sheet or asset failure warning from a sensor. These actors are structured into "swim lanes" which these swim lanes are the processes and functions that the individual actors perform, these are indicated by rectangles and the flow by solid arrows. A process map will always have the swim lane Exchange when information is exchanged between the actors it is highlighted within this swim lane and the flow of information by long dotted arrows. The manual exchange of information is indicated by an envelope while the automatic exchange is indicated by a sheet with a folded corner as per the IDM and BPMN standards. As part of the BIM design model classification process, BS 1192 provides a standard set of roles (actors) that should be used as guidance which defines such roles as a facility manager, contractor, client, civil engineer, building surveyor and structural engineer [34]. Furthermore, UNIClass table Project Management (PM) provides a classification of design, construction and EAM key roles and actors [53]. The defined actors should be classified where possible to allows for future automatic data extraction and filtration per actor type. Figure 6, provides an exchange of a process map show the essential functions and processes within the actors' swim lanes and the exchange of information within the activity of asset failure.

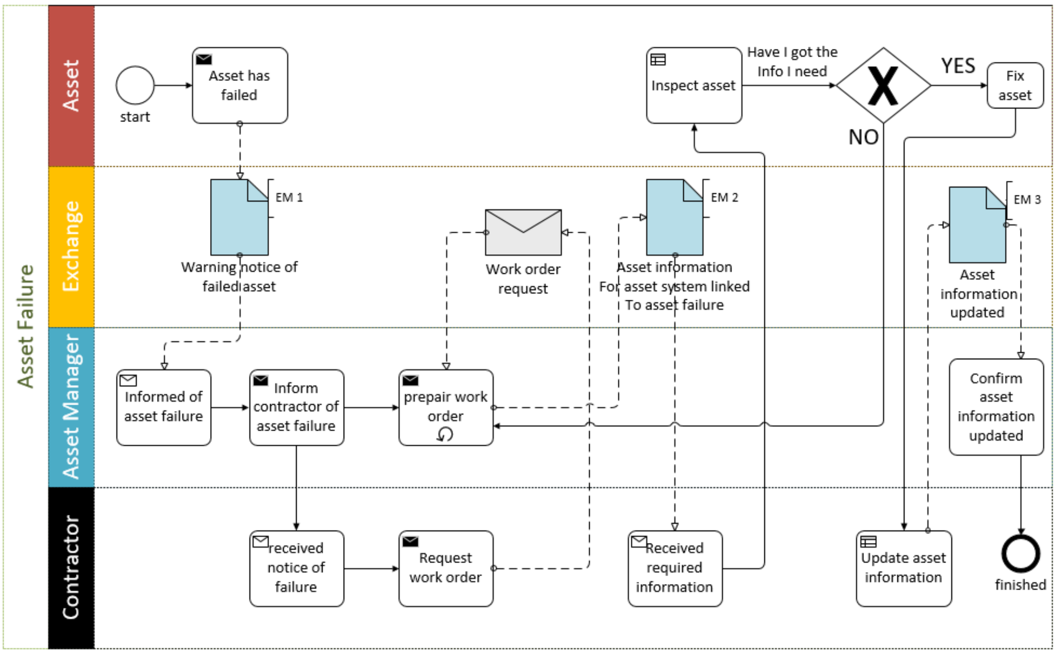

Figure 6 Information Delivery Manual, Process Map

The final requirement of the IDM methodology is to develop exchange requirements (ER), these indicate the specific information that is exchanged at a given time or after a function or process between the actors. The ER should capture two elements of the exchange: firstly, the information unit that is an exchange, including a description of the information unit and its use. Secondly, any information constraints such as data types.

The critical part of this step is to develop a comprehensive set of AIR. The main exercise in this step is developing a set of process maps that identify the processes and functions for a given EAM activity and highlights the information exchange between the given actors. The exercise is designed to capture the current (as-is) flow and exchange of information, the developed ER are analysed within a collaborative workshop environment and analysed on their capability to aid in answering the questions developed within the OIR (Step 3), if they are deemed appropriate they are captured within the information requirements matrix and form part of the AIR.

Step 6 – Validate the developed information requirements

the sixth step is to validate that the captured information requirements are fit for purpose and support the line-of-sight required from the organisation objectives to the performance of the assets and confirm if the objective is being achieved (or not). Furthermore, this step also confirms that the information requirements captures are the correct ones needed and an adequate quantity has been developed.

The validation process, much like the OIR, AIR and FIR developed should be completed within a collaborative workshop environment, utilising the same methodology of JDA and stakeholders' engagement. The validation process is complex in nature. Firstly, it requires diverse stakeholders with often conflicting goals to reach an agreement [55]. Secondly, real validation of the information requirements can only be achieved within their "real world" usage, which is often an expensive and timely task.

addressing the first challenge, it is required to resolve the conflicts between the different stakeholders without efficient the individual goals and requirements. Robison and Volko [56] propose a negotiation project lifecycle model that incorporates the organisational point-of-view, by first setting out their goals and objectives in the early stages of the negotiation, the overarching theme is a level and common playing field where all participants are working towards a single set of goals and objectives. The advantage of using this approach are two folds. Firstly, as part of this framework, we have already established the organisational goals and objectives within step 1, there can be used as the overarching goals of the negotiation process. Secondly, as described in section 2 one of the key challenges within EAM is its multifunctional aspect that is often neglected within information requirement development. The common playing field approach with common goals and objectives support the collaborative framework and environment that supports the required cross-functional negotiation processes

Addressing the second challenge, we utilise the same IDM methodology that was used within step 5, but this time focusing the developing process maps that show the to-be (future) processes and exchange of information and not the as-is (current). The process maps are developed within the same steps but solely focused on the newly developed information requirements. The focus should be given to ensuring that the information exchange is efficient in meeting the OIR and ultimately the organisational objectives. It might be found in this step that new organisational processes need to be developed to support information exchange. As an example, notifying the financial department of any unscheduled asset renewal costs before the commissioning of the asset. The process maps to aid in validating that all the information requirements are fit-for-purpose by analysing the flow of information within EAM activities. Furthermore, utilising IDM process maps allows for a quick, comprehensive and easy validation process, without having to develop complex and expensive IMS for testing.

The critical outcome of this step is a comprehensive set of negotiated and validated set of information requirements. The organisational requirements, OIR, FIR and AIR should be validated. As stated the OIR is developed at the organisational functions level, as such, the clear majority of these requirements will be managerial and financial related. Therefore, the appropriate stakeholder who understands these functions should validate the OIR. furthermore, the FIR and AIR are more technical related and therefore require more technical stakeholders to validate their requirements.

Step 7 – Document and communicate the developed information requirements

The seventh and final step of this framework is the need to document and communicate the information requirements, this includes documenting the output of the classification of organisational objectives (step 1), asset classification (step 2), OIR (step 3), FIR (step 4) and AIR (step 5).

As stated within step 1, the organisational objectives are extracted and given a unique ID, categorised, the name of the document extracted from and finishing timeline of the objective. The objectives should be easily accessible by both the management team and maintain / operational teams. Care should be taken to ensure that the format of the objectives is not overly complicated and is easily understandable by the whole organisation.

Regarding the asset classification system (step 2), the classification of individual asset functions, systems and products should be documented. Furthermore, the parent-child relationship between the asset function, systems and products (see Figure 4) should be documented. The asset classification should be captured as part of an asset register, which then supports efficient data filtering, extraction and exploitation. The database of the asset classification its self should be stored in a relational database which is widely accessible to the organisation such as Structured Query Language (SQL), Microsoft Access or Excel. The classification database should be used as a reference for the development of an asset register and classification of objects within BIM design models.

Building on the documentation of the objectives and asset classification, it is then possible to start documenting the developed information requirements (OIR, FIR and AIR). The OIR is captured as per Table 3 within step 3. Along-side the information requirements, other identifying information is captured as Critical Success Factor, categories, plain language questions and data types. It is critical that the information requirements themselves are accessible, as they will support the development of the FIR and AIR. When documenting the FIR, we utilise the Information Requirements Matrix (see Figure 5), this allows for the alignment of the OIR and the asset functions. A pivotal step to documents within the FIR process is the top 3 to 5 asset functions that impact the Organisational Objective, an Information Requirements Matrix is developer per each highlighted function, which therefore develop the FIR. As within the development of the OIR, it is critical that the information requirements captured within the FIR process are accessible as they support the development of the AIR. AIR also utilise the Information Requirements Matric to store the identified information requirements.

4 Case Study

This section aims to demonstrate the practical applicability of the methodology by applying this in two case studies – the Estate Management department for a university and a major city public transport provider. A brief overview of the approach taken for the case studies is provided first, and a summary of feedback, lessons learnt and challenges within methodology implementation is provided at the end of this section.

4.1 Case Study Approach

Initially, one to one interviews with structured and unstructured questions were conducted to ensure the organisation has the appropriate documentation, resources and skills to participate within the case study. The case studies followed the same steps as outlined in Figure 3. As discussed within step 3, the case studies were developed utilising JDA. In total two OIR workshops per case study where completed involving 4 to 6 personnel from senior management positions from the departments of financial management, resource management, customers management, O&M management and the asset management teams. Both the FIR and AIR workshops involved 5-10 technical and operational personnel from the maintenance response team, maintenance planners, spares management, procurement and invoicing, customer engagement teams and quality controls. Two workshops each for FIR and AIR were carried out per case study. Excel-based templates were developed that provide a constrained and structured approach to data capture. After each workshop, the data was analysed with a summary and feedback provided to the organisation within an informal meeting.

Feedback on the results of the case study was obtained by interviewing personnel within the organisation to validate that the information captured using the process aided in supporting their strategic needs. Further validation was achieved by witnessing (or through feedback) the organisation being able to make greater informed decisions within their asset management system.

4.2 Methodology Review

The Estate Management team provides all of the university's O&M requirements while managing the financial costs, planning and scheduling of works and commencing of new assets / buildings. Furthermore, Estate Management also manages the IT applications that are used to support asset management activities such as capturing maintenance reports. Historically the Estate Management team has struggled to report efficiently on their assets' performance (financial and non-financial) and are often focused on acting reactively. This is partly due to poor information management. Specifically, Estate Management had not implemented a standard asset classification system or used a structured approach to the development of AIR, which means they struggle to filter and extract the data that meets their requirements. Recently Estate Management embarked on a transformation process that includes adopting asset management and BIM. As part of this transformation we have implemented the methodology presented in this paper to support their information requirements development. The newly developed Strategic Asset Management Plan (SAMP) was exploited and 18 objectives were extracted. This included financial (reduce operational costs), environmental (reduce environmental impact) and operational (less reactive and more predictive maintenance) objectives. Furthermore, the broader university strategies were utilised to obtain high-level customer and reputational objectives. Secondly, their current asset register was reviewed and the assets were classified into functional outputs and asset systems using the UNICLass classification. This was validated by interviews with key personnel in the Estates Management team. In total, 42 functions were classified with their associated asset systems. OIR’s where developed within collaborative workshops that saw CSFs and PLQs being developed for each individual objective. On average 4 CSFs where developed her objective and 15 PLQ. Finally, the FIR and AIR were developed utilising the newly created asset classification system and working within collaborative workshops, with the correct stakeholders both at the FIR and the AIR level. Developing the FIR helped to bridge the gap between the OIR and the AIR, allowing non-technical management to engage with the process at a level that was understandable and were able to articulate their requirements.

The public transport provider case study is currently in its initial stages and is significantly larger then Estate Management. This organisation maintains and operates all of the roads, rail, bus and metro within a major city. One of the first challenges for this organisation was extracting and organising the objectives as they were spread over several documents including Balance Scorecards, environmental frameworks, business plans, SAMP and customer engagement policy. In whole 87 unique objectives where identified. This exercise identified overlapping and conflict objectives within the broader organisation that could be addressed and consolidated as needed. As the organisation already has a comprehensive asset classification system, it was only required to classify the functional outputs and develop the relationships between the already classified asset systems. At this stage, we are currently in the process of developing OIR and FIR.

From these case studies, it could be seen that a structured methodology for the development of OIR and AIR allows organisations to effectively develop information requirements that meet their requirements. Both organisations had some kind of AIRs developed within their asset management tools, but they were often developed in an ad-hoc manner and only focused on the technical requirements. Furthermore, both organisations did not have a single OIR document. While some of these requirements would be in their management processes, they were poorly documented and often misunderstood. Moreover, there was a clear challenge in how to translate often abstract and high-level OIR into AIR.

Following this approach allowed the organisations to focus on their high-level requirements (OIR) and to be translated into AIR. The FIR acted as an effective stepping stone to translate from OIR to the AIR. The easily understandable nature of functional outputs aided non-technical personnel to be able to engage in the process and have their requirements captured.

4.3 Lessons Learnt

While the methodology as a whole supports the development of AIR, the processes and tools used within the methodology are not without their own challenges. Stakeholder engagement and selection was critical to ensure the correct personnel were in the workshops. It was often a challenge to ensure that the appropriate personnel were in the different workshops to support the development of specific information requirements. The case studies revealed that the development of IDM during the AIR workshop can often create conflicting process maps and highlight multiple workflows for the same action. This can result in challenges within the negotiation process for prioritising the workflows. Finally, while the methodology was generally accepted as useful and generated the results that were valuable to the asset managers, it was noted that organisational departments that are not typically associated with asset management would require extra support throughout the processes. It was also noted that further work is perhaps necessary to ensure that the methodology can be used by practitioners at large without support from the authors.

5. Conclusion and Future Research

this paper proposed an organisational lead asset information requirements development process that is guided by the traditional concept of engineering requirements and the emerging domain of BIM.

The literature review (within section 2) discovered that the development of information requirements is a complex and often puzzling task. The earliest development of IMS within the 1960/70's often neglected the task of information requirements development and result in reduced operational perf=ormance. Furthermore, the adoption of IMS within EAM is immature compared to other domains. While a branch of software engineering called Requirements Engineering (RE) has provided a framework for the development of information requirements, the standard techniques used within the framework have limited use within EAM due to its multifaceted nature. BIM has been described as an enabler for the adoption of an IMS within the construction and EAM sectors. While BIM has been actively implemented within the design and construction phases, it is adoption within the operational phase has been limited. This is partly due to the complexity of capturing OIR within the initial stages of the BIM information management processes. While there are a few example methodologies within the reviewed literature, they fail to create the required alignment between the OIR and the AIR and therefore do not address the BIM requirements. There is a definite requirement for the development of new techniques that build of the work completed within RE and accompanies the emerging domain of BIM and EAM.

Section 3, firstly, recommends an extension to the current BIM information management relationships (see Figure 2), this involves aligning high-level EAM documentation such as organisational policies, objectives and plans to the OIR. This provides a direct link between the organisational documentation and the development of the OIR. .It was witnessed that the link between the OIR and the AIR was too much of a leap for EAM organisations and a new set of information requirements to support the OIR generating the AIR, which takes advantage of the organisational point-of-view of their assets as the functional output they support and proposed Functional Information Requirements (FIR). Step 1 involves reviewing organisational documentation, specifically EAM related and extract objectives from the documentation. Once the objectives have been extracted, they are then categories by operational, environmental, health & safety, financial and reputational. Step 2 requires the organisation to classify their engineering assets as per the functional output they support and the asset systems that support that function, with a parent-child relationship. Step 3 is the development of OIR, a set of OIR’s are developed per objective extracted within step 1. Step 4 is using the functions that were classified within step 1 and the OIR developed within step 3 to develop the FIR. Each function is put within the Information Requirements Matrix (see Figure 5) and information requirements are captured under the categories of technical, managerial and financial. Step 5 is the development of AIR, the critical feature of the AIR development is completing an AS-IS (current) IDM process map, to capture the points of exchange and the information exchanged. step 6 aims to validate the created information requirements. This is achieved in a collaborative workshop environment that supports the negotiation process to allow conflicting and often diverse stakeholders to agree on the information requirements. Step 7 is the final set to document all the created information requirements. All documentation should be both human readable and machine readable, machine-readable aspect is out of the scope of this paper. Any parent-child relationships, such as those developed within asset classification should be maintained.

Traditionally AIR our generated from the bottom-up, meaning they are more technical operational requirements, as maintenance and operational personnel have developed them for their own requirements. This means that organisational financial, environmental and reputational requirements are often missed within the AIR. The proposed framework provides a direct alignment between the organisation objectives and the information that is captured at an asset level. This is achieved by directly developing OIR from the organisation objectives that generate the AIR via FIR. This has several advantages. Firstly, it supports the capture of organisational requirements at the asset level. Secondly, it means that only information that is relevant to the organisation is captured. finally, it provides a structured and repeatable framework, no matter the sector or industry.

Future research should focus on how the structure of the captured information in the sense of technical development. This should include elements of how the information is stored, in what format and how information is exchanged between the different stakeholders’ and lifecycle phases. Furthermore, to the dynamic nature of organisational objectives and the manual task of extracting them within step 1, future research should investigate how emerging technology can support organisations to digitalise their organisational documentation and streamline this step.

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