

1 **A Building Information Modelling approach to the alignment of organisational**

2 **objectives to asset information requirements**

3 Abstract

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

17 Keywords

18 Building Information Modelling, BIM, Engineering Asset Management, EAM, Information
19 Requirements, Organisational Information Requirements, Asset Information Requirements,
20 Requirements Engineering

21 1 Introduction

22 The importance of information management within the whole-life cycle of engineered assets is gaining
23 momentum both in academic literature and industrial applications. Information management within the
24 domain of Engineering Asset Management (EAM) is being guided by a set of industry specifications
25 and standards that are solely focused on information management processes for the individual life-
26 cycle phases (design, construction, Operations and Maintenance (O&M) and disposal / renewal) of
27 engineered assets [1–3]. Most notable is the adoption of Building Information Modelling (BIM) that has
28 seen a step change in how information is managed during the design and construction phases, with

29 widespread evidence demonstrating a reduction in design and construction cost, increase in
30 productivity and improved risk management [4–6]. Despite this, it can be seen that the adoption of
31 BIM within the O&M phase is relatively limited [7]. The complexity of adopting BIM within the O&M is
32 multi-pronged, common BIM information management challenges highlighted within the literature are
33 summaries below:

- 34 1. *Fundamental lack in understanding how to demonstrate the value of BIM within the operational*
35 *requirements.* [7].
- 36 2. *Historically the O&M industry has been hesitant to adopted new and emerging technology processes,*
37 *resulting in a culture challenge that spans the whole industry. Indeed, the lack of BIM and general data*
38 *management skills of personnel within the O&M industry strengthen this cultural challenge* [8].
- 39 3. *The interoperability between BIM related data (e.g. 3D models) and the existing O&M management*
40 *systems such as Enterprise Resource Management (ERM) is limited* [9–11]. *Resulting in the often*
41 *manual and ad-hoc approach of using BIM data and devaluing the business case for BIM within O&M*
42 *[12].*
- 43 4. *O&M personnel are rarely consulted on their requirements for a BIM-enabled project, this results in a*
44 *BIM model that is not optimised for O&M* [13].

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

57

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

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

69 2 Background

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

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

87 21]. These techniques were the result of extensive research efforts in the early 1980s and '90s that
88 sought to solve the problems of developing information requirements.

89 2.1 Requirement Engineering

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

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

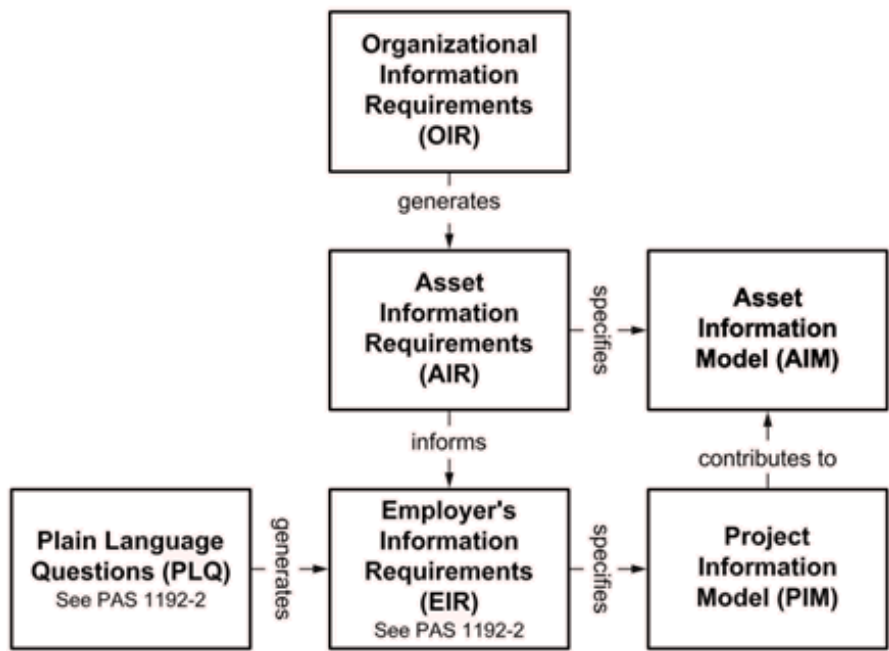
102 RE has predominantly been implemented within none asset-centric organisations such as financial
103 firms, communication firms and marketing, with limited implementation in asset-heavy industries such
104 as rail, highways and estate management. This is partly due to the late and poor adoption of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

106 2.2 Information Management Within Engineering Asset Management (EAM)

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

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

118 BIM has been widely cited as an enabler to supporting the development of information management
119 processes within EAM, most notably supporting the exchange of information throughout the lifecycle
120 of an asset and supporting the development of information requirements [32]. BIM is the process of
121 designing, constructing or operating a building or infrastructure asset using object-oriented design
122 [33]. The British Standards Institute (BSI) has developed an array of BIM related specifications and
123 standards for an asset’s lifecycle management including the exchange of information (geometry and
124 non-geometry), information management processes, common data environment and level of detail
125 [14,33–37]. Most notably, PAS 1192-3:2014 aims to provide a specification for information
126 management within the operational phase of assets [14]. One of the critical components within the
127 specification is defining the relationship between elements in the management of information. Figure
128 1 demonstrates the relationships by visualising the dependencies and hierarchy nature between
129 information requirements developed within a BIM-enabled organisation.



130

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

132 The purpose of the Asset Information Model (AIM) is to be a sole source of validated and approved
133 information related to specific assets. The development of Organisational Information Requirements
134 (OIR) which helps generate Asset Information Requirements (AIR) is a complex task, with very few

135 examples of this being implemented in practice [38,39]. OIR and AIR development is led by technical
136 guidelines, codes, regulations and specifications and will, therefore, struggle to meet the commercial,
137 financial, managerial and customer management requirements of the organisation. Therefore it is
138 critical that a systematic approach is used for developing the OIR from the stakeholders (e.g., clients,
139 operators) requirements [40].

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

162 **2.3 Standards to Support Information Management Processes within Engineering Asset**
163 **Management**

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

179 **2.4 Summary**

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

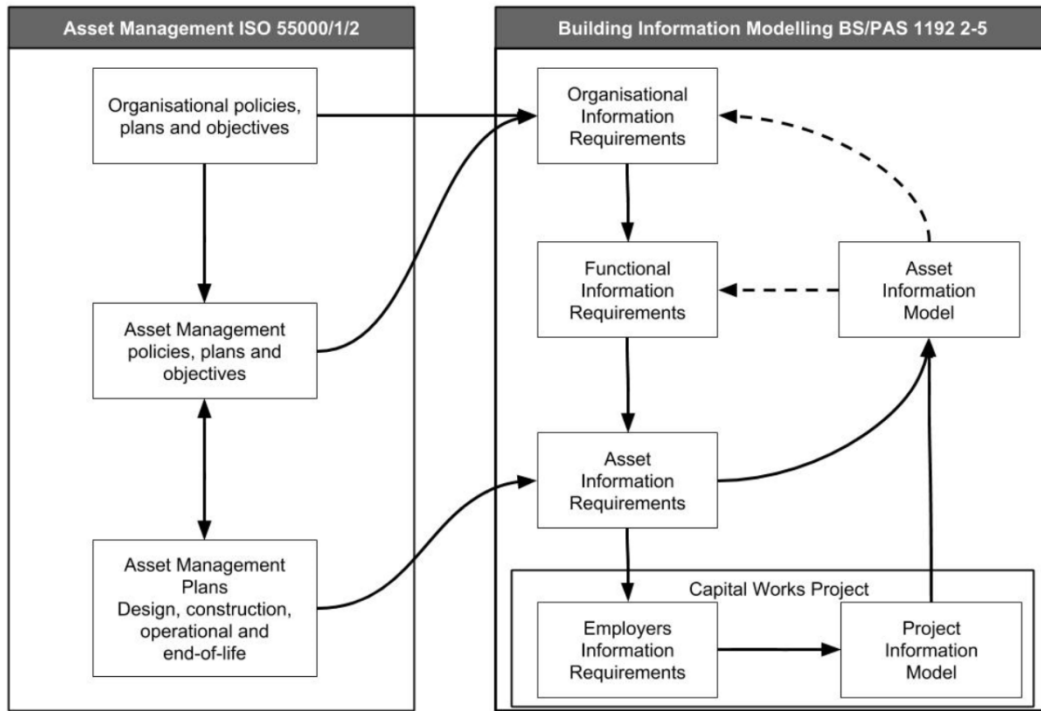
192 witnessed that the jump from OIR to AIR is a challenging step for most organisations. The reasons for
193 this challenge are multifaceted and summarised below:

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

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

202 **3. Information Requirements Development Methodology**

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

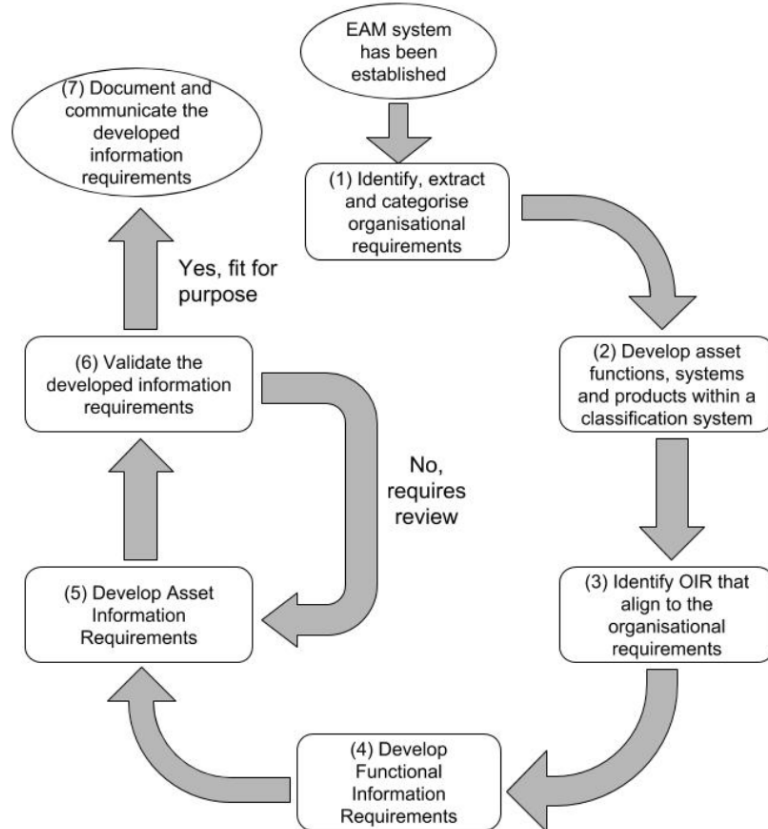


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Figure 2 proposed extension to the BIM information management relationships adopted from [1,14]

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221

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Figure 3 Information Requirements Development Framework

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

225 **Step 1 – Identify, extract and categorise organisational objectives**

226 The first task is to identify the organisational and EAM objectives, Depending on the size and context
 227 of the organisation, these can be spread over several documents often developed in isolation within
 228 individual departments. The set of documentation that should be analysed includes annual reports,
 229 environmental impact strategy, customer strategy and financial growth reports. Analysing the
 230 documents involves comprehensively reviewing the documents and extracting the objectives within
 231 them. Care should be taken to extract SMART¹ objectives, where available. Some documentation list
 232 objectives within a separate section, while other documents have objects embedded into the broader
 233 text, hence why the documents require a comprehensive review. Finally, if the text is not clearly
 234 stated as an objective, then it should be validated with the author / business owner to ensure that it is
 235 an objective. If the organisation has developed an EAM system as defined within the ISO 55000
 236 standards [1], the documents produced to develop such a system including asset management
 237 policies, asset management plans and objectives should be prioritised for analysing. Furthermore,
 238 BIM related documentation such as Information Management Processes (IPM), Employers
 239 Information Requirements (EIR) and BIM data security strategy should also be analysed, to captures
 240 BIM related objectives. A common set of organisational documents that should be analysed are
 241 summarised in Table 1. If necessary, the objectives can also be identified through targeted interviews
 242 with key decision makers within the organisation. Where interviews are used to capture the
 243 objectives, care should be taken to ensure that personal biases of the interviewees are avoided
 244 through useful triangulation. If the organisation has developed a balanced scorecard, this can be a
 245 valuable tool to extract non-financial performance measures and objectives [52].

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

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

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

Table 1 Key Documentation for identifying organisational requirements

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

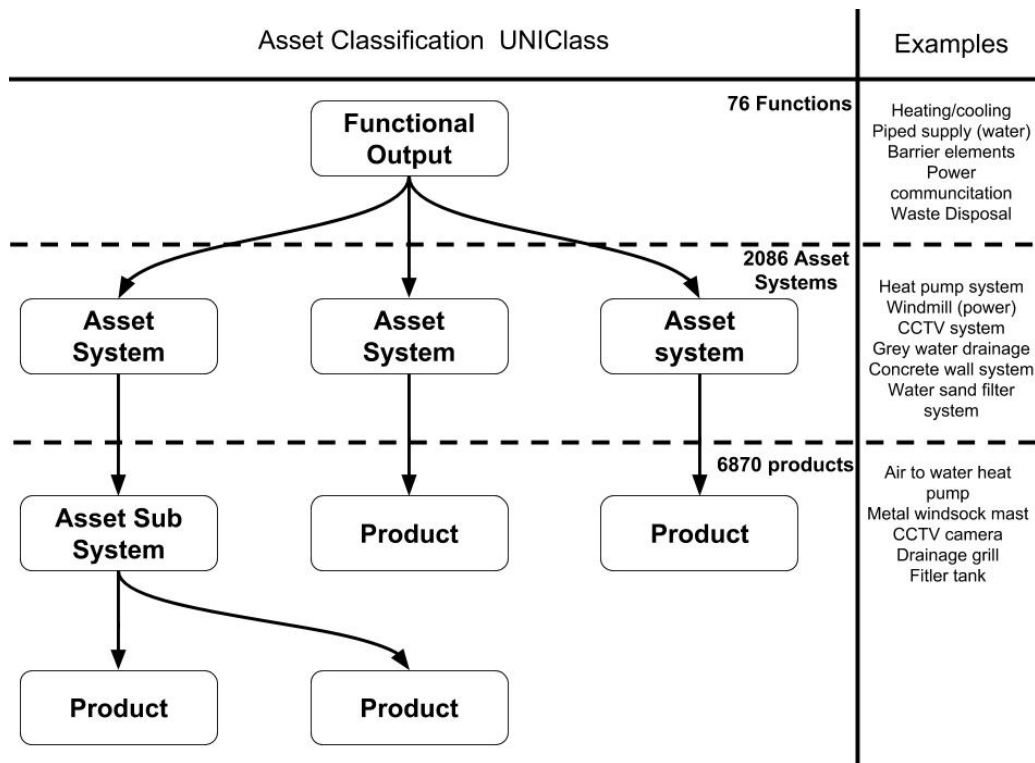
- 255 (i) Large organisations could have over a hundred requirements, and analysing these
256 requirements is made simpler by categorising them.
- 257 (ii) The categorisation can help identify any gaps within a specific category.
- 258 (iii) It allows for identifying conflicting or duplicate organisational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

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

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

265 The second step requires the organisation to classify its asset portfolio using an asset classification
266 system. An organisation classifying its engineering assets is a crucial element of the methodology as it
267 supports the future development of information requirements. The parent-child Hierarchy relationship
268 within the classification systems is utilised to support the developed multiple levels of information
269 requirements, from high-level requirements (e.g. heating or ventilation requirements) to low-level
270 granular requirements (e.g. radiator or air supply fan). The most comprehensive classification systems
271 that support EAM are UNIClass and Omniclass [53,54]. They both follow the industry standard ISO
272 12006-2 [46] for classification of assets.

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



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282

Figure 4 Asset Classification Hierarchy

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It is proposed when implementing a classification system that the organisation first classify the

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functional output of their engineering assets. UNIClass Table EF provides a database of 76 functions

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that offers a comprehensive set of functional output covering all sectors including infrastructure,

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buildings and civil works. The key benefit of such a classification system is having a starting point for

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engineering asset classification that is understood through different organisational departments. As an

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example, the customer relationship department within an estate management company won't have

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expert knowledge on the engineering asset systems or products that support the function of heating,

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but they will understand the performance requirements (e.g. temperature) that the tenants require.

291

Furthermore, classifying the assets functional output enables the alignment of the functional output to

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the asset systems and the products that support that system, this creates a direct line-of-sight from

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the asset functional output to the asset systems and products. Moving down the classification

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hierarchy, it is then required to classify the asset systems that support the functional output.

295

UNIClass Table Ss provides a classification of 2085 asset system. Only asset systems that support

296

the functional output should be classified. A sub-system might be required to be classified depending

297

on the specific organisational requirements. Finally, the lowest level of the engineering asset

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classification system is the individual products that support the asset systems. UNIClass Table Pr

299 provides a classification of 6870 products. Care should be taken when classifying products, as
 300 classifying all the products within the asset systems can be an extensive task, only products that are
 301 critical to the organisational objectives should be classified.

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

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

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

Information Requirement Category	Summary
Financial information requirements	<i>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.</i>
Managerial information requirements	<i>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.</i>
Technical information requirements	<i>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</i>

performance data, design parameters and dependencies and interdependencies

316 *Table 2 Summary of Information Requirements Categories*

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

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

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

		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

338

Table 3 Organisational Information Requirements Summary

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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.

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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

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351 questions that an organisation asks of their engineering assets, the data received will aid in answering
352 the questions. Furthermore, the top three asset functions that impact the objectives are captured and
353 used in the following steps.

354 **Step 4 – Develop Functional Information Requirements (FIR)**

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

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

369 The development of FIR is best achieved within a multi-discipline collaborative workshop
370 environment. The workshop should be developed from such requirements engineering techniques
371 including stakeholders’ engagement, Joint Design Application (JDA), brainstorming and prototyping.
372 Stakeholders’ engagement should focus on highlighting the critical personnel required in the
373 workshop. The FIR is vital in aligning the organisation with its engineered assets, as such the key
374 personnel should understand the organisational management framework such as risk management,
375 capital investment decisions and customer management processes. Typical personnel include asset
376 managers, financial directors, risk managers and customer engagement managers. Due to the multi-
377 discipline nature of this process using the user involvement nature of JDA to structure the workshop is
378 a natural fit. While there is no hard structure for the development of JDA workshops, there are some
379 fundamental building blocks that include facilitation, agenda setting/structure, documentation and

380 group dynamics. Brainstorming is a group creativity technique that aims to find a dynamic conclusion
381 to a set of problems. specifically, guided brainstorming is used as part of the group exercise within the
382 JDA and therefore in the development of FIR. Depending on the complexity of the organisational
383 objectives and the asset functions it could be beneficial to develop a set of prototypes, simulating the
384 use of the information requirements within the FIR workshops to support the decision-making
385 processes. The benefits are two-fold: firstly, it supports the validation that the development
386 information requirements are fit for purpose. Secondly, it limits the risk of an IMS being developed that
387 is not fit for purpose and requiring expensive upgrade and reworks. It is important to state that not all
388 prototypes have to be software development related, it can emulate an event happening and the
389 exchange of information within current business and software processes, therefore validating if the
390 correct information requirements have been captured for the associated organisational objective.

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

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

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

405

406

Figure 5 Information Requirement example

407

the critical outcome of this step is a comprehensive set of FIR's that aligns to supporting asset

408

systems. The information requirements are developed within a collaborative workshop environment,

409

utilising elements of brainstorming and prototyping. While the information captured should be

410

comprehensive, it is worth noting that it should only focus on the information required at the functional

411

level of the asset and not the asset systems level, these will be captured in the following step. The

412

FIR should aim to provide answers to the questions that were raised in the developed of the OIR (step

413

3).

414

Step 5 – Develop Asset Information Requirements (AIR)

415

The fifth step is to develop the AIR for the asset systems that have been defined within the functional

416

information requirements matrix. To avoid confusion with the associated BIM 1192 standards, this

417

step will develop asset information requirements as defined within the 1192 standards, both asset

418

systems and products information requirements are captured within the AIR. The definition of an AIR

419

is “any information that is captured at an assets system, sub-system or product level of an

420

organisations asset classification system that supports the organisational requirements for their

421

assets, including operational and maintenance management, spares management and risk

422

assessments”. The AIR should aim to provide the data for the information requirements developed

423

within the FIR.

424

Much like the development of FIR, the development of AIR is best achieved in a multi-discipline

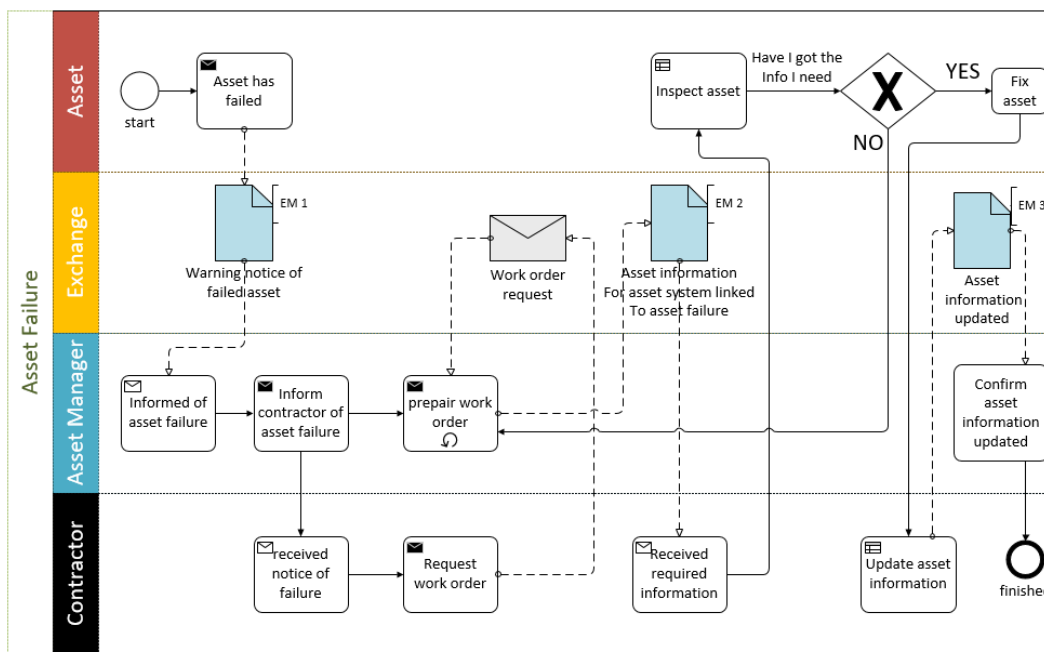
425

collaborative workshop environment. The workshop should utilise the same methodologies such as

426 stakeholders' engagement, joint design application and brainstorming. In addition to this, a new
427 dynamic group exercise is introduced called the Information Delivery Manual (IDM) [44,45]. While the
428 limitations of using the IDM methodology as a single solution for the development of information
429 requirements was expressed within section 1, in the context of this framework and more specifically this
430 step it provides a structured approach to the capture of AIR. Regarding stakeholders' engagement at
431 the AIR level, it is required to have the personnel that operate and maintain the asset portfolio at the
432 asset system and product level. As such, it is required to have operational and maintainer engineers
433 that have a strong technical understanding of how the assets within a system and as individual
434 assets.

435 The IDM methodology utilises process maps that are defined using Business Process Modelling
436 Notation (BPMN), specify the actions for a given activity and the supporting data and information
437 requirements that support the given activity. The IDM methodology is divided into three discrete parts
438 including process maps, exchange requirements and technical implementation. The IDM methodology
439 is used to capture the current (as-is) flow of information between the defined actors of an asset-
440 system for a given EAM activity. This process will capture the specific information that is exchanged
441 to support activities such as maintenance, commissioning of new assets and risk assessments. While
442 not all these activities will directly relate to an organisational objective, they will support in achieving
443 the objectives. As an example, the information captures the activity of maintenance will have an
444 impact on the objective to reduce business costs by 5%. The information highlighted is analysed
445 within a workshop environment and if demanded appropriate to help answer a question or questions
446 developed within the OIR, it is captured within the information requirements matrix (see Figure 5) and
447 forms part of the AIR. The process map should be completed in a collaborative workshop
448 environment with stakeholder from the above stakeholders' engagement exercise. Firstly, an EAM
449 activity is selected, care should be taken to prioritise the key activities that will impact the
450 organisational objectives. Secondly, the actors are identified. These are actors that within some point
451 within the activity they send or receive information as part of the process, manually such as an email
452 or a phone call and automatically such as an automatic work order sheet or asset failure warning from
453 a sensor. These actors are structured into "swim lanes" which these swim lanes are the processes
454 and functions that the individual actors perform, these are indicated by rectangles and the flow by
455 solid arrows. A process map will always have the swim lane Exchange when information is

456 exchanged between the actors it is highlighted within this swim lane and the flow of information by
 457 long dotted arrows. The manual exchange of information is indicated by an envelope while the
 458 automatic exchange is indicated by a sheet with a folded corner as per the IDM and BPMN standards.
 459 As part of the BIM design model classification process, BS 1192 provides a standard set of roles
 460 (actors) that should be used as guidance which defines such roles as a facility manager, contractor,
 461 client, civil engineer, building surveyor and structural engineer [34]. Furthermore, UNIClass table
 462 Project Management (PM) provides a classification of design, construction and EAM key roles and
 463 actors [53]. The defined actors should be classified where possible to allows for future automatic data
 464 extraction and filtration per actor type. Figure 6, provides an exchange of a process map show the
 465 essential functions and processes within the actors' swim lanes and the exchange of information
 466 within the activity of asset failure.



467

468 *Figure 6 Information Delivery Manual, Process Map*

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

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

481 **Step 6 – Validate the developed information requirements**

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

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

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

503 support the collaborative framework and environment that supports the required cross-functional
504 negotiation processes

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

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

522 **Step 7 – Document and communicate the developed information requirements**

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

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

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

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

552 **4 Case Study**

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

558
559

560 **4.1 Case Study Approach**

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

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

580

581 **4.2 Methodology Review**

582 The Estate Management team provides all of the university's O&M requirements while managing the
583 financial costs, planning and scheduling of works and commencing of new assets / buildings.

584 Furthermore, Estate Management also manages the IT applications that are used to support asset
585 management activities such as capturing maintenance reports. Historically the Estate Management
586 team has struggled to report efficiently on their assets' performance (financial and non-financial) and

587 are often focused on acting reactively. This is partly due to poor information management.
588 Specifically, Estate Management had not implemented a standard asset classification system or used
589 a structured approach to the development of AIR, which means they struggle to filter and extract the
590 data that meets their requirements. Recently Estate Management embarked on a transformation
591 process that includes adopting asset management and BIM. As part of this transformation we have
592 implemented the methodology presented in this paper to support their information requirements
593 development. The newly developed Strategic Asset Management Plan (SAMP) was exploited and 18
594 objectives were extracted. This included financial (reduce operational costs), environmental (reduce
595 environmental impact) and operational (less reactive and more predictive maintenance) objectives.
596 Furthermore, the broader university strategies were utilised to obtain high-level customer and
597 reputational objectives. Secondly, their current asset register was reviewed and the assets were
598 classified into functional outputs and asset systems using the UNICLass classification. This was
599 validated by interviews with key personnel in the Estates Management team. In total, 42 functions
600 were classified with their associated asset systems. OIR's were developed within collaborative
601 workshops that saw CSFs and PLQs being developed for each individual objective. On average 4
602 CSFs were developed per objective and 15 PLQ. Finally, the FIR and AIR were developed utilising
603 the newly created asset classification system and working within collaborative workshops, with the
604 correct stakeholders both at the FIR and the AIR level. Developing the FIR helped to bridge the gap
605 between the OIR and the AIR, allowing non-technical management to engage with the process at a
606 level that was understandable and were able to articulate their requirements.

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

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

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

629 **4.3 Lessons Learnt**

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

643

644 **5. Conclusion and Future Research**

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

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

662 Section 3, firstly, recommends an extension to the current BIM information management relationships
663 (see Figure 2), this involves aligning high-level EAM documentation such as organisational policies,
664 objectives and plans to the OIR. This provides a direct link between the organisational documentation
665 and the development of the OIR. It was witnessed that the link between the OIR and the AIR was too
666 much of a leap for EAM organisations and a new set of information requirements to support the OIR
667 generating the AIR, which takes advantage of the organisational point-of-view of their assets as the
668 functional output they support and proposed Functional Information Requirements (FIR). Step 1
669 involves reviewing organisational documentation, specifically EAM related and extract objectives from
670 the documentation. Once the objectives have been extracted, they are then categorised by operational,
671 environmental, health & safety, financial and reputational. Step 2 requires the organisation to classify
672 their engineering assets as per the functional output they support and the asset systems that support

673 that function, with a parent-child relationship. Step 3 is the development of OIR, a set of OIR's are
674 developed per objective extracted within step 1. Step 4 is using the functions that were classified
675 within step 1 and the OIR developed within step 3 to develop the FIR. Each function is put within the
676 Information Requirements Matrix (see Figure 5) and information requirements are captured under the
677 categories of technical, managerial and financial. Step 5 is the development of AIR, the critical feature
678 of the AIR development is completing an AS-IS (current) IDM process map, to capture the points of
679 exchange and the information exchanged. step 6 aims to validate the created information
680 requirements. This is achieved in a collaborative workshop environment that supports the negotiation
681 process to allow conflicting and often diverse stakeholders to agree on the information requirements.
682 Step 7 is the final set to document all the created information requirements. All documentation should
683 be both human readable and machine readable, machine-readable aspect is out of the scope of this
684 paper. Any parent-child relationships, such as those developed within asset classification should be
685 maintained.

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

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

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