A framework for the development of Asset Information Models to support Asset Information Requirements throughout the lifecycle of buildings

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Abstract

The development of building projects is increasingly being considered as a whole life cycle activity in several initiatives especially by public sector procurers. Despite the growing use of Building Information Modelling (BIM) workflows, there are still key challenges hindering the smooth delivery of data and information to the operation phase of buildings. Central to these challenges is the contemplation and delivery of owners' requirements for building lifecycle. Indeed, investment decisions in the Architecture, Engineering and Construction (AEC) industry are still focused mainly on the minimisation of capital costs.

This paper proposes a framework that supports building owner's requirements throughout the lifecycle of buildings. The framework exploits open standards, including Industry Foundation Classes (IFC) and Information Delivery Manual (IDM), in the creation of Asset Information Models (AIMs). The AIM is a data model that contains all digital data that is required to operate an asset. The process for creating the AIM considers the Asset Information Requirements (AIRs) which define the owner's requirements for building lifecycle including the maintenance strategy. A use case is developed to illustrate the logic of the proposed framework and the feasibility of its processes.

Keywords: BIM, Asset Information Requirements, Asset Information Model, IDM, IFC

1 Introduction

The management of owners' requirements in construction projects has been the subject of several studies (Kamara et al. 2000; Yu et al. 2010; Kassem et al., 2011; Love et al. 2014). The development of construction projects is still focused on costs, time, quality, and safety performance at the capital delivery phases. Indeed, the operation and maintenance costs are often overlooked by owners and project stakeholders despite they could represent over half of the total building life cycle cost (Becerik-Gerber et al. 2012, Kelly et al., 2013). To support building owners' requirements, it is fundamental to consider total expenditure (capital and operational costs) from the inception stage of projects.

The consideration of total lifecycle costs in building projects presents several challenges. While life cycle costs can be determined from the early stages of building development and progressively fine-tuned throughout the design and construction phases, the intended use for the building often changes throughout its lifecycle. This often results in unpredicted effects on costs, especially those related to energy, maintenance and retrofit operations, limiting the validity of life cycle cost estimations. To reduce this uncertainty, a robust methodology is needed to support the development and checking of owner's data and information requirements throughout the lifecycle of the building.

The Building Information Modelling (BIM) methodology aims to provide means to support the exchange of information across the lifecycle of buildings through the interchange of data in neutral formats between different technologies. The use of BIM in a whole lifecycle approach can provide the support of the needed information for asset maintenance planning and execution (CIC 2012). Within this context, this research utilises BIM to support a methodology for the definition and verification of client's requirements throughout the lifecycle of a building. The need to support the owner's requirements in the definition of asset information models has been recognized in the PAS1192-3:2014, which specifies an information management methodology for the operational phase of building assets based on open BIM standards – IFC and COBie (BSI 2014a). While the PAS1192-3:2014 focuses on the operational phase of assets, its recommendations should be considered from the early stages of the development of construction projects (BSI 2014a). Information in building models should reflect the owner's requirements so that at the handover stage, handover data can be an input for the owner's Asset Information Model (AIM). The AIM is different from the record model of the building. While the AIM contains data that is required to run the facility, a record model is a record of the facility at handover which will often include information that will not be useful to the owner.

Several other standardisation efforts are proposing the use of the information management capabilities of BIM to support building lifecycle information. These include: ISO 15686-4:2014 use of open BIM standards IFC and COBie for service life planning (ISO 2014); BS 8544:2013 lifecycle costing during the maintenance phase of buildings (BSI 2013); and BS 1192-4:2014 supporting owner's information exchange requirements using COBie (BSI 2014b).
The above standardisation efforts outline the general requirements and processes to support building lifecycle phases. However, a methodology to support the definition and verification of the owner's requirements throughout the lifecycle of the building is still missing. The use of BIM and its underpinning open standards can provide the opportunity for structuring these information requirements and supporting their changes throughout the lifecycle of the building.
This paper proposes a framework that supports the definition of owner's requirements in the form of Asset Information Requirements (AIR), considering the input from designers and facility managers, and the verification of these throughout the lifecycle of the building. The framework utilizes open standards including Information Delivery Manual (IDM), and Industry Foundation Classes (IFC) and Construction Operations Building information exchange (COBie). The proposed framework is based on the Service Oriented Architecture (SOA) paradigm, which includes a collection of services (i.e. self-contained, well-defined, and reusable functions) that can support a mixture of planned and unplanned maintenance tasks that can happen with any order during the use phase of buildings. The framework, in such context, is intended as an abstraction of the generic functionality of the SOA.

2 Research Methodology

This research aims to support the definition and verification of AIRs throughout the lifecycle of a building using open standards such as IDM, IFC and COBie. To deliver this aim, we first conducted a literature review covering current research on BIM for owners and facility managers, and related standards in this field. Based on findings from the literature, and on discussions with designers and facility managers, a framework is proposed to support the definition and checking of owner's requirements throughout the lifecycle of a building. The definition of owners' requirements focuses on AIR and considers the input from the design team and facility managers. The framework utilizes the IDM methodology to allow the owners to obtain an AIM that conforms to their requirements, including the support for changes in such requirements. The proposed framework supports the input of various construction project stakeholders (i.e. architects, engineers, contractors, client, owners and facility managers to the AIM through the adoption of a Service-oriented architecture (SOA). A use case is developed to showcase how the proposed framework can support maintenance tasks. Finally, a discussion is provided to clarify the significance of the results from the development of the framework and to outline future developments.

3 Literature Review

3.1 BIM for Owners and Facility Managers

BIM can be used by building owners as a tool to check and validate their requirements. Potential benefits that building owners can gain by using BIM for requirements checking include (Eastman et al. 2011): increased building energy performance; reduced financial risks through earlier and more reliable cost estimates; shortening of project schedules by using BIM models for coordination; assuring program compliance through the analysis of the BIM model against owner and local code requirements; and optimised facility management and maintenance through the definition of the relevant information for the AIM.

The importance of owner requirements in construction industry has been the subject of numerous studies. Understanding owner requirements is considered as one of the key factors to improve construction processes (Egan 1998). However, in current practice there is still a lack of clarity in the definition of clients' project briefs and a limited engagement of the client in the briefing process (Yu et al. 2010). In an attempt to address the need for a framework to support owner's requirements, a process model to convey the information in client requirements to downstream stakeholders in design and construction was provided (Kamara et al. 2000). More recently, a framework was proposed to assist asset owners in realizing the value from investing in BIM. From the asset owner's perspective, the investment in BIM needs to consistently generate value (Love et al. 2014). This is only possible if the benefits can be measured, and for this to happen it is fundamental to define requirements in a structured way. It is also essential that the information produced in BIModels conforms to the owners' requirements so that an AIM can be produced to support facilities management tasks.

Facilities management (FM) can be defined as an integrated approach to operating, maintaining, improving and adapting building and infrastructure assets in order to support the primary objectives of the occupants, owners and facility managers (Atkin and Brooks 2009). FM constitutes an extensive field encompassing multidisciplinary and independent disciplines whose overall purpose is to maximize building functions while ensuring occupants wellbeing (Atkin and Brooks 2009, Becerik-Gerber et al. 2012). FM functions require extensive data and information from various fields and disciplines to fulfil their purpose. Traditionally, FM data and information are organised and maintained in dispersed information systems such as Computerised Maintenance Management Systems (CMMS), Electronic Document Management Systems (EDMS), Building Automation Systems (BAS), etc. Currently, the information and data required for such systems comes from different sources, is created and manipulated several times during the asset life cycle, and is not synchronised between systems, resulting in error-prone processes (Becerik-Gerber et al. 2012). The limited use of open standards that define the information requirements for specific FM tasks is also considered a key barrier for improving the information handover to the FM phase. There is a need for open systems and standardised data libraries that can be utilised by any FM system (BIFM 2012). The availability of such open standards and data specifications will represent a significant opportunity if they are successfully adopted by the industry on new and existing assets (Volk et al. 2014). For existing assets, built before the emergence of BIM, the challenge is even greater as their FM legacy systems do not support open BIM standards such as COBie and IFC. They require a robust business case to migrate their existing systems to new open standards compliant FM systems (Kelly et al. 2013).

Several initiatives are addressing the aforementioned issues. Examples include: supporting the transfer of structured information between project parties based on COBie (BSI 2014b); using open standards (i.e. IFC) and data specifications (i.e. COBie) for the definition of Asset Information Models (AIMs) and exchange between AIMs and existing enterprise systems (BSI 2014a). It is expected that the implementation of these standards will facilitate the integration of legacy systems in BIM-based solutions, and support the definition and verification of owner's requirements throughout the lifecycle of buildings and civil infrastructure.

3.2 Case studies

Several case studies discussed BIM applications in FM in both new and existing buildings. One of the earliest attempts at using BIM for FM was in the 'ifc-model based Operations and Maintenance of Building' (ifc-mbOMB) project (Nisbet 2008). This project recreated the design process of a college building using BIM workflows and deliverables which included room-briefing, layout, detailing, environmental analysis, mechanical and electrical equipment requirements, product selection and substitution. During this process, the IFC schema and a model server were used to capture the information needed for asset management. Asset management information was then translated into Maximo facility management format through the mapping of the IFC model to the Maximo data structure (Nisbet 2008). Outcomes from this project provided the bases for the development of COBie.

A notable BIM for FM case study is the Sydney Opera House (CRC 2007). In this project, the Sydney Opera House was modelled specifically for FM purposes using the IFC standard. This project demonstrated the different applications of BIM in FM and highlighted the need for changing current workflows and processes. The project identified the lack of support of the IFC standard by FM tools as a key barrier. Shen et al. (2012) presented an information integration framework that supports software and hardware applications, using agent-based web-services, in providing decision support for facility management and maintenance.

A recent BIM for FM case study, focused on the Manchester Town Hall Complex, explored a combined approach using commercial tools (Artra, E-documents and Concerto) to generate a location-based asset register, and support digital documents such as Health & Safety file, O&M manuals and the building log book (Goodman-Simpson et al. 2014). Outcomes of this project include the identification of the lack of awareness of the potential of BIM in the FM phase and the need for clear guidelines for its implementation in FM as key challenges (Codinhoto et al. 2013).

Another case study by Kelly et al. (2013), focusing on the use of BIM for the management of existing university campus buildings, identified the improved accuracy of records of geometric information and the increased workforce and process efficiencies as two key benefits. The authors also concluded that the lack of: clear requirements for the implementation of BIM in FM; quantifiable key performance indicators; interoperability; clear roles and responsibilities, and contract and liability framework are the main challenges facing BIM in FM applications.

The BIM for FM is now considered a growing area of interest for researchers and practitioners alike. This growing interest is boosted by the rapid development in both BIM standards and technologies. Within such area, this research addresses the current gap of limited support of owner lifecycle requirements.

4 Proposed Framework

The proposed framework aims to provide the functionalities and processes for supporting and checking AIRs throughout the lifecycle of buildings through the development of AIMs. The framework considers the role of the various stakeholders during the lifecycle of a building in the definition of AIRs. The subsequent sections illustrate the framework's components and the role of IDM and IFC standards in defining and checking the AIRs.

4.1 AIR definition

Asset Information Requirements specify data requirements for the Asset Information Model. AIRs are generated based on the Organizational Information Requirements (OIRs) and should include information about the asset that can provide the answers to the questions raised in the OIRs (BSI 2014a).

The definition of AIR often constitutes a challenge to the owner since these documents specify requirements for all the disciplines involved in the development of the project and the management of the building until the end of its lifecycle. On the other hand, well defined AIRs are essential to control the information centric processes that support various tasks during the design, construction, maintenance operations, and demolition throughout the lifecycle of a building.

PAS 1192-3 (BSI 2014a) proposes a set of information requirements for AIR based on PAS 55:2008-1 (BSI 2008). AIR definition should also take into account the input from designers and facility managers. Professionals from these fields can help determine: a) what are the assets and b) what is the intended use of handover data, so that it can be used by the owner for his asset management needs.

The design of built assets must fulfil the AIR, including support for the functions that have been defined by the owner, and requirements in building standards and other relevant legislation. In order to fulfil these functions, a maintenance policy should be established, where maintenance targets are defined for each of the identified asset functions. Maintenance targets evaluate whether the desired functional performance of an asset is guaranteed (Moubray, 1997).

To support the collaborative processes involved in the definition of AIRs, the validation of AIMs and the several tasks during the lifecycle of the building (i.e. operations and maintenance, renovations and retrofit), we propose the implementation of a SOA. The IDM methodology is used for process definition specifying the flow of activities, the supporting data and the information requirements that need to be fulfilled to perform the specified processes. Exchange requirements describe specific information requirements which must be achieved to accomplish certain tasks. A service inventory can be defined to support the various exchanges of information throughout the lifecycle of the building. Based on exchange requirement specifications, services can be defined to support the processes defined in IDMs, and to enable the validation of AIM exchanges. The concept of application server is adopted to support the various data exchanges defined at the process level. Services establish the connection between the process level and the data level. Project specific requirements are supported through the definition of business rules. Separating the logic of project specific business rules from process definitions enables the reuse of defined processes and exchange requirements in different projects (ISO 2010). It also enables the support of requirement changes throughout the lifecycle of the building.

An overview of the proposed framework is outlined in Fig. 1.

The support of AIR in the creation of the AIM from the Project Information Model (PIM) using the connection between Bimserver and openMaint is shown in Fig. 2. AIR can be supported through the definition of Exchange requirements which specify the IFC entities that should be imported into the AIM using openMaint. The support for digital documents including O&M data such as H&S file and O&M manuals is provided through the use of an EDMS.

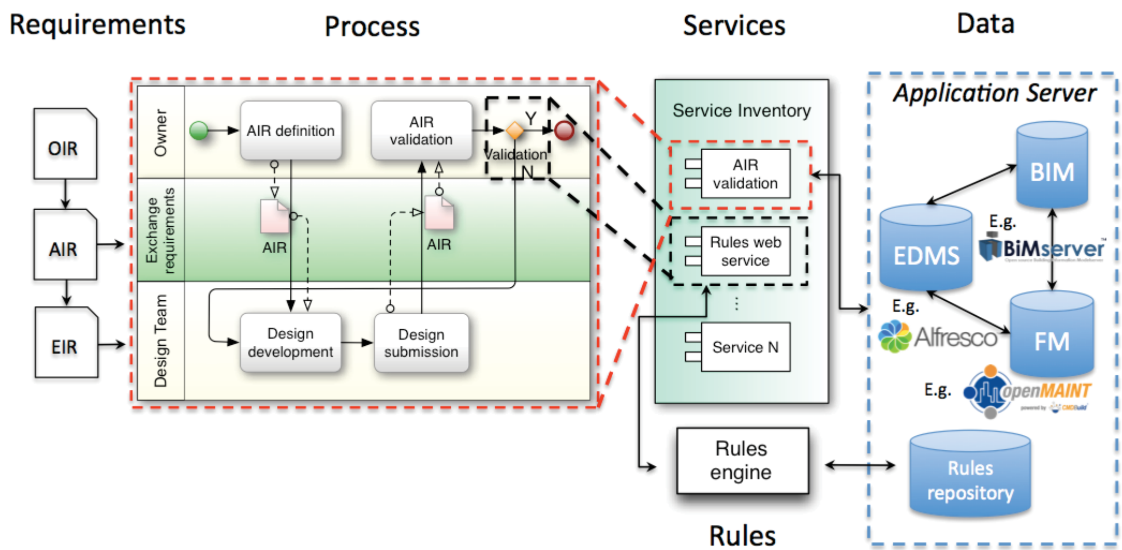

Fig. 1 – Proposed framework including the relations between owners' requirements, process definitions, services, rules and data layers

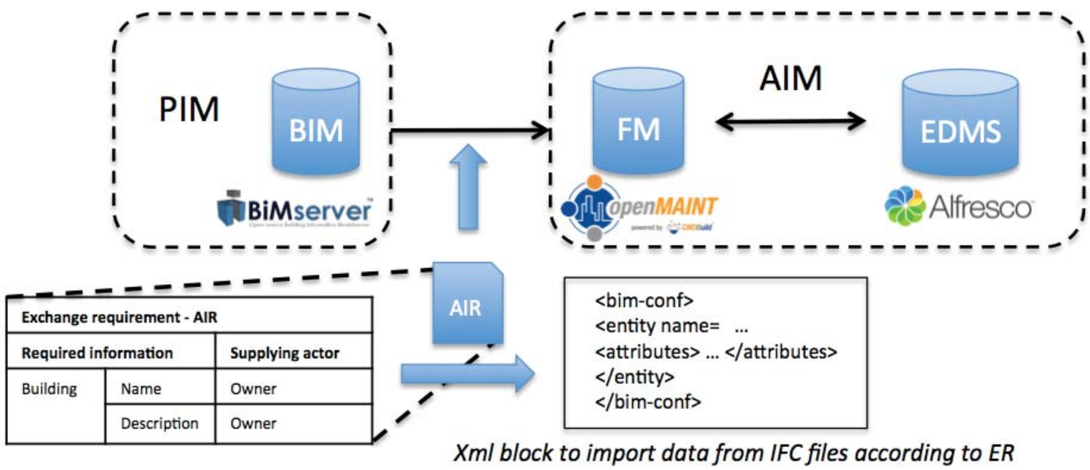

Fig.2 – Support of AIR using exchange requirements in the definition of the AIM in FM application (openMaint)

4.2 AIR verification

Checking the information delivered as part of the AIR is a key requirement. In the proposed framework, the AIR checking is achieved through the adoption of the IDM methodology. The purpose of the IDM methodology is to specify the exact information to be exchanged and how this information can be supported in data models (ISO 2010). In the framework's context, IDM can be used to define specific data requirements that can be used to audit IFC/COBie submissions against the AIR to ensure that the data is provided in a suitable format according to the needs of the asset owner to become part of the owner's AIM.

Process maps are defined using the Business Process Modelling Notation (BPMN), specifying the flow of activities and supporting data and information requirements that need to be fulfilled to carry them out. The defined processes can be converted into Business Process Execution Language (BPEL) to enable their execution (ISO 2010). Exchange requirements are defined by specifying data and information requirements to support the defined processes. Functional Parts, which are reusable units of information that specify IFC Entities, Property sets and other Functional parts, are grouped together to support Exchange requirements in the form of Exchange requirement models. Process maps and Exchange requirements are defined in a way which is independent of the project in order to enable their reuse in different contexts. This way it is also possible to define a service inventory based on the process maps and exchange requirements with web services that can be reused across different projects and support changes in owners' requirements. To enable the use of IDMs in a specific context, business rules have to be defined. A business rule engine can be deployed as a web service to enable the definition and execution of business rules (Geminiuc 2015). This way it is possible to define specific rules to support specific project-related AIRs using the web services defined based on the IDMs. Fig. 3 shows how an exchange requirement model can be used in a specific context through the application of a business rule and how this is supported at the service level.

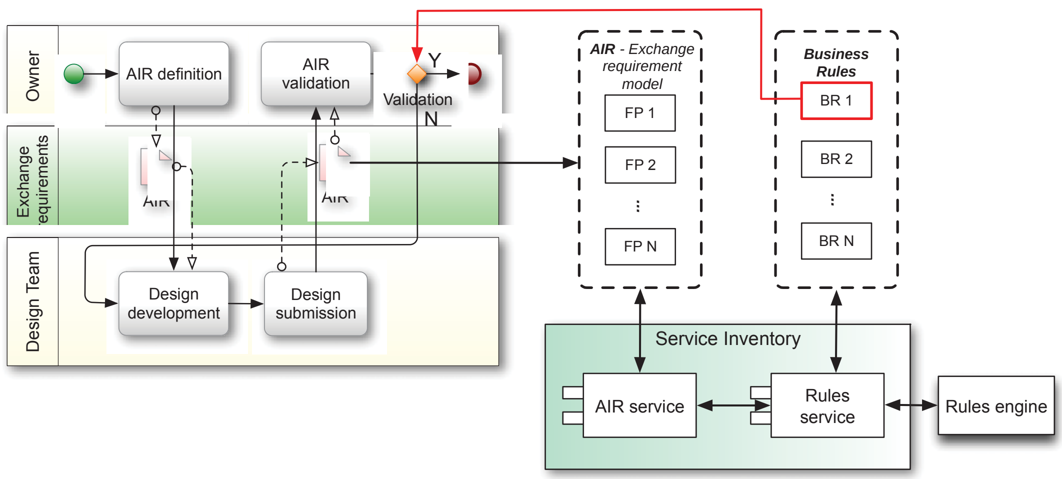

Fig. 3 – Business rules to support a specific exchange scenario using an exchange requirement model (AIR); Support of exchange requirement models and business rules by web services

5 Use case development

To illustrate the proposed framework's capabilities, a use case has been developed focusing on asset maintenance in building mechanical and electrical (M&E) systems. A general maintenance process has been defined using the IDM methodology. The goal of this use case is to demonstrate how the AIRs can be supported through the definition of both a generic maintenance process, and specific business rules according to the BS 8544 standard (BSI 2013).

The development of this use case follows the IDM methodology, including the definition of a Process Map (Fig. 4), Exchange Requirements and supporting Functional Parts (Table 1) and Business Rules (Table 2). The process map describes the sequence of tasks and how they are supported by the AIR exchange requirement. The AIR exchange requirement defines specific data requirements that must be included in M&E components, which are defined as custom IFC property sets in the corresponding Functional Part. These are Asset Criticality Ranking (ACR), which can be critical, or non-critical; Percentage of Asset Remaining Life (PARL), which is given by equation (1); and Asset Renewal Condition which specifies whether the asset should or should not be replaced.

Business rules were defined using MvdXML (buildingSMART 2015) in Table 2 to support the determination of critical assets (Decision Point 1. Asset Renewal) in the specific context of the BS 8544 (BSI 2013).

$$PARL\ (\%) = \frac{Current\ Age}{Remaining\ Service\ Life} \times 100 \quad (1)$$

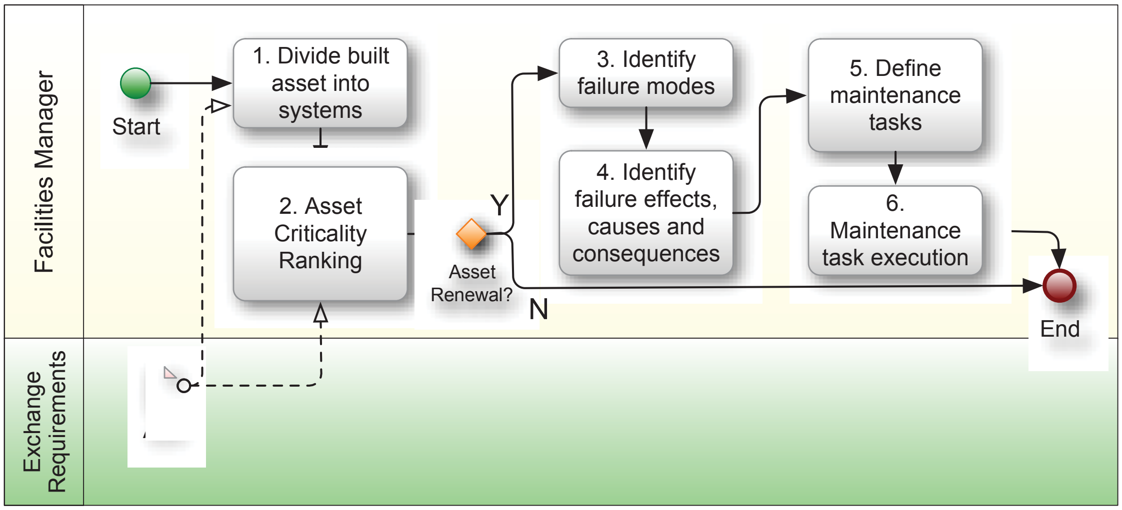

Fig. 4 – Process map to support the execution of maintenance tasks

Table 1 - Definition of AIR Exchange requirements and Functional Parts to support the maintenance process

Exchange requirements			**Functional Parts**
Required information	**Supplying actor**	**Data type**	**Entity/Property set/ Functional part**
Asset Criticality Ranking (ACR)	Owner	String	Pset_AIM.ACR→IFCPropertySingleValue::IfcText
Percentage Asset Remaining Life (PARL)	Owner	Real	Pset_AIM.PARL→IFCPropertySingleValue::IfcReal
Asset Renewal	Owner	Boolean	Pset_AIM.AR→ IFCPropertySingleValue::IfcBoolean

Table 2 – Business rule definition to support Decision Point 1. Asset Renewal; Textual description, Pseudo code definition, and MvdXML definition excerpt

Business rule – Asset Renewal		
Documentation	**Pseudo code**	**MvdXML rule definition for property ACR**
Determination of PARL is mandatory for critical assets. If PARL is less or equal than 20%, asset must be renewed.	1. **Rule** AssetRenewal { 2. **If** ACR == “critical” 3. **Evaluate** PARL 4. **If** PARL <= 20 5. AR = true }	1. <Rules> 2. <TemplateRule Parameters="ACR[Value]='critical'" /> 3. </Rules>

6 Discussion

The goal of the developed use case was to verify the proposed framework by illustrating the practical application of its IDM methodology. The use case focused on the role of business rules to enable the use of a IDM process in a specific context i.e. supporting the maintenance process proposed in BS 8544 (BSI 2013).
Assumptions in the development of this use case are that the method for PARL calculation will remain constant throughout the lifecycle of the asset and therefore it can be implemented in the

AIR service and allows its reusability. The method to determine if the asset should be renewed is implemented by a business rule. The logic is based on the BS8544:2013 standard. Standards used in calculations throughout the lifecycle of buildings can change for several reasons – the standard might become obsolete, or the owner might wish to use a different standard. By keeping the business rules logic separate from the process logic the defined processes and services will remain applicable, if such a change occurs.

Using the proposed framework architecture and logic, it will be possible to generate a set of IDMs that are adaptable to changes in AIRs, enabling their reuse in different contexts, e.g. supporting different standards and different projects. The automation of AIR verification can be enabled by the definition of a service inventory based on the defined IDMs which separates the process logic from the business rules logic. Use cases to be supported by the framework include also the automated checking of AIR against COBie deliverables, following the BS 1192-4 code of practice (BSI 2014b). The use of the proposed framework can increase the support of owner's requirements throughout the lifecycle of the building. In particular, it can help in the definition of AIR from the inception stage of projects by gathering knowledge from different AEC/FM stakeholders (e.g. considering the input of the Design Team and Facility Managers) in IDMs. The framework's capabilities for the definition of AIRs and their support in AIMs are also expected to improve the transition between the construction and use phases.

7 Conclusions

This study proposed a framework to support the definition of owner's requirements in the form of AIRs. The framework considers the input from construction stakeholders such as designers and facility managers and addresses the verification of AIMs against AIRs throughout the lifecycle of the building. The framework suggests the use of the Service Oriented Architecture together with the IDM and IFC and COBie standards to support the automation of this process.

The proposed framework was verified and demonstrated by conducting a use case. The capability of the proposed framework to contemplate numerous specific use cases – such as the one demonstrated in the use case – demonstrate its capability to accommodate different project contexts and to support changes in owner requirements. These results represent an important starting point for the implementation of the framework since they show how the concepts of logic abstraction and process reusability can be achieved. Future work will address the technical development of the framework, including: 1) further exploration of the MvdXML format for the definition of rules, 2) identification of suitable design patterns for the development of the framework, 3) identification of suitable technologies for implementation and 4) consideration of information security issues through the adoption of e-service security standards for the proposed environment and individual services.

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