Information Futureproofing for Large-scale Infrastructure

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Abstract

There are challenges of maintaining, refurbishing and modernising infrastructure assets under limited investments available for such purposes. Potential technological and operational challenges exist as a barrier to long-term information retention, which also plays a crucial role, amongst other factors, to futureproof major infrastructure. These issues appear to be trivial for short-term data management where informal information management practices suffice but over a 50+ year timeframe these issues are critical. The purpose of this paper is to highlight the challenges in futureproofing infrastructure information, and to present a selection of approaches that companies take to address them. It is proposed that strategies of large-scale infrastructure companies should incorporate technological and organisational elements of information futureproofing. An approach to develop information futureproofing strategies is also proposed.

1 Introduction

1.1 Problem Area

Effective design, maintenance, use, upgrade and decommissioning of infrastructure are critical to national competitiveness. The availability of the right information at the right time to the right decision-makers in the right format and quality is essential for effective asset management (i.e., making the right decisions at the right time). Due to the complex operational and technological environment in which infrastructure assets exist, identifying the information requirements for their through life support and management of this information is a challenging prospect, even with the advancement of information technologies. Specifically due to the long lifetime of infrastructure, one of the key challenges in infrastructure information management is the long-term retention and retrieval of asset information. For example, statutory retention of design, material and construction information is typically limited to a period of ten years and beyond this the data is often destroyed. Changing asset owners, loss of documentation, misplacement and obsolete file formats are some of the other factors that can impact on long term availability of critical infrastructural data.

Having seen advances in the use of Building Information Modelling (BIM) in the USA and Nordic countries, there is a major UK initiative underway to ensure the development of formalised infrastructural information via the so-called BIM legislations. This and other related initiatives are helping to ensure that adequate information retention becomes an organisational imperative. There is a need for information, via Construction Operations Building Information Exchange (COBie) drops, to inform on-going building maintenance [1]. In order to benefit from full collaboration, there is also a need to adopt open, sharable and non-vendor specific data formats, typically Industry Foundation Classes (IFCs) [1]. According to recent National BIM Report 2013, only 31% of respondents currently use IFCs, while only 8% use COBie drops [1]. With developments such as BIM as well as 3D design models, and electronic project management, long-term preservation and availability of such information has attracted much attention from stakeholders in the infrastructure sector.

1.2 Futureproofing Infrastructure

The use of the term ‘futureproofing’ is emerging in various domains, e.g. business futureproofing, career futureproofing, infrastructure futureproofing and information futureproofing, to indicate long-term sustainability. Some others argue that nothing can be futureproofed but only improved or optimised. In this paper, *infrastructure futureproofing* is referred to as “the process of incorporating future developments while changing from an unplanned and uncontrolled state to a planned and controlled state of a resilient infrastructure asset or product service system with minimal negative consequences”. This could be achieved by adopting strategies to identify and mitigate multiple risks and inducing flexibility and reconfigurability in future developments e.g. reuse of foundations, adding multiple floors or completely changing the purpose of a building. Amongst other strategies of futureproofing infrastructure, information could also play an important role in supporting whole life decision-making.

1.3 Futureproofing Information (for Infrastructure)

Information futureproofing requirements in infrastructure are defined as “the information requirements to ensure that required information is identified for whole lifecycle of infrastructure assets or product service systems when needed". In order to define digital continuity requirements, the individuals or organisations need to identify what they require of the information for it to be [2]: *Found* (located effectively by the user); *Opened* (viewed in available technology applications); *Worked with* (as needed, such as read, edited, printed, published, re-used); *Understood* (interpreted correctly by the user); and *Trusted* (relied upon by the user as suitably authentic, accurate or timely, including suitability to be used as evidence if required). The *information lifecycle* consists of acquisition, indexing, preservation, collection, access and utilisation stages. Futureproofing, in an information context, endeavours to extend the time until upgrades are required by assessing needs in the time to come and allowing for this by procuring ICT systems that exceed their current needs in terms of storage, processing, speed and functionality so that the system can grow with the organisation [3]. So, *Information futureproofing (in infrastructure)* is defined as "the process to ensure that required information is retrievable (reusable) throughout the whole lifecycle of infrastructure assets or product service systems when needed. The key characteristics of information futureproofing may include *representability, retrievability, reusability and accessibility*". Information and infrastructure futureproofing concepts are further explained in Figure 1.

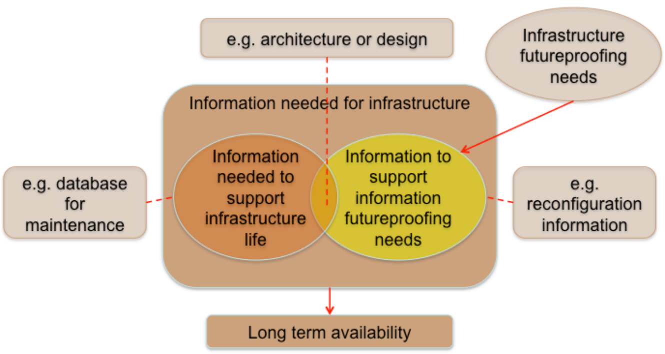

Figure 1: Information and infrastructure futureproofing

So, why is information futureproofing so important? Long-term availability of information is crucial in making decisions required to futureproof infrastructure amongst adopting other strategies. Another reason to why today's IT organisation will not work tomorrow is due to lack of practices in futureproofing IT [4]. The reasons might include current contractual working practices in which projects last for shorter periods of time than required for adopting information futureproofing practices. The main drivers for adopting information futureproofing practices in infrastructure are identified as requirements of Government legislation, BIM Task Force, standards, organisational strategy (e.g. becoming 20% more efficient), treating information as an asset, reliability, availability, decision support and lifecycle cost [5]. Some companies also see commercial benefits in achieving a competitive edge over others to win projects e.g. in the reuse of foundations where having information about old foundations is key to winning contracts.

The above issues are identified as being pivotal to be resolved for the industry's ability to operate, service, maintain, and reconfigure their infrastructure assets. Moreover, there is a need to consider the futureproofing needs of the infrastructure itself and ensure that information which will support the futureproofing needs is also retained and made available in the long term. Therefore, it is imperative that infrastructure managers include information futureproofing strategies within their asset information strategy.

In summary, the key questions related to futureproofing infrastructure information are:

- What information (amongst all the information related to the asset) needs to be futureproofed from the context of regular management of the infrastructure?
- What information is required for futureproofing the infrastructure?
- What challenges are faced in futureproofing the above two types of information?
- What are the technological and non-technological solutions to address these challenges?
- How can the most appropriate solution be selected?

1.4 Outline of the Paper

In this paper, we highlight the challenges faced in futureproofing infrastructure information and present a selection of approaches currently used in industry to address some of these challenges. The rest of the paper is organised as follows. Section 2 presents challenges faced in futureproofing information. Section 3 presents approaches to address information futureproofing challenges, which will also cover the role of information, information requirements for infrastructure futureproofing, and IT for information futureproofing in infrastructure. Section 4 presents case studies followed by conclusions in section 5.

2 Challenges faced in Futureproofing Information

This section highlights the challenges faced in futureproofing infrastructure information. A set of semi-structured interviews of 14 infrastructure related companies were conducted during 2012-13, the results of which suggest the following challenges in information futureproofing [5]: identifying, classifying and prioritising challenges and strategies for futureproofing; value vs. cost comparison for futureproofing; linking information futureproofing needs with BIM and other standards; identifying suitable file formats for futureproofing; long term degradation of information quality; fast changing nature of technologies and systems; lack of communication between stakeholders and challenges in information access; strategic approach to treat information as an asset is needed; and investigating cloud computing as a futureproofing strategy (see Figure 2). The industries involved in these semi structured interviews dealt with Construction, Bridges, Highways, Buildings, Railways, Utilities, Facilities Management (FM), IT, Technology and Water systems across the stages of the life cycle encompassing concept, requirements, design, build, maintain and disposal.

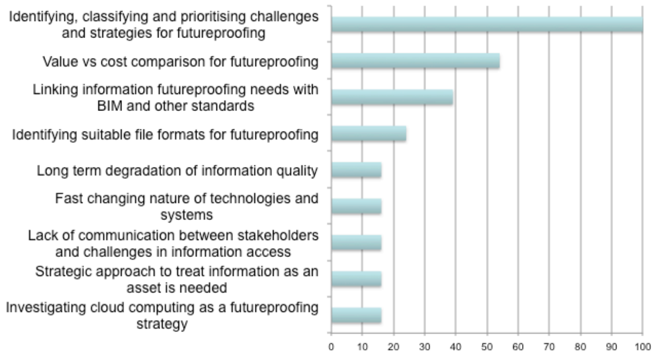

Figure 2: Challenges of information futureproofing in 14 infrastructure asset companies (%) [5]

Loss of digital continuity is a serious information risk and is more likely to happen during times of change, when technology is superseded, older file formats become obsolete, or there are changes in organisation structure and personnel [6]. Such information loss could be due to obsolescence and physical deterioration of storage media. In the relatively short history of digital information, many storage systems and file formats have come and gone again (e.g., punched media, magnetic tapes, 5.25” floppies, Zip disks, 3.5” floppies, etc.). Obsolescence of information reading, storage and access devices including unavailability of interfaces, power sources, or the devices themselves are amongst challenges. Changes to file formats, and meta data (contextual information) – historically it has been observed that many file formats and data structures become obsolete or knowledge relating to the access of such data formats is lost. Loss of knowledge as to the whereabouts of critical information – a seemingly simple yet non-trivial operational challenge is the retention of information location data. These, and other issues, appear to be trivial for short-term data management where informal information management practices suffice but over a 50+ years timeframe these issues are critical. The information futureproofing challenges identified during company visits are classified in the following [5]. We can classify the challenges broadly into two types: technological and organisational challenges.

2.1 Technological Challenges for Infrastructure Information Futureproofing

This section highlights the technology related challenges in futureproofing information due to changes in storage technologies, changes in information technologies in general, changes in software, and changes in technologies used for asset management e.g. introduction of augmented reality for enhanced maintenance management systems. *Hardware-related challenges* follow. Sharing information in 3rd party solutions e.g. cloud hosting; and reusing information effectively e.g. information related to demand, capacity, usage, age, condition, functional condition, planned vs. executed activities, various life cycle costs, etc. *Software-related challenges* include: BIM and COBie challenges (e.g. having digital signatures on drawings, using single model throughout lifecycle); and reusing (or searching) information effectively e.g. information related to demand, capacity, usage, age, condition, functional condition, planned versus executed activities, various life cycle costs. Preservation and format/protocol-related challenges also include interoperability issues in information retaining file formats. Types of information required include design, personnel, logistics, equipment, maintenance, capacity, usage etc. Across such a variant set of information requirements, some of the information is used statically and the other dynamically for which storage and retrieval requirements might be different.

2.2 Organisational Challenges for Infrastructure Information Futureproofing

This section highlights the Organisational (non-technology related) challenges in futureproofing information. The organisational challenges include those imposed due to the long life of infrastructure assets. There are regulatory obligations that require the long-term retention of documents and records. Changes in ownership also pose challenges of information loss during such changes. Lack of appreciation of potential value of information in the long-term means limited availability of resources and funds for such activities. Lack of understanding of what information needs to be futureproofed means loss of opportunity and set back if such requirements are identified at later stages. Other challenges include alignment with information management practices and strategies throughout the organisation in the wake of compliance with multi standards and strategies in large organisations, and alignment with working practices and standards in the organisation.

Having a clear vision and strategy is crucial for information futureproofing. Standardisation of information (and its structure) is complex. Translating information into different domains (individual vs. organisational perspective) is challenging. Aligning current management systems with BIM requirement levels and IFC and COBie drops is also challenging. It is also challenging to determine the appropriate length of time, support and funding required in complex and varying planning time horizons and this impacts decisions e.g. 5-15 years planning horizon vs. 50+ years futureproofing. There are difficulties in information futureproofing to support whole life cycle costing or value. There are challenges in becoming adaptable, flexible and reconfigurable (i.e. using new methods). Mapping reconfigurability characteristics e.g. modularity, integrability, customisation, convertibility, diagnosability. Reusing information effectively e.g. information related to demand, capacity, usage, age, condition, functional condition, planned vs. executed activities, various life cycle costs is also challenging. Another challenge is related to location of information, i.e. ability to share information between different parties successfully.

3 Approaches to address Information Futureproofing Challenges

The aim of this section is to discuss various approaches that companies could take to address the challenges listed in previous section and propose an approach to develop an information futureproofing strategy.

3.1 Establishing Information Requirements for Infrastructure Futureproofing

A 12-box service information requirements model was developed to represent the information flows associated with the design, delivery and evaluation of a service contract. It represents the three key stages of the service process (design, delivery, evaluation) as well as the main elements of the definition of the service (customer need/fulfilment, specification or use, the service offering itself and the supporting infrastructure). For each stage of the process and definition of the service, the key decisions and information required is captured in the model. This has been applied extensively in the context of complex engineering services including IT and aerospace domains (see Figure 3) [7]. When discussed with the industrial partners of the current research (infrastructure asset management companies), they expressed their interest of having a customised information requirements model for infrastructure. The 12-box model has used a decision-oriented approach from which associated information is then determined. The same approach applies in the infrastructure model.

	Service Operation	Service Offering	Service Specification	Service Need
Design	4 Technical information to plan and develop the delivery of the offering	3 Technical architectural/legal information to design offering	2 Information to formalise service contract	1 Conceptual information about customer requirement
Delivery	5 Technical info to run service/infrastructure	6 System level functional information to fully supply service offering	7 Information with respect to service use	8 Information from provider enabling user to exploit service
Evaluate	12 Operational information on performance of service infrastructure and operations	11 Info relating to the effectiveness of service offering and its SLA metrics	10 Information to illustrate the perception/ expectation of the service – vs SLA	9 Information to determine fulfillment of customer need

Figure 3: Service information model [7]

3.2 Role of BIM in Information Futureproofing

The role of BIM in information futureproofing requirements is becoming more important (and poses a challenge) as most of the information required is stored within BIM the environment nowadays [5]. The National BIM Survey Reports from the last three years suggest that the use of BIM is increasing dramatically for storeage and retrieveal of information [1] [8] [9]. The aim of information futureproofing is perhaps beyond current BIM level 2 requirements (or may be covered in advanced BIM levels), which could also potentially include a futureproofing aspect and fill in the shortcomings of BIM. Monetising data within BIM is challenging; however achieving this could play an important role across lifecycle and economic factors for futureproofing, such that it is given a tangible value. This could prevent information being lost when, for example, failing companies are liquidised. It would also help clarify ownership of data and information. There is limited knowledge on which information futureproofing is required, so it becomes challenging to come up with a solution. An important consideration would be to know how intelligence could be attached to information required and to be retained for long term in BIM environment. Currently, the infrastructure companies adopt and comply with standards and emerging paradigms for asset management e.g. BIM, IFC, COBie, PAS55, BS1192, and BS15489 [5]. PDF is currently the chosen document file type for storing and viewing information. Health and safety (H&S) Files (multi format, paper and electronic) are kept. Data migration is in practice when required.

3.3 IT for Information Futureproofing in Infrastructure

IT has a crucial role to play in collection, storage and retrieval of information to meet the information requirements for infrastructure as outlined in previous section. This section deals with surveying and examining possible IT strategies for information futureproofing in infrastructure including organisational and technological (i.e. software and hardware) aspects covering techniques, formats, standards, etc.

Some infrastructure managers consider the proprietary software tools used by their companies as a means of retaining information for the longer term. A few examples include: MAXIMO Asset Management solution used for asset lifecycle and maintenance management [10] [11], IBM Ventyx Ellipse used as an enterprise asset management / enterprise resource planning application suite that provides complete visibility and management of assets for the capital-intensive industries [12], Computer Aided Facility Management software or systems used in FM domain that are also compliant with CAD and BIM solutions, Product Lifecycle Management solutions used to integrate CAD and planning software solutions, Bentley Exor Asset Manager software used for lifecycle management of public assets either commonly located or associated with road, railway, and water network [13], WDM integrated asset management system that links condition data with accidents, structures, customer services, inventory, routine maintenance, works orders, street works and street lighting [14], and Symology Infrastructure Asset Management Systems used for assessing asset condition and valuation and strategic lifecycle planning of assets [15]. Geographical Information System (GIS) based bespoke and in-house developed software are also used for information capture, storage, analysis and reuse.

Currently, the risk of information loss is mitigated through regular data backups, regular migration of data programs, adopting standards e.g. Open Archival Information System (OAIS), provision of guidance e.g. digital continuity guidance [16], provision of business continuity and disaster recovery tools including tools to identify file formats. Currently used are tools which provide functions to perform format-specific identification, validation, and characterization of digital objects include the following: PRONOM - a File Format Registry [17], UDFR – Unified Digital Formats Registry [18], GDFR - Global Digital Format Registry [19], XENA – XML Electronic Normalising for Archives [20], DROID - Digital Record Object Identification [21], JHOVE – JSTOR/Harvard Object Validation Environment [22]. Self-contained Information Retention Format (SIRF) is a logical container format for the storage subsystem appropriate for LTDP, being developed by Storage Networking Industry Association where IBM is a leading partner [23].

As part of an EU/FP7 research project called Cultural, Artistic and Scientific knowledge for Preservation, Access and Retrieval (CASPAR), a new OAIS-based preservation-aware long-term data storage solution, named as Preservation DataStore, is being prototyped by IBM [24]. The following EU/FP7 research projects are also looking into long-term preservation of information: ARCOMEM, SCAPE-SCAlable Preservation Environments, ENSURE – Enabling kNowledge Sustainability, Usability and Recovery for Economic value, TIMBUS – Digital Preservation for Timeless Business Processes and Services) [25]. Other long-term storage and retrieval solutions include: Digital Information Archiving Solution [26], Long Term Digital Preservation (LTDP) Assessment tool [26][25].

Section 4 will present results of industrial case studies from infrastructure and non-infrastructure domains followed by an approach to develop information futureproofing strategies in section 5 and conclusions in section 6.

4 Results of Industrial Case studies

A number of case studies were carried out within the infrastructure and asset arena as well as non-infrastructure domain. This section presents a selection of different approaches used by organisations in the infrastructure and non-infrastructure sectors in addressing the challenges related to information requirements, collection, storage and retrieval. The individual case studies presented here will describe company sector, information that was futureproofed, challenges faced and approach used to address that challenge where possible.

4.1 Case study 1 – Information Requirements for Reuse of Foundations in Construction Sector

This case study was carried out with an organisation, which builds foundations in the construction sector. This particular company worked on a project to determine whether re-using existing foundations, created some 20 years earlier for a previous building on the site of interest, would be feasible.

In order to determine the key information requirements for this problem, the 12-box service information model, adapted for infrastructure, was applied to the project in question. It was tailored such that the top four boxes provided the key focus for the information requirements, looking at the plan/design/build stage of the project. The main information categories, with examples of the types of information required, are shown in Table 1. Some of the information types are required for the long-term while the others are for the short-term. The long-term information types might require futureproofing.

Information requirement category	**Examples of specific information**	**Long-term or Short-term use**
Original design data requirements	Loading regime Materials Constraints	Long-term Long-term Short-term
Original 'as-built' data requirements	Pile depth Location Ground condition Site investigations	Long-term Long-term Long-term Long-term
New build design requirements	Loading regime Location of piles	Long-term Long-term
Quality/ integrity of existing structures	Concrete core samples Quality/ condition of piles	Long-term Long-term
Site information requirements	Site constraints Access Materials Manpower Plant & equipment requirements Supplementary piles Build sequence Contaminated ground issues	Short-term Short-term Short-term Short-term Short-term Long-term Short-term Long-term

Table 1: Classification of information requirements

This case study demonstrated that the information requirements were either explicit and recorded in the information for the project, or implicit and not recorded in the formal documentation provided to the asset owner. For example, much of the technical detail of the actual build is recorded and handed over, while the implicit information is kept by the contractor, and not handed over, which might include details such as additional piles within and around the construction site, used for temporary cranes and piling rigs, as well as drains and bridges, which were not part of the building design. In the case of this project, such omissions in the recorded information led to the need for these piles to be removed causing the project to cost twice that of the original plan and take four times as long to complete. Furthermore, some of the key information remains static over time, while other information is of a more dynamic nature. For example, the condition of the piles will change over their life, while the original build data will be constant.

4.2 Case Study 2 - Collect (data capture) using Augmented Reality in Rail sector

An example of a proof of the concept project, to use augmented reality (AR) at one of the London train stations to implement new technology for data captures and visualisation purposes, is given in the following. Demonstrating use of AR as an enabler of information futureproofing was challenging. AR provides a real-time view of the real world environment with aspects augmented by computer-generated sensory inputs such as video, graphics and GPS data. While this approach greatly enhances the opportunity to contribute further data to the CAD model, the information gathering techniques could also have significant implications for the maintenance of complex buildings and installations. In essence the real world of the user becomes the platform upon which the user can intuitively interact with virtual information. With the proof of concept implementation of AR at the London train station, it was demonstrated that there was a potential to enhance computer controlled imagery and object recognition which in turn enables information about the real world to be used interactively and/or be digitally manipulated. Such capability depends on the capacity of handheld devices (ipads in this case) and their capability to monitor the on-going real-time situation. Current mobile AR systems use one or more tracking technologies including digital cameras, optical sensors, accelerometers, GPS, gyroscopes, solid-state compasses, and RFID/wireless sensors. AR could be used for predictive maintenance while sitting within BIM; Easier storage/retrieval of information in proposal; Publicity for being innovative and different (brand image); and Exposure to new technology for potential future use.

4.3 Case Study 3 - Information Storage and Retrieval using BIM in Waste-water Treatment Sector

Key lessons learnt from the implementation of BIM in a waste-water treatment project includes that it has brought in maintenance and construction teams together. It has become evident that information only exists in people's heads and not written down. A weakness of this specific implementation is lack of quality management system, which is not in place yet (i.e. processes). Future data capture trends might include information related to health and safety, quality, project improvement reports, team surveys, inspections and audits. Important consideration from software and hardware dimensions include software licenses, server access, configure, secure, who gets access to it in future (i.e. project team), a free viewer software, a web based corporate application, standard viewers e.g. PDF file viewer, etc. Current practice in futureproofing IT systems include use of PC/server-based systems and HDD as storage media. Data is encrypted in general but challenges include: low speed, difficulties in accessibility, increasing storage size requirements, corruption of data in short and long terms, hassle of keeping backups and HDD failure. There is no benchmark available for information futureproofing. However, BIM could be an enabler of information futureproofing if all levels of BIM are achieved and the collaborators are practicing the same BIM levels too while retaining, sharing and reusing the information.

4.4 Case Study 4 – Information Retrieval (search/reuse) in Aerospace Sector

In this case study from aerospace sector, retrieval (search/reuse) issues were explored. The following strategies were used: data archiving (after 2-3 years), knowledge management systems, internal search engines and servers, and considering changes during supply chain risk analysis and engineering, manufacturing and design stages. The backup solution helped in such cases where important and safety related information was stored on external media. However, challenges still exist in terms of searching stored information and having robust retrieval processes in place. The planning lifecycle (across different horizons) helps large aerospace organisations to align their current as well as future needs (including information futureproofing) by putting more focus on next generation spanning from 2-5 years period. However, challenges of information loss still exist.

4.5 Preliminary Analysis

The existing information futureproofing approaches presented in section 3 are either at research stages or being used mainly in space, aerospace, libraries, archives, government offices, healthcare, clinical trials and financial sectors mainly for preservation purposes. The infrastructure domain is, however, still lacking information futureproofing approaches. In order to understand what this means to the IT systems required to collect/store/retrieve data and how to ensure these IT services are available at the required point in time, a preliminary analysis of the case studies is presented in the following. Defining criteria for identifying information risks as well as information futureproofing complemented by standards, software and hardware enabling information futureproofing could ensure availability of these IT services at the required point in time.

Software enabling information futureproofing will consider applications, operating systems through to file formats. Selection of file format for long-term preservation depends upon following issues [28]: ubiquity, support, disclosure, documentation quality, stability, ease of identification and validation, intellectual property rights, metadata support, complexity, interoperability, viability and reusability. Other strategies may include use of open schema, data storage independent of applications and cloud storage/software services.

Hardware enabling information futureproofing will consider devices and media used for information storage. Selection of storage media for long-term preservation depends upon following issues [29]: longevity, capacity, viability, obsolescence, cost and susceptibility. The following hardware storage solutions are found to possibly enable information futureproofing: hybrid storage (HDD, tape), data centres (digital continuity and disaster recovery), and cloud storage (hybrid, private, public). Use of cloud storage and retrieval is an emerging solution for information futureproofing [30] [31]. While the cloud solutions offers benefits in terms of better preservation, access and enhanced availability of information to name a few, it also poses challenges, for example, in information sharing and security.

Change management is vital in futureproofing of IT services whether this is in terms of technology or human resources. Examples may include rolling out of new office or ERP software applications in large organisations that takes a long time to complete, employees leaving the company or moving from one organisational unit to the other. The following *standards* are imperative in ensuring that the business continuity is ensured while also providing standardised provision/research of information futureproofing solutions: i) ISO 22301 – Business Continuity Management that consists of elements related to Business Impact Analysis, Risk Assessment (refers to ISO 31000 for systematic risk assessment) and Business Continuity Strategy; ii) OAIS / ISO 14721 - Space data and information transfer systems -- OAIS -- Reference model [27]; iii) PDF/A has emerged as a standard for reading documents, which has been there for decade; and iv) Various standards for graphics e.g. STEP, DXF, DWG, IGES, IFC. The graphics application tools provide conversion mechanisms that are generally okay but some times partial details are lost during conversion process. Alignment of standards related to information futureproofing with other organisational standards e.g. ISO9000 series, PAS 55 is very important especially for large organisations.

5 Approach to Develop Information Futureproofing Strategy

Based on case studies and literature review, the process flow shown in Figure 4 is proposed to develop information futureproofing strategies for large-scale infrastructure. Infrastructure futureproofing needs will be identified by further identifying possible unplanned, uncontrollable disruptions and long term change management needs. Followed by this, the information required for infrastructure futureproofing shall be identified through identification of decisions that impact on futureproofing and information required to support the decisions. Identification of temporal retention requirements for information types, identification of technical and organisational challenges and evaluation and prioritisation of risks involved in those challenges are key. Developing information futureproofing strategies will come next, which will identify current and potential systems/technologies and their capabilities followed on by the development of criteria for information futureproofing.

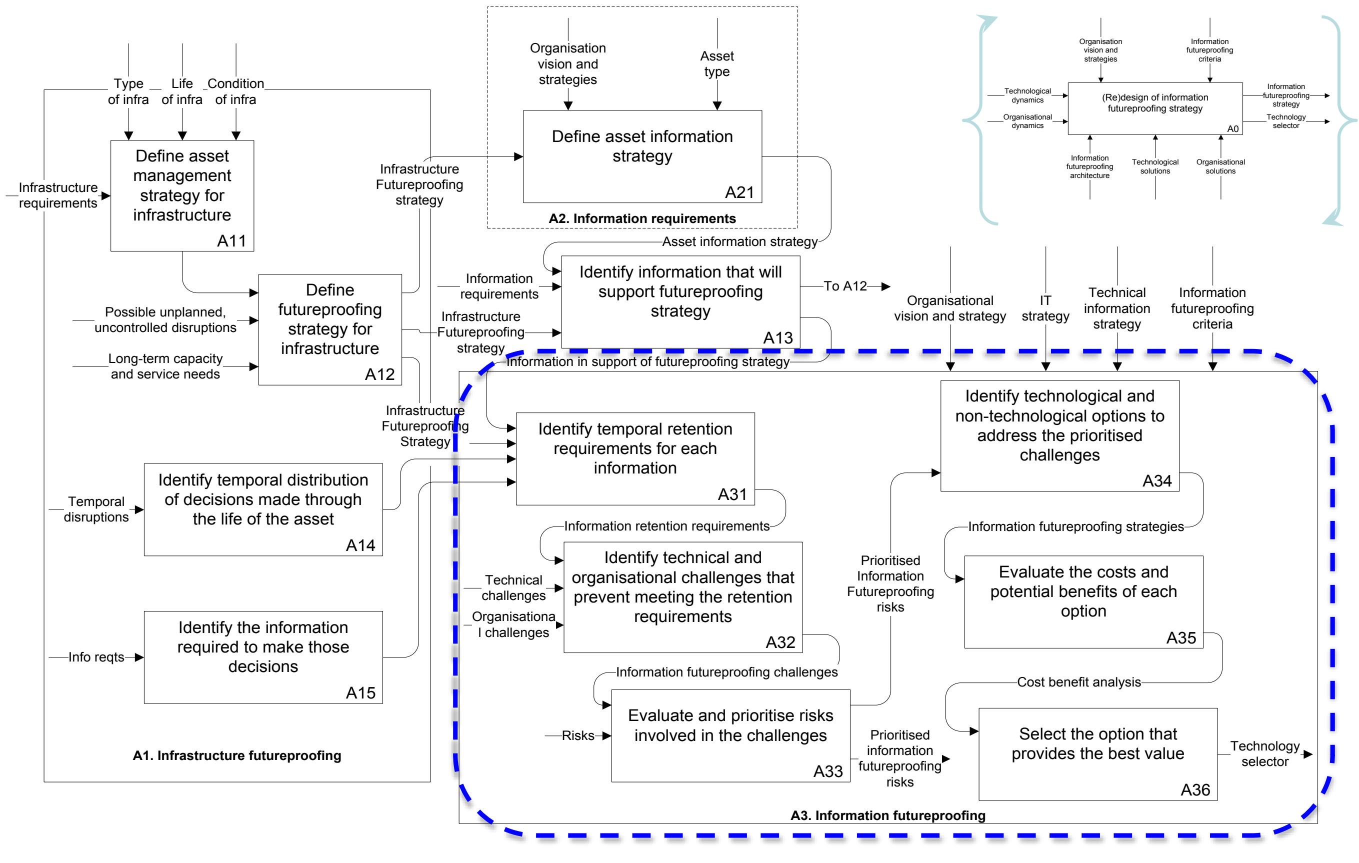

Figure 4: Approach to developing information futureproofing strategy

Preliminary criteria for information futureproofing are also proposed in the following, which is based on foregoing discussion. Identification of risks of information loss is crucial in initiating an information futureproofing project. Existence of a plan or strategy is imperative in setting a clear direction to information futureproofing. The specification of information requirements, e.g. understanding which data is needed when, is also crucial. A clearly understood process from identification/capture to reuse would ensure that information futureproofing tasks are carried out in systematic ways. Keeping up-to-date, understanding and adopting information futureproofing technologies (easy to use/intuitive data retrieval approach with examples where previously stored information has been effectively retrieved and used) would help in ensuring that the information is futureproofed. Adoption of continual change management practices (formatting presentation of data is immune to updating redundancy) would keep implementation of information futureproofing strategies on track. The cost of information capture/storage/retrieval/updating should be understood and budgeted for at all times to ensure commitment to implementation of the information futureproofing strategy.

6 Conclusions

The paper has discussed the need of futureproofing asset information in the context of regular infrastructure management. Information requirements for futureproofing the infrastructure are also discussed. The challenges faced in futureproofing information are also identified. Information futureproofing will become more important in the wake of advanced BIM levels and increased use of BIM. A number of exploratory case studies from infrastructure and non-infrastructure industries (e.g. construction, rail, aerospace, waster-water treatment) are elaborated. The preliminary analysis suggested enabling technological and organisational strategies or solutions for information futureproofing might include elements of software, hardware, change management and standardisation. An approach outlining the process steps to develop information futureproofing strategies is also proposed along with criteria.

Future work will include further development and assessment of the criteria and process steps for information futureproofing, developing framework for information futureproofing strategies. Demonstration case studies are also anticipated to further validate the framework, for example, embedding auto-ID technologies e.g. RFID tags in concrete.

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