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Smart Enterprise Asset Management

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Abstract
An asset is anything with actual or potential value to an organisation. An asset costs money to operate and its performance should be measureable, therefore an asset could be university building, an office block, a meeting room, a lift or an air conditioner unit. Sustainability within a built environment should be considered throughout the asset's whole lifecycle - from Design and Build (D&B) phase into Operational phase and with insights fed back into D&B / Refurbishment or Decommissioning phase. A holistic and cyclic end-to-end approach for sustainability throughout the whole lifecycle asset management should cover key areas such as: (i) Building / refurbishing only what is needed using evidence based data; (ii) Reducing waste, inventory, re-works, unnecessary resource effort and energy consumption; (iii) Using right suppliers, products and materials, and only ordering and using parts when needed – ensure right time, right part from preferred supplier; (iv) Measuring, optimising and maximising existing asset performance and demonstrating 'fit for purpose'; (v) Improving compliance, health and safety and well-being. To deliver these, organisations need to be collaborative to ensure respective solutions and services within a whole lifecycle asset management approach are open, interoperable (non-proprietary), modular that can be tailored to meet customer needs as well as remaining cost-effective and able to deliver on desired business outcomes including the growing importance of sustainability. Our proposed Smart Enterprise Asset Management Ecosystem brings together partners covering innovative technology such as IoT, Asset Management (CMMS, CAFM), 3D Scanning and BIM, Digital Twin, E-procurement and Supply Chain, Big Data Analytics, Blockchain, all underpinned by industry sector expertise and academic rigor. This unique breadth and depth of partner collaboration focuses on end-to-end asset whole lifecycle management which helps remove silos and barriers for the end customer therefore allowing them to deliver on desired business outcomes such as energy sustainability, performance, cost reductions, well-being, etc., rather than them getting embroiled and lost with systems and technology architecture.

1. Introduction
According to ISO (2014), the ISO 55000-2014 standard describes asset management as "a coordinated activity of an organisation to realise value from assets". Typically, assets are managed with information in silos due to the lack of system interoperability. This could result in user frustration, sub-optimal decisions and even chaos without a holistic perspective of the entire asset and its complete lifecycle. In this paper, we adopt an ecosystem approach to address the inadequacies of the current siloed approach for asset management. We present our proposed Smart Enterprise Asset Management (SEAM) approach, and its ecosystem of solutions as well as partner organisations. This paper describes the ecosystem in the context of a smart government building (within the built environment - note due to NDA, no specific reference can be made) to demonstrate the interoperability across a diverse range of innovative technologies and work in an asset management that encompasses the entire lifecycle. A smart government building has been chosen as a use case for this paper because of the UK Government's commitment to build new buildings and improve maintenance for older buildings. This provides timely opportunities to operationalise plans for digital buildings and estates that will improve life-cycle performance, environmental sustainability and digital transformation and traceability and reduce back log maintenance. Building and estate digitisation, sustainability, and efficiency will be

central to the approved plans of all government building projects, though unfortunately many stakeholders have not fully considered / understood the benefits nor addressed how they will meet the required Treasury Green Book (e.g. evidenced based 'fit for purpose') (HM Treasury, 2018), transparent and measurable outputs needed to identify what success looks like and therefore how initiatives can and should be continuously improved. However, our ecosystem of partners are working together on a more sophisticated digitisation, environmental sustainability, traceability and accountability across various programmes to improve inefficient building, estates and operational performance. In so doing, we need to address several challenges listed below:

- **Challenge 1 – Technical Challenge**
  For the smart government building, the ecosystem of partners will utilise some of the latest interoperable and innovative technologies and seek to introduce improvements in day to day, real-time operational capability as well as providing key re-usable data for analysis to support longer term strategic 'Smart' Building and Operations objectives. As part of a planned 'think big – start small – scale fast' approach, this process will provide the platform which can be extended to support the proposed new builds and the existing estate.
- **Challenge 2 – Cultural Challenge**
  Current approaches to estates, digital systems and data are diverse, siloed, poorly coordinated and lead to massive inconsistency, duplication and wasted effort; and do not longitudinally maximize the value of information towards ensuring sustainable, efficient and resilient performance. Communication barriers (lack of openness and transparency) within and across internal teams, stakeholders, data types and technologies increase errors, costs, causes delays in data transmission and rework – this can occur during build phases and more importantly in operation. Processes are challenged with lack of openness to participation and inclusiveness to all stakeholders (individual groups such as procurement, finance, soft and hard FM teams). Systems are constantly challenged when attempting to maintain consistency, reliable evidenced based information, integrated and holistic outcomes for 'clients' and continuous improvement across asset lifecycles. There is lack of transparency, often resulting from social and sometimes localised political interference and a lack of digital automation, which leaves asset and operational management vulnerable to inertia and prevents stakeholders from being open to communicate and share information and best practice freely. Improvements through new ways of working based on digitised, integrated, interoperable and holistic thinking offered by the ecosystem of partners will allow all stakeholders the opportunity to participate and have transparency through a single source of the truth over the connected, sustainability, digital and efficiency programmes proposed.
- **Challenge 3 – Sustainability Challenge and Data Re-usability**
  Underpinned by the 'Smart' and interoperable approach the ecosystem partners offer, the aim is to develop a data collection and management structure that supports the delivery and operation of resilient, sustainable, new and existing built environment facilities whilst ensuring the principles of the Green Building Council publication (Net Zero Carbon Buildings (UKGBC, 2019)) and the suggestions set out by the digital advisors and supported by academic rigor. A Sustainability strategy will be developed in line with a Digital / Data strategy that will provide operational information and foster knowledge for effective and efficient delivery and operation.

This paper is organised as follows: Section 1-Introduction; Section 2-Literature Review; Section 3 – Methodology; Section 4 – Smart Enterprise Asset Management Ecosystem; Section 5 – Conclusion.

2. Literature Review

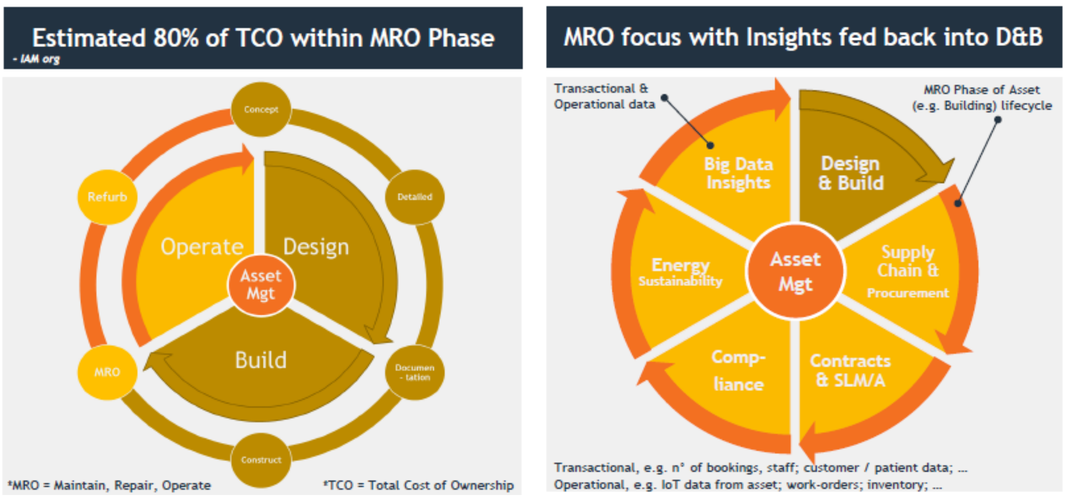
The notion of smart asset management, which is rooted in asset management (AM), focuses on the technology as a driving process to enhance the captured information to assist in making strategic decisions (Urmetzer, et. al., 2015). Thus, asset-owning organisations rely on AM performance strategies to excel in the competitive business environment. The overarching aim of our proposed SEAM is to improve AM strategies in an organisation, using cutting edge technologies. Moreover, SEAM has more to offer, such as a robust structure to validate and improve asset performance by collecting and incorporating reliable asset information in strategic business decision making (Shah, et. al., 2009). The needs of a clear definition of SEAM and a delineation of its implementations have dramatically increased as a result of the potential for enhanced asset analysis and performance possibilities in any business structure. Recent studies have shown the current use of SEAM in the industry is not documented, and with only few research and white papers have referred to some form of development and classification of smart assets. Several other studies have shown variations in implementing SEAM extensively across different organisations. Thus, in these interpretations of SEAM, a common ground needs to be identified. This calls for the need of a concise definition of SEAM to avoid conflicting terminologies, and establish a basis for future research. It is in these conflicting terminologies that various concepts have already been established in existing literature (Lampe, et. al., 2003; Liyanage, et. al., 2009; Bughin, et. al., 2010; Nel, et. al., 2018). Although these concepts are acknowledged separately, they relate to the central idea of technological entities management. These separate ideas also need to be addressed to establish a foundation for further development of SEAM.

In recent decades, global businesses operate in an era of technological performance which sees overwhelmingly diverse variations in electronic goods and technology affordances. Market competition is a driving factor for organisations wanting to acquire and at the same time, offer cutting edge innovative expertise (Wang, et. al., 2014). According to literature, there is a business need for implementing SEAM (see business outcomes in Figure 2). Therefore, it is imperative for academics and industrial researchers investigating SEAM and its implementation, to first and foremost establish the implementation prerequisites. As a result of information availability through interconnected communication structures, researchers have established a clear link between technological/business performance management and electronic convergence (Nel, et. al., 2018). Thus, such a link unravels the potential for businesses to offer comprehensive and meaningful information across multiple platforms, rendering knowledge (and business intelligence) more accessible to various stakeholders in the organisation. With such advancement of technical capabilities, organisations could fully exploit the creative use of a portfolio of technologies to create added value and competitive advantage. The general benefits of implementing asset management strategies are: reduce operational cost, improve profitability, and improved competitive edge in the market place (Aberdeen Group, 2009; Aberdeen Standard Investments, 2018). However, it is imperative for the portfolio of technologies to be interoperable so that resources could be well coordinated and managed to reduce costs (e.g. manufacturing, etc...) (Nel, et. al., 2018). The emphasis here, will be the use of technologies to monitor, and manage physical assets (through shared essential information) in optimal as well as optimised conditions, thereby, delivering predetermined targets in Quality of Service (QoS – high performance), Quality of Effectiveness (QoE – excellent user satisfaction), and Quality in Sustainability (QiS - environmental friendliness).

To reiterate, it is evident that asset managers are at the helm of innovative technologies where strategic, tactical as well as operational decisions about assets need to be appropriately addressed to exploit their technological potential. The subsequent sections will discuss how these diverse technologies could be seamlessly integrated and the benefits of our proposed ecosystemic approach to SEAM.

3. Methodology

In this section, we shall discuss smart enterprise asset management and digital twin methodologies. The smart management macro-level methodology is depicted in Figures 1 (a)-(b) and discussed in sub-section 3.1 while the micro-level discussion of each component in smart enterprise asset management is in sub-section 3.2 and Table 1. Detailed discussion of the digital twin methodology is also in sub-section 3.2.



(a) (b)

Figure 1: Smart Enterprise Asset Management Lifecycle

3.1 Smart Enterprise Asset Management Lifecycle

ISO 55001:2014 (BSi, nd) is framework for asset lifecycle management which aims to achieve the best return from assets and reduce the total cost of ownership (TCO). It encompasses financial, organisational and physical assets. Such a standard helps reduce asset ownership associated risks; improve customer satisfaction through provision of quality-assured products and services; invoke new business acquisition and supports international business growth. The asset management lifecycle is iterative. According to PECB (2016), the 4 stages in asset management lifecycle are: planning, acquisition, operation cum maintenance, and, finally, disposal. However, in this paper, we propose a 3-phase Asset Management (see Figure 1(a)). The phases and their sub-phases are: design concept initiation followed by design specification and documentation that will feed into the subsequent phase; build (involves construction based on specification); and operate (MRO – Maintain, Repair, Operate and asset refurbishment). In this lifecycle, it is estimated that 80% of TCO is within the MRO sub-phase.

Figure 1(b) is an extension of Figure 1(a) where MRO is a major part of the entire lifecycle and its focus is to feed back insights into the Design and Build phase. The insights are afforded through big data analytics of relevant data relating to: transactions (e.g. smart building context – room booking, usage, relevant business/health transactions, etc…); and operations (for the same smart building context – IoT data, environmental monitoring, building performance, etc…). The sub-phases that subsume under MRO phase are: supply chain and e-procurement; contracts and service level management/agreement, SLM/A; compliances; energy and sustainability.

3.2 Digital Twin

A digital twin is a digital representation or virtual replicas of a real-world entity or system (e.g. physical objects, process, organisation, person, or abstraction) (Gartner, nd; Networkworld, 2019). Data from multiple digital twins can be aggregated to model real world systems comprising composite entities, operations or processes (e.g. city, factory, etc…) (Gartner, nd). Additionally they could be exploited to build simulations or IoT platforms (e.g. Azure Digital Twins) to explore optimisation as well as what-if scenarios (Networkworld, 2019) for prediction and gain deeper insights into drivers of better products/services to enhance customer experience (Microsoft, 2020). Gartner (2019) conducted a recent IoT implementation survey and found that 75% of organisations implementing IoT already use digital twins or plan to within a year. Digital twins have been deployed for asset management (Arc Advisory Group, 2020) and integrated into asset management lifecycle to create value and support decision making (Macchi, et. al., 2018). It is viewed that assets could be rendered 'smarter' by means of digital twinning (DNV.GL, nd). In this paper, we discuss how multiple digital twins could be integrated into smart enterprise asset management lifecycle to create business values (see Figure 2). Gartner (2019) maintains that it is necessary for multiple digital twins to be integrated and here, we shall discuss multiple digital twins (for a diverse range of areas of interest) that are relevant to smart enterprise asset management:

i. **3D Model Scanning:** Point clouds could be created via photogrammetry or LiDAR (Light Detection and Ranging) technologies (Vercator, nd). The captured point cloud data are used to make 3D scans of relevant assets (e.g. 3D laser scan) that are subsequently fed into the development of a virtual model, easily accessible as a digital twin (Hannovermesse, 2018).

ii. **BIM Integration:** BIM focuses on an entity's design and construction (for e.g. a building). On the other hand, a digital twin models the entity's operations and interactions with other entities within a system (adapted from IoTforall, 2019). This is aligned to Gartner's notion of the next generation digital twins which include users, processes, and behaviours. Such related data is collated through the deployment of sensors (discussed in point iii).

iii. **Connecting Assets:** Connected assets via sensors provide useful information (through data analysis discussed in point iv) on how they perform in real time, and to prevent serious accidents through potential failure prediction (CIOB, 2019).

iv. **Data Analysis:** In order to realise the full promise of digital twins, it is essential to integrate systems and data across the entire organisational ecosystems (Deloitte, 2020). Real time data will be analysed and fed into simulations to clearly understand what-if scenarios, predict outcomes accurately and trigger appropriate actions or events to manipulate the physical world (ibid).

v. **Asset Performance Management:** Asset Performance Management (APM) involves the deployment of sensors to collect real time performance and condition data for assets and analysed (using AI and machine learning algorithms). Such collected and systematically analysed data are inputs into digital twins that assume the form of realistic and interactive 3-D models (Walters, 2016) that provide evidence-based decisions about the assets

(Negi, 2019). According to Walters (2016), APM provides the "power of combining all systems into one that can deliver actionable intelligence" and this facilitated through the convergence of engineering (electronics, and instrumentation), operational (sensor and controls) and information (software, hardware, and systems) technologies. A framework for setting targets (with metrics) in APM measurement have been developed (Green, et. al., 2016).

As listed in Figure 2, the positive business outcomes of integrating multiple digital twins into the entire lifecycle management of smart assets are: improved critical asset uptime; energy efficiency; improved productivity; reduced procurement overheads; drive predictive maintenance; improve health and safety compliance; and optimise asset performance. The integration of digital twins for end-to-end whole lifecycle asset management ought to be highly prioritised to afford migration and integration of solutions as customer requirements grow. The key benefits of integrating multiple digital twins (3D Scan, BIM Integration, and Connected Assets via IoT technologies) with asset management for a smart building use case are: (i) precise (accurate to 5mm) and up to date 3D model of building to support and expedite architectural and redesign activity; (ii) highlight key assets and locations, colour coded asset status, asset specification data, and their real-time performance; (iii) quick and easy retrieval of asset or location information in an intuitive 3D model; (iv) improve collaboration between different internal and external teams covering asset whole lifecycle; (v) spatial and contextual information readily available for assets and locations to assist with health and safety compliance, highlight access restrictions and plan work ahead of site visits. Their beneficiaries are: (i) administrators, designers and architects who need to plan site alterations, repurpose areas within the facility and/or to introduce temporary works; (ii) engineering and maintenance teams by providing ready contextual access to asset and location data for faster corrective and more timely preventive actions as well as assisting with identification and scheduling of predictive tasks. Visual information also helps optimise visits by remotely assessing on-site requirements to avoid wasted visits and by assisting with the identification of nearby assets or locations that can be attended to in one visit; (iii) operation team to manage staffing based on demand (footfall) and visually control, manage and report energy consumption and CO_2 emissions; (iv) purchasing team to allow visual reference to assets and locations when identifying what is needed and by intuitive access to specifications to enable accurate ordering of spares and/or replacements.

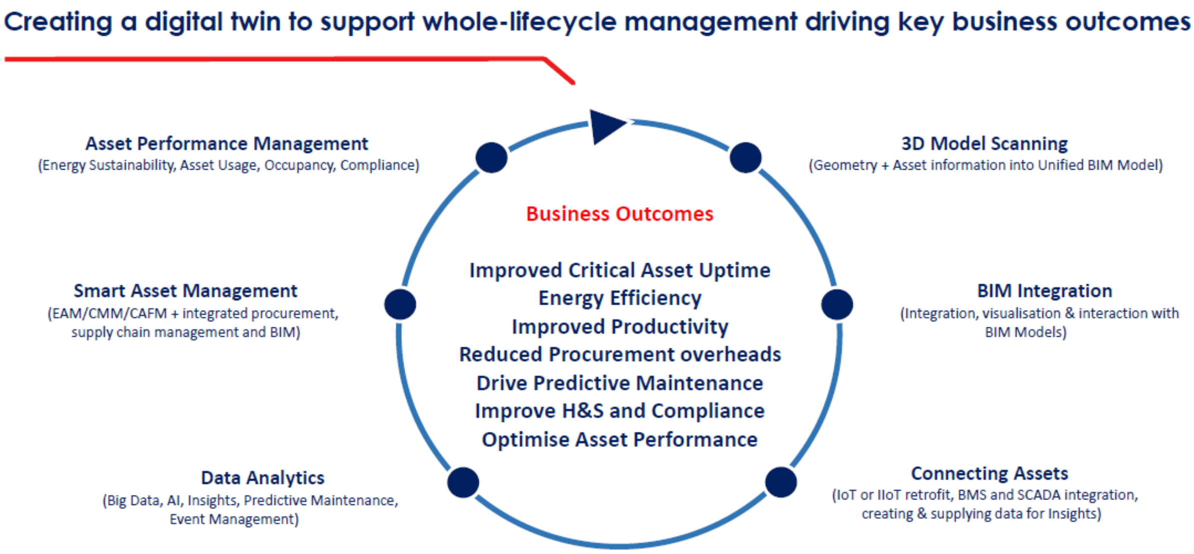
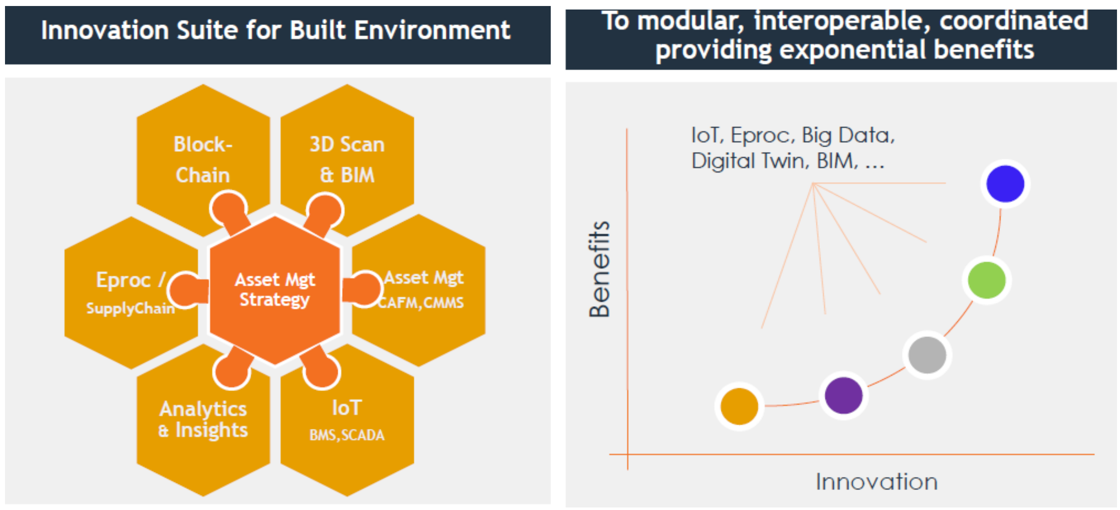


Figure 2. Digital Twin and Smart Enterprise Asset Management

4. Smart Enterprise Asset Management Ecosystem

According to NCA (nd), in the natural world, biodiversity and ecosystems afford numerous benefits (also known as "ecosystem services") to mankind while UNEP (nd) view healthy ecosystems and a rich biodiversity vital for proper functioning of cities. Gartner (2020) has developed a digital ecosystem framework to analyse digital ecosystems and understand how the various elements work together within the ecosystem. Inspired by these, we draw a parallel for a smart enterprise asset management ecosystem in the built environment context (depicted in Figure 4 and discussed in sub-section 4.3). Such an ecosystem requires diverse yet complementary technologies and it aims to break down technological silos to create a collaborating and interconnected multi-disciplinary system for the ultimate goal of interoperable as well as seamless ecosystem service provision. Our proposed smart enterprise asset management ecosystem demonstrate the essential characteristics of jointness (yet modular), coordinated, scalability, and interoperability.



(a) (b)

Figure 3: (a) Innovation Suite for Smart Enterprise Asset Management; (b) Benefits of the Innovation Suite

4.2 Smart Enterprise Asset Management System Ecosystem - Joined-up digital strategy

UK Department for Transport (nd) views the importance a joined-up digital strategy for consistent system operations through the adoption of innovative 'agile' approach for the design of services and platforms. The benefits would be user experience enhancement, efficiency maximization, and costs reduction. Central customer-related information coordination would provide a joined up cross-ecosystem view that would be more reliable and comprehensive. Figure 3 (a) depicts the 6 different technologies that are essential for a built-environment related smart enterprise asset management: 3D Scan and BIM; Asset Management; IoT; Big Data Analytics and Insights; Supply Chain and e-Procurement; Blockchain. Figure 3 (b) depicts the exponential benefits afforded when these 6 modular technologies are well coordinated, and interoperable to function as an ecosystem. To reiterate, all the depicted components of the smart enterprise asset management ecosystem will have their individual digital strategy. However, the overarching need is to have to a joined-up digital strategy for the ecosystem to provide seamless quality services that will ensure an optimised trade-off amongst Quality of Service (QoS – high system performance), Quality of Effectiveness (QoE – excellent user experience), and Quality in Sustainability (QiS – reduced environmental impact).

4.3 Smart Enterprise Asset Management – Ecosystem Solutions for a Smart Building Use Case

Our proposed smart asset management ecosystem (known as Smart Enterprise Asset Management System, SEAM, as depicted in Figure 4) comprises 6 integrated modules (note: 3D model and BIM are considered as separate).

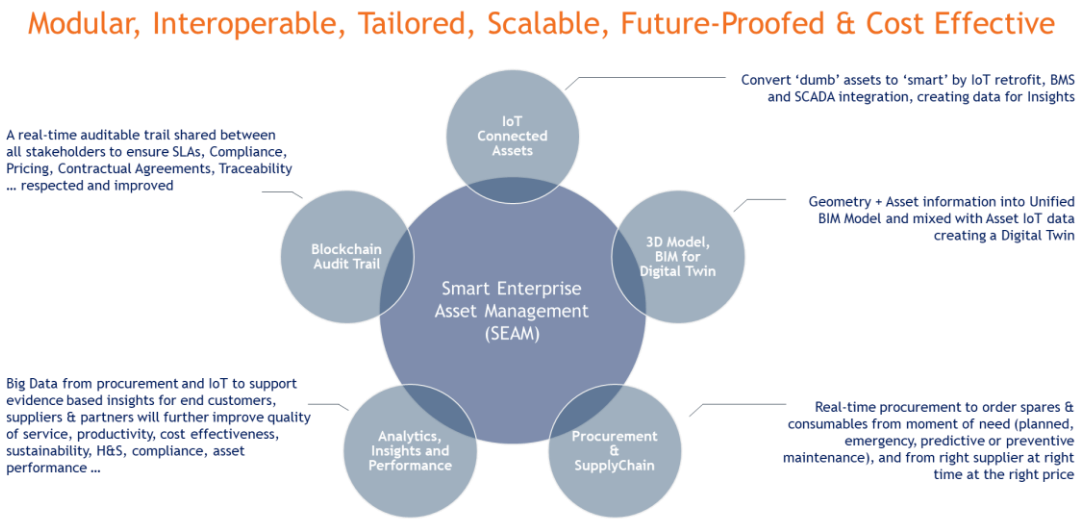


Figure 4: Interoperable, Scalable and Future Proofed, Smart Enterprise Asset Management solution

To exploit an end to end, interoperable ‘Smart’ Enterprise asset management [SEAM] system would typically require the 5 modules, their associated data and ecosystem partners (tabulated in Table 1).

4.4 Smart Enterprise Asset Management and Ecosystem of Partners

The end to end digital asset management capability is unique as it brings together open and non-proprietary usage of some of the latest digital technologies in a way that will ensure a building and its assets can operate effectively and efficiently to support the workforce delivering the services to the end clients in an optimal way. These outputs are all immediate to medium term benefits and do not include the academic outputs. The 6 modular and interoperable components that underpin the ecosystem value proposition and associated proposed partners (for a smart building use) case are tabulated in Table 2.

Ecosystem Modules	Description	Data Sources	Benefits	Beneficiaries
3D (and/or 2D) Scan and BIM digital twins	Dimensionally accurate 3D replication of the built environment and M&E assets; sufficient to; navigate as if walking the building, architect changes, provide training, locate critical fixed / mobile assets and visualise other critical materials/assets within, including near real-time traffic light status for monitored critical assets.	2D drawings 3D Scans 3D models and data schemers e.g. Revit, IFC, etc. Standard or Manufacturers product 3D images and data sheets	(i). Improve collaboration and handover from Design and Build to Operate lifecycle phase; (ii). Data from existing BIM models can be pulled into Asset Management solution; (iii). Using 3D models (digital twins) to interact with assets and locations in an intuitive manner; (iv). Quick and easy retrieval of asset or location information by navigating 3D model and selecting item of interest; (iv). Easily access functionality of asset management, CAFM / CMMS solution.	Designers Architects Builders Contractors Developers
IoT Connected Assets	Sensing Capability either 'As built' or enhanced 'Retrofit' for key Assets/Spaces, to support data creation for measurement and reporting of desired outcomes: Staff experience, Availability, Performance, Sustainability, Compliance, Utilisation, Safety, Efficiency.	Sensor data gathered to meet client requirement BMS files type of sensor feeds data to information repository E.g. Footfall sensor, Occupancy sensor, Air Quality, Power usage etc.	Benefits of an integrated IoT strategy are: (i). Easy 'plug and play' style deployment and commissioning of most IOT sensors; (ii) Ability to join-up data sources from different assets, e.g. BMS HVAC + room occupancy and temperature; (iii). Operations – reactive, predictive, and proactive maintenance for improving asset availability and uptime, remote monitoring / metering and trigger event on threshold breach; (iv). Provide insights - optimise / maximise asset performance via trends measurement, SLAs improvement and TCO reduction, and data provision to ensure fit for purpose and evidence based insights; (v). Health and safety / Compliance – provide insights into workers' wellbeing, working environment condition (noise, Co2, air quality, temperature), heart rate and fatigue detection, proximity / danger area and PPE detection.	Property Consultants, Administration, Designers and Architects looking maximising & optimising location (space) or assets Facilities Management for evidence-based insights for third party SLA measure and control Engineers and Operations ensuring easy deployment and visibility of assets performance, availability and ability to continuously improve.
Asset Management and Database Management	Support key Asset Specification and performance information; sufficient to locate, understand condition or origin, monitor status, measure performance, report for service, service, assess spares requirement, record repair activity, replace and retire.	COBie file Existing BMS, CAFM or EAM system Manufacturer data sheets Commissioning records Operating and Maintenance procedures Service providers Service history record Product / Asset Data Templates	(i). A scalable world-class CMMS/CAFM solution with unique integrated BIM, IoT, E-procurement and potential blockchain interfaces.; (ii). Central and easy access to information related to assets and locations: name, reference, criticality, associated contracts and SLAs, spares, documentation, plans, etc. ; (iii).Schedule work-orders based on asset and process criticality, appropriate & available resource; (iv). Manage, Track, Measure and Continuously Improve operations based on work-order data; (v). Auditable adherence for H&S and Compliance regulations and guidelines. Record for audit purposes. Avoid corporate exposure and liability; Measure and continuously improve supplier contract (vi). Service Levels. Align Service Levels with asset & underpinning process criticality, costs to deliver and negotiations; (vii). Create Digital Twin. Improve collaboration throughout whole asset lifecycle. Intuitive visualisation & navigation of asset & location information for faster decision and accuracy; (viii).Ensure right product, right price and at right lead-time based on right criteria (criticality, compliance, sustainability, etc). (ix). Simplify procurement process and reduce cost of procurement. Reduce number of suppliers. Reduced and ensure Just-In-Time inventory. Improve Uptime (c.50% downtime due to parts not available); (x). Ability to integrate with 'shared ledger' capabilities across end-to-end process enabling a real-time auditable trail that can be shared between customer and 3rd parties to ensure SLAs, Compliance, Pricing, Contractual Agreements, Traceability, etc., are controlled, respected and improved.	Site Operations and engineering Finance and Purchasing departments Facilities Management Property Consultants, Administration, Designers and Architects
	Storing critical asset performance data, merging and analysing with other associated or external data to form evidence and insights to support complex decision making. E.g. Sustainability, Space repurposing, Capital projects, Supplier negotiation etc.	Revit data / Scan data Construction data Commissioning data Maintenance data Sensor data Performance data 'Client' data Climate data Other external information		

Supply Chain and e-procurement Management	Capability to store and order product and service supplier 'best value' contract information, stores and inventory information and monitor and gather performance against SLA to support QoS, renegotiation and sustainability goals.	COBie file Finance / Procurement ERP system Procurement contract/ supplier database Asset performance data Asset Service history Stores Inventory data	(i). Ensure auditability of right product, right price, right lead-time based on right criteria to ensure uptime, compliance, Health and Safety, SLAs, target KPIs; (ii) Just-in-Time Inventory – Planned and IoT Predictive maintenance to ensure parts delivered on-time, in stores and reserved for jobs; (iii) Improve Uptime: c.50% downtime due to parts not available; (iv).Optimise Procure-to-Pay for materials, spares and consumables. Single order for multiple suppliers and single monthly invoice; (v). Improve Supplier Performance, Management and Consolidation, including performance reporting; (vi). .Traceability of parts and materials ordered, why they were ordered and for which asset and job	Finance: Procurement, Payment teams – consolidated orders, consolidated suppliers, monthly invoices; automated / semi-automated ordering process (remove non-value add tasks) Operations teams – ensuring right product, right time, right price.
Blockchain and Auditability/Compliance	Provides audit trail and ascertain compliance. Capability to provide immutable evidence of supplier product traceability, service performance or contract compliance by automatically registering (writing) transaction steps into a shared ledger (blockchain) which cannot be edited or changed.	Any system that records relevant transactional activity	(i). Ensure auditability and traceability; (ii). Ensure visibility and compliances; (iii). Enhance supply chain management through monitoring of supply chain activities; (iv). Facilitate integrated and distributed ledger for production management; (v). Shared information system; (v). Fosters distributed and certified systems; (vi). Timeliness of delivery; (vii). Prove authenticity and provenance of goods.	Producers Forwarder Broker Consumer
	Provides distributed shared ledger that is consensually shared and synchronised across multiple sites, geolocations, accessible by multiple users. Provides secured fund transfer.	Blockchain and distributed ledger technology Smart contracts for digital certification and distributed SLA management	(i). Confidence and improvements in services: measure actual performance of 3rd parties and suppliers SLAs vs expected; (ii). Invoking potential penalties on immutable evidence if SLAs not respected; (iii). Reduction in time & effort in any 'validation' within this process, e.g. PO – invoice payment record reconciliation (everything on immutable ledger, so need only sample checking); (iv). Potential reduction in insurance premiums, e.g. auditable evidence of compliance, Health and Safety; ensure genuine products and certified operators used to complete the work-order; (v). Reduce procurement overheads and improve Buyer and Maintainer productivity.	Operations Finance Buyers 3rd Parties
Big Data Analytics and Insights	Collect and analyse big data from e-procurement and IoT sensors to provide evidence-based insights for end customers, suppliers and partners. This will provide support for decision making and informed actions to improve Q0S, productivity, cost effectiveness, sustainability, Health and Safety, compliance, asset performance, etc…	Sensor data Relevant system data	(i). The ability to provide data analysis solutions covering a wide range of requirement, skill sets, cost and providing data sources and platform to trigger events & visualise data for front-line teams; (ii). Merging transactional (client, procurement) and operational (IoT, assets performance) data to produce evidence based insights and triggering events or visualising data aimed to improve building or service performance, worker care and experience; (iii). Detect and predict anomalies and improve building, asset or workforce efficiency; (iv). Facilitate complex decision making by applying machine learning & artificial intelligence; (v). Applying business rules quickly, easily and effectively to ensure events are triggered at right time for right team; (vi). Reduce unplanned downtime, boost asset & equipment longevity, yield, quality and effectiveness.	All teams Operations, Finance, Procurement, Architects & Designers, etc. – as data sources and insights could potentially cover performance & optimisation improvements for assets, locations, buildings, services – all those listed above.

Table 1: Smart Enterprise Asset Management Ecosystem Innovative Modules

Module	Partners
Digital twin from 3D Scan/BIM model Project delivery managed under a BIM level II framework	1st Horizon, SiteDesk TP professional Services
Core asset/building management control platform	SRO Solutions
Asset & location monitoring and IoT sensing	IAC, Beckhoff
Big data analytics and insight	EdenBridge, LBU
Integrated and streamlined eProcurement capability	Mercateo
Tracking and tracing suppliers and supply using shared ledger	SRO Solutions

Table 2: Smart Enterprise Asset Management Ecosystem of Partners

Through the introduction of an ecosystem of subject matter experts from industry and academia with the ability and track record of delivering digital innovation, sustainability outcomes, a smart building (e.g. Government Building) will be able to create the foundations of a unique 'end to end' approach to full asset, life-cycle and sustainability management. This will be delivered by integrating open and interoperable services such as 3D scanning, digital twins, BIM / visualisation, Internet of Things (IoT) sensors, predictive maintenance, and automated maintenance repair and operation procurement. The ecosystem, working with a Government Building, has the capability to improve overall productivity in line with the Government's digital and sustainability objectives, by using interoperable modules that can be combined to deliver end to end, efficient and operational support. These modules can integrate with existing systems, (e.g. Building Management Systems), creating visually live IoT driven data monitoring i.e. 'digital twins' of a building / asset, allowing failures to be predicted and actioned via automated service request management, including contract/spares management, stores control and e-procurement services before services are impacted e.g. critical plant assets such as HVAC; lighting, power and waste management, fridge temperature etc. The wider benefits include the ability to track building / department footfall / usage statistics which can then be married with people flow data to identify if the department/ building can being optimised. Estate management system and mobile tools that digitise the assets (i.e. digital twin), provide evidential data that will simplify and increase the ability to reliably control the management of buildings and assets, to enabling robust decisions to be made on how and when they can be used. With the assets being i.e. engineering, spaces, desks, lifts, fridges, rooms, theatres, etc., the entire asset if required - a complete digital twin.

4.5 Summary of Smart Enterprise Asset Management

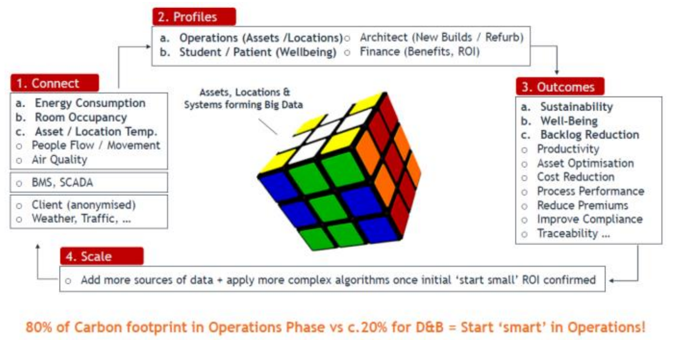


Figure 5: Re-usable and Interpoerable Data for Different Profiles and Outcomes

Our proposed smart enterprise asset management ecosystem provides re-usable and interoperable data that will be made available for different profiles and business outcomes (see Figure 5). All pertinent data is aimed to be re-usable and stored in 'Big Data' environment to be viewed through lens of different profiles seeking different business outcomes (e.g. Operator for Productivity gains; Finance for Energy reduction; etc…). To ensure cost-effectiveness and ROI, it is planned to include additional data sources in different phases. Once smart data management is implemented, it is anticipated that predictive maintenance and autonomous decision making can be developed for key sections of the asset (such architecture being developed with BIM, FM and digital twins in mind). Initially, data-collection architecture design for the critical energy and performance systems will be prioritised to reduce energy and improve operation of the asset. The aim is to capitalise on both historic and real time performance data so that evidence-based decisions can be made on future projects. Central to effective operation is avoiding duplication of practice and unnecessary resource use. The effective utilisation of performance data will radically change understanding of asset performance, enhancing whole lifecycle management.

5 Conclusion

The USP and innovation of our proposed smart management ecosystem stems from 8 organisations sharing the same vision of an end-to-end, interoperable, smart building solution. Our 'think big – start small – scale fast' approach provides a cost-effective solution that mitigates risk for customer. This offering will help democratize adoption of innovative technology such as IoT, Data Analytics, Digital Twin, etc., delivering exponential benefits as modular solutions are joined-up. Our initial work with a government building has seen the ecosystem offering for Digital Sustainability / Smart Building being integrated into a repeatable template for future capital projects.

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