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Big data: A new revolution in the UK facilities management sector

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List of abbreviations

APM	Association of Project Management
AR	Augmented Reality
AV	Augmented Virtuality
BAS	Building Automation System
BDA	Big Data Analytics
BEMS	Building Energy Management System
BIFM	British Institute of Facilities Management
BIM	Building Information Modeling
BMS	Building Management System
BPCA	British Pest Control Association
CAD	Computer-Aided Design
CAFM	Computer-Aided Facility Management
CBM	Condition-Based Maintenance
CCTV	Closed-Circuit Television (or video surveillance)
CIBSE	Chartered Institution of Building Services Engineers
CMMS	Computerised Maintenance Management System
COBie	Construction Operations Building Information Exchange
DBMS	Database Management System
EMS	Environmental Management System
ERP	Enterprise Resource Planning
FDD	Fault Detection and Diagnostics
FM	Facilities Management
GIS	Geographic Information System
GPS	Global Positioning System
HVAC	Heating Ventilation and Air Conditioning
ICAEW	Chartered Accountants in England and Wales
IEMA	Institute of Environmental Management and Assessment
IFC	Industry Foundation Classes
IFMA	International Facility Management Association
IoT	Internet of Things
IWMS	Integrated Workplace Management System
KPI	Key Performance Indicators
LAN	Local Area Network
LiDAR	Light Detection and Ranging
MAR	Mobile Augmented Reality
NFC	Near Field Communication
PIR	Passive Infrared
RFID	Radio Frequency Identification
RICS	Royal Institution of Chartered Surveyors
RTLS	Real-Time Location System
RTMS	Remote Temperature Monitoring
SFG20	Service and Facilities Group
SMS	Short Message Service
VE	Virtual Environment
VR	Virtual Reality
WSN	Wireless Sensor Network

Executive summary

Background

In today's competitive economy, Facilities Management (FM) organisations are facing increasing pressure from client organisations to manage facility portfolios with stringent goals for both cost efficiency and environmental impact. The ability to integrate, visualise and closely monitor building data (such as space demand and utilisation, energy usage and cost, air quality, temperature variations, lighting etc.) is critical to achieving these goals. While it is commonly accepted that big data (data that surpasses the processing capability of traditional database systems) and analytics present major opportunities to generate value for a wide variety of safety and maintenance operations, many within the FM sector have yet to fully recognise this value. Therefore, this study was conducted to explore how Big Data Analytics (BDA) is currently utilised and the opportunities it offers for FM organisations. The aims of the research are twofold:

- to examine the drivers, challenges, opportunities and benefits of using BDA for FM
- to develop a methodological framework to implement BDA into FM organisations.

Methodology

A mixed methods research methodology was adopted with an exploratory sequential research design utilising both qualitative and quantitative inquiries. The qualitative aspect of research focused on a case-study approach to provide a context for understanding the novel research area and formulate a theory regarding BDA implementation in FM organisations. Three UK-based organisations implementing BDA were reviewed and semi-structured interviews were conducted with nine domain experts (three in each organisation). The interview responses were then analysed using cognitive mapping. The themes that emerged from qualitative research informed the development of both a quantitative research instrument (questionnaire) and a methodological framework. The output variables were tested through a questionnaire survey from 52 respondents. Data triangulation was applied to ensure validity of the data and results.

Main findings

The descriptive statistical findings in general indicate a rising interest in applications of BDA and Internet of Things (IoT), with interest expected to further increase in the future. In terms of big data maturity, the majority of the respondents (72%) highlighted that their organisations were still in the early stages (i.e. pre-adoption 37% and early adoption 35%) of deploying big data and analytics. Given the incipient stage, operational systems like Computer-Aided Facilities Management (CAFM), Building Management System (BMS), Environmental Management System (EMS) and Building Information Modeling (BIM) were confirmed to be the key sources of BDA. The study also revealed that larger FM organisations have been the early adopters of this technology.

In a fiercely cost-competitive market place, FM organisations are banking on automation and innovation to keep up with ever-expanding client demands and remain competitive. In a price-constrained market, BDA and IoT applications are deployed to:

- stay competitive
- reduce business risks
- maximise asset and equipment performance
- enhance customer-oriented services.

The combination of big data and analytics is driving opportunities to automate maintenance monitoring, maximise equipment uptime, minimise risks and streamline contracts. To efficaciously bring innovation driven strategies to fruition, focus must be placed on creating an absolute connection between broader strategic ambitions and downstream operational applications.

Despite the growing interest in a data-driven approach, organisations are facing significant hurdles to extract value from big data usage. The key challenge currently facing organisations is securing access to reliable and potent big data. BDA implementation, more than anything, requires getting the basics right – ensuring that asset/facility data is consistent, accurate and complete. Other challenges include:

- the analytics talent gap
- issues with legacy systems
- establishing a clear business case for funding.

Given these challenges, the rollout and appropriation of BDA occurs when organisations commission pilot projects, proof-of-concepts (areas that can provide value to business) and evaluate ways of integrating big data with existing systems and processes in an agile manner. This will invariably require:

- training the existing workforce to put digitisation into place
- investing in sophisticated CAFM systems to digitise asset portfolio
- knowledge sharing/collaboration to refine predictive rules.

As such, the findings have illuminated the centrality of focusing on methodology, people, technologies and best practices to develop comprehensive and viable big data strategies. The drivers, challenges, strategies and outcomes are summarised in Figure 1 on page 9.

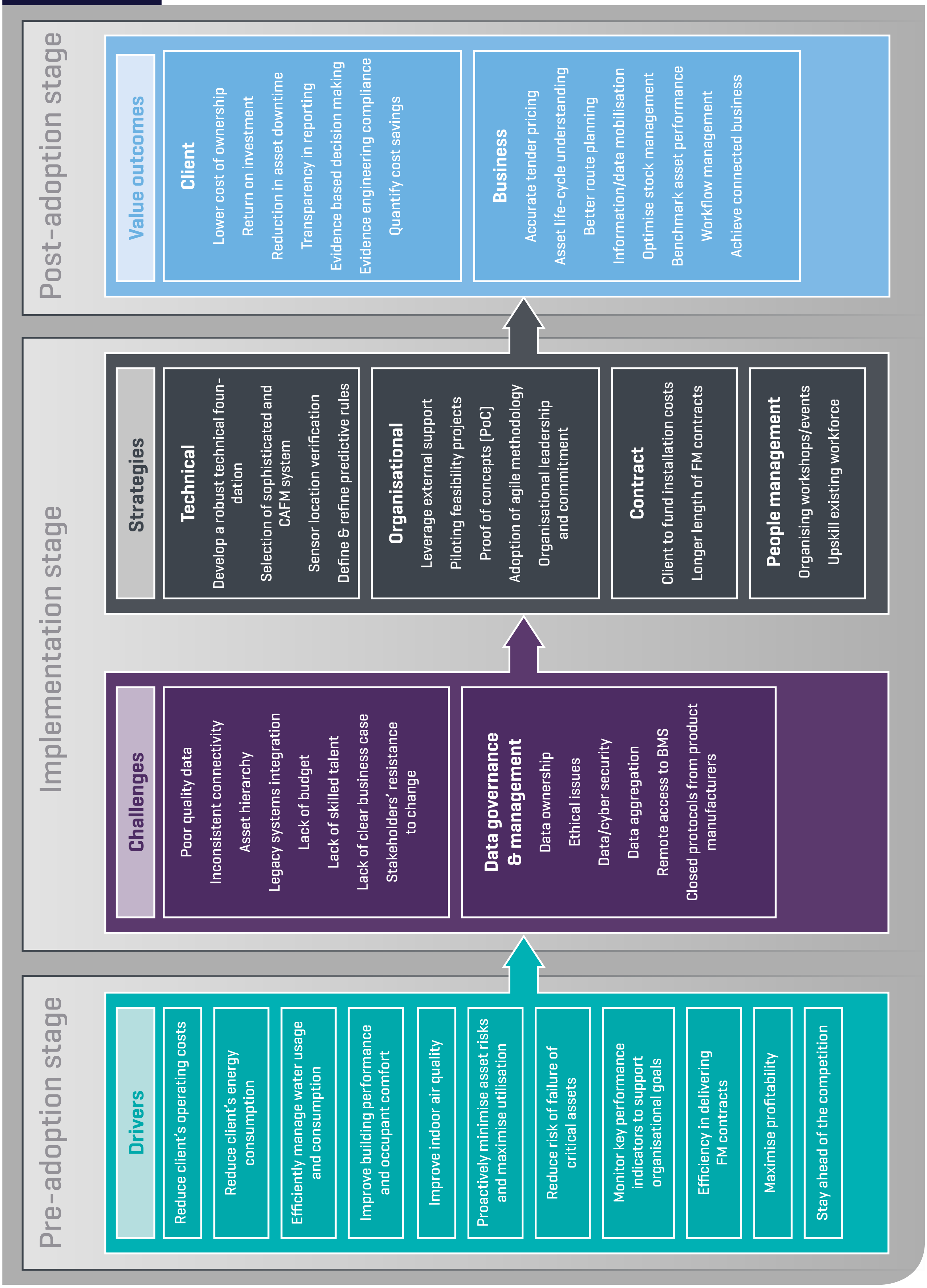
Conclusion and implications

Although this has been a ‘dipping toe in water’ kind of an exercise for most FM companies, it is clear from the results that BDA is becoming imperative for transforming maintenance engineering. The newly acquired ability to bring assets together in a smart network for efficient working is providing greater visibility into plant/asset features, trends, signatures and performance than ever before. The digital asset footprints are in turn serving to meet the information/compliance demands from clients, regulators and decision makers. In future, big data investments by FM organisations will continue to gain traction as sophisticated and new technologies emerge. The respondents expect their respective firms to increase BDA investments by:

- developing comprehensive IoT platforms
- building analytical capabilities
- utilising artificial intelligence (AI) and augmented reality (AR).

This would require FM organisations to partner/collaborate with technology firms, consultants and higher education institutions to scale-up the applications for enterprise level adoption.

Figure 1 Theoretical framework for BDA implementation within FM



1.0 Introduction

1.1 Background on facilities management in the UK

Facilities Management (FM) is defined by ISO (41012:2017) 'as organisation function which integrates people, place and process within the built environment with the purpose of improving the quality of life of people and the productivity of the core business'. This ever-expanding industry employs around 10% of the UK's workforce and is estimated to be worth more than £120 billion a year (British Institute of Facilities Management (BIFM), 2017). With buildings responsible for nearly 42% of energy consumption (Herczeg, et al., 2014), there is huge pressure on FM professionals to improve the performance of these complex systems. Increasing expectations in terms of comfort, usability, environmental factors, changes in technology, shifting economies and the threat of climate change are also having a profound impact on building management.

The burgeoning trends within Big Data Analytics (BDA), Internet of Things (IoT) and cloud technology are rapidly transforming the FM landscape. The increased instrumentation (continual digital measurement and monitoring) of facilities and assets means that every aspect of building performance (e.g. electrical, lighting, heating, cooling, security, fire, and life safety of a building) can be captured. This can help FM professionals and business managers determine how effectively a building or asset is being used. These trends not only allow for the integration of different pieces of building equipment, systems and data sources, but also enable the conversion of the massive amounts of big data (data that surpasses the processing capability of traditional database systems) relating to building operations into actionable information through the use of analytics. Powerful analytics software can enable organisations to:

- develop automated fault[1] detection and diagnostics (FDD) tools for improved predictive maintenance
- extend asset life through condition-based maintenance (CBM).

FDD methods provide proactive rather than reactive solutions and support smarter decision making. Proactive solutions include recognising when equipment is not running at the usual level of efficiency or effectiveness, indicating that a fault has occurred, or is likely to occur, and identifying the root cause for the problem, while reactive solutions involve repairs that are done when equipment has already broken down.

1 Faults in this case relate to a system's performance i.e. though the system is operating, it is performing sub-optimally.

BDA could reinvent building performance management by identifying opportunities for energy efficiency and reducing carbon emissions. Energy management tools are now being developed to provide data-driven insights into energy use, displaying real-time analytics on computers and mobile devices. These solutions include graphical dashboards, which provide more visibility into a building's behaviour, helping building users and facilities managers understand where and how energy is being expended. Increasingly, facilities managers are now using advanced Building Management Systems (BMS) / Building Automation Systems (BAS) / Building Energy Management Systems (BEMS) to control lighting, refrigeration, security, heating, ventilation and air conditioning systems. Historically, these systems were operated as standalone entities. Integrating these systems through an internet protocol (IP) network allows building managers to efficiently manage them with one console as opposed to several and to gather data about building performance and energy usage. As a result, dramatic savings could be achieved by reducing business operating costs through delivering a leaner, cleaner and more exciting environment.

1.2 Research questions, aims and objectives

The research aims are twofold. These are to examine the drivers, opportunities and benefits of using BDA for FM, and to develop a methodological framework to implement BDA.

Identifying the core variables and issues relating to adoption of BDA has its own challenges. It needs careful consideration of various factors that encompass people, processes and technology. The research questions framed after an in-depth review of the literature investigated are the following:

- Why is BDA critical for an information intensive industry like FM?
- How are FM organisations capitalising on disruptive technologies, particularly BDA and IoT to deliver operational efficiencies?
- How is BDA implementation being managed in an FM environment?
- What are the key benefits and challenges facing FM organisations when adopting BDA?

1.3 Research objectives

In more detail, the specific objectives of the study are to:

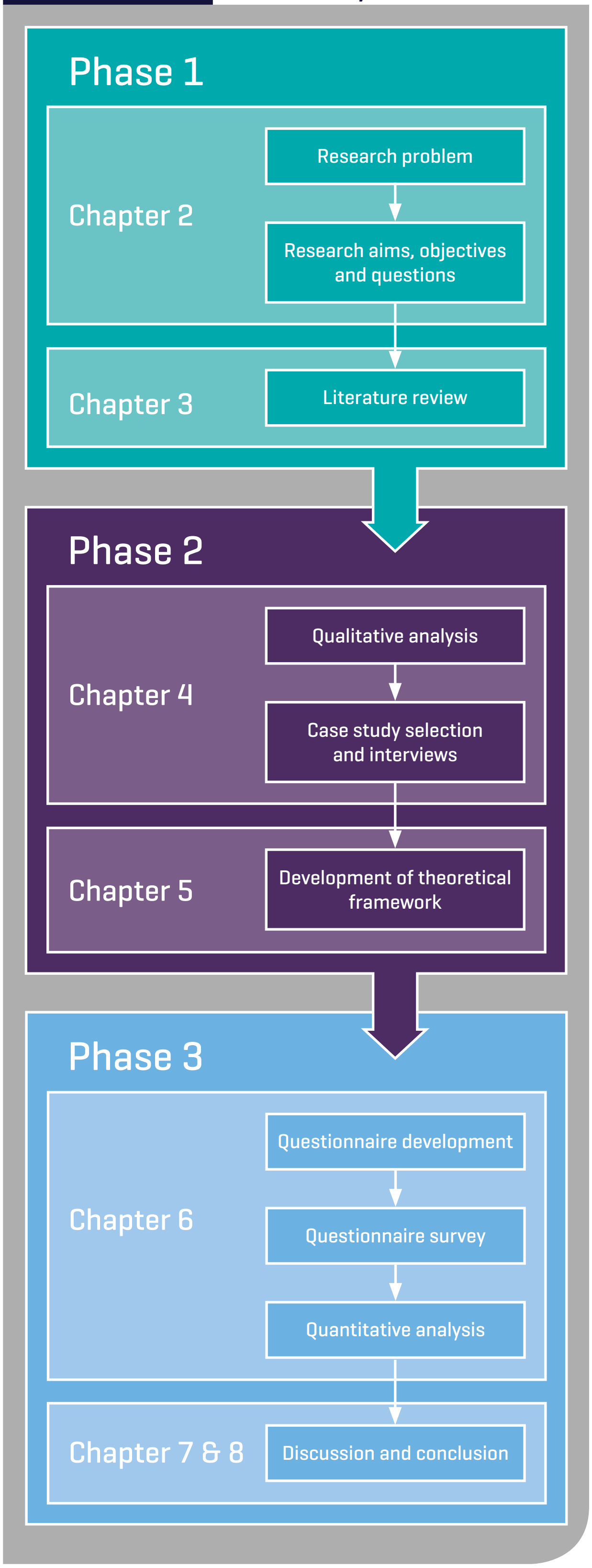
- Provide a critical review of the technological trends transforming the FM sector and the paradigm shift in the way building services are delivered.
- Document the key benefits that can help facilities managers make data based smart decisions.
- Help to close the existing knowledge gap by proposing a comprehensive strategy for FM organisations to handle big data.
- Propose recommendations for FM organisations to:
  - effectively utilise and exploit technological innovations to add value to core business processes, and
  - raise awareness of key challenges associated with data collection, analysis and storage.

1.4 Research methods

In order to address the research objectives, the present study utilised a sequential exploratory mixed methodology and triangulation of methods to complement the possible limitations of both qualitative and quantitative approaches.

Owing to the mixed methods design, the research process for the current study included three phases (See Figure 2). The first phase included a review of the relevant literature. This was followed by case study data collection (semi-structured interviews with FM practitioners) in phase two. The purpose of conducting semi-structured interviews was to gain a deep understanding of the process of BDA adoption and implementation in case study organisations. Qualitative data analysis involved content analysis of the transcribed interviews. Empirical findings and insights extracted from case studies and cross-case analysis informed the development of the conceptual framework for BDA implementation and theory development. Phase three of the research focussed on developing a questionnaire research instrument and quantitatively analysed the results in line with the objectives outlined in Section 2.2.

Figure 2 Research plan and design for the study



1.5 Contribution of the study

This study was devised to explore the emerging concepts of BDA and IoT and to shed light on the strategies used in industry to deal with and adapt to disruptive change. The research aims to make a significant contribution to the existing literature and practice in the following ways:

- It provides an account of the practical steps taken by selected forward thinking FM companies to integrate analytics into organisational decision making. In doing so, it provides insights into the degree of technological maturity that FM organisations have compared to other industries.
- It provides an important starting point for organisations that are evaluating the potential of BDA and IoT applications for their operations. The study highlights the important decisions that companies need to make when considering any investment in developing their digital capabilities. Organisations can therefore learn from the experiences and journey of other leading FM organisations.
- The overarching contribution of this research has been the development of the theoretical framework, containing the insights gained from the case study investigations and the literature review. The findings present a spectrum of drivers, implementation strategies, challenges, data governance issues and outcomes/benefits both for the client and the FM business as a whole. Overall, this framework will help FM practitioners to review their current implementation practices and analytics capabilities to proactively manage their facilities across the business.

This study focuses on larger scale organisations because the level of investment and commitment required for such initiatives suggests that it is currently restricted to larger organisations.

Information management has become a quintessential aspect of FM business. The current market conditions suggest that by gaining management and operational insights from big data, companies can improve their growth potential. However, to reap these benefits, organisations must be well equipped with the knowledge, skills and strategies required to untangle a host of issues associated with data governance and management.

2.0 Literature review

2.1 The evolving facilities management sector

FM is a vast service industry responsible for supporting and improving the effectiveness of an organisation's core business activity (Chotipanich, 2004). It covers a broad spectrum of services from building/asset maintenance, financial systems, resource management, health and safety compliance, space management, hospitality, contract management, real estate management, sustainability and domestic services (Atkin and Brooks, 2000; Amaratunga et al., 2000; Kok et al., 2011; Nutt and McLennan, 2000). Given that FM can take a holistic view of the businesses or organisations it supports, it is well-placed to position itself as a key strategic partner and to significantly enhance business performance.

A general perception remains that it is hard to quantify the strategic value of FM services. Studies in the past have revealed that the great majority of clients do not understand the contribution good FM can make to their organisations' success (Davies and Sharp, 2014). The position of the FM sector is further aggravated by the fact that companies are predominantly assessed against budget performance, which means that qualitative impacts or the level of service achieved is overlooked. The domination of financial results reveals that though FM as an industry is dealing with the cost of services and operations on a daily basis, it is still considered to offer minimal business value (Ware and Carder, 2012). Therefore, in many organisations the potential of the FM services as contributor to workforce attraction, retainment and wellbeing is not understood.

In the context of this cost-centric approach, it is not surprising that not enough thought goes into considering how the FM sector can make a tangible contribution to an organisation's business strategy and goals. Ware and Carder (2012) reveal that organisations that actually manage their facilities as a strategic resource are still in a distinct minority. Furthermore, research conducted in the UK in spring 2013 identified that:

'90% of clients still feel that FM holds a supporting, rather than a strategic, role and will only achieve a higher ranking within an organisation's hierarchy when it finds new ways to deliver value' (Davies and Sharp, 2014).

In the current uncertain business climate, it is imperative for every part of an organisation to think and act strategically, with the aim to sustain and increase their competitive advantage. It is of critical importance that systematic efforts are made to highlight and maximise the FM sector's potential role as a value contributor.

The first area of value contribution is exploring the strong link between FM and the sustainability of buildings, which includes environmental, economic and social aspects e.g. a building's CO_2 emissions, its cost of maintenance and impact on occupants' health. PwC research involving 1,344 CEOs (PwC, 2014) indicates that 76% believe that sustainability is important for any company. The reason for increased interest is clear. Sustainable practices are profitable because they can reduce risk, make businesses and clients more efficient and technologically up to date while reducing environmental and social concerns.

Over the past few years, the sustainability agenda has received considerable attention with very ambitious targets set for energy efficiency, waste management, resource utilisation and carbon foot printing. Since all these goals fall within the traditional remit of FM services, raising the sustainability profile of organisations represents an excellent opportunity for the FM sector to prove its worth and highlight its professionalism. Though the environmental and economic aspects of sustainability are greatly valued, addressing the social dimension (well-being and productivity) is equally important to add dynamism to the company's strategic positioning. This transition from a cost-centric mindset to a people-centric mindset is pivotal to developing an integrated workplace and talent attraction strategy.

2.2 The digital revolution in facilities management

A recent poll of FM experts by Service Works Group in 2016 (SWG, 2016) revealed that technology and digital connectivity are considered to be increasingly important to achieving resource optimisation and delivering customer-centric services. Nevertheless, the majority of FM contracts (both hard and soft[2]) are typically dominated by the delivery of manually intensive tasks with limited automation.

2 Hard services relate to the physical fabric and building systems. Soft services relate to support services that provide a safe, clean and productive workplace.

This manual labour tends to be very expensive, difficult to integrate and traditionally such contracts only concern the monitoring of core systems such as heating, ventilation, air cooling (HVAC), lighting and metering (Streather, 2016). Additionally, facilities managers find themselves unable to fully embed sustainability practices throughout their business as they are unable to collect the right level of data, interpret it effectively and communicate its implications to the business (BIFM, 2014). Motamedi (2013) state that the root causes for the FM industry's reluctance to technology results from:

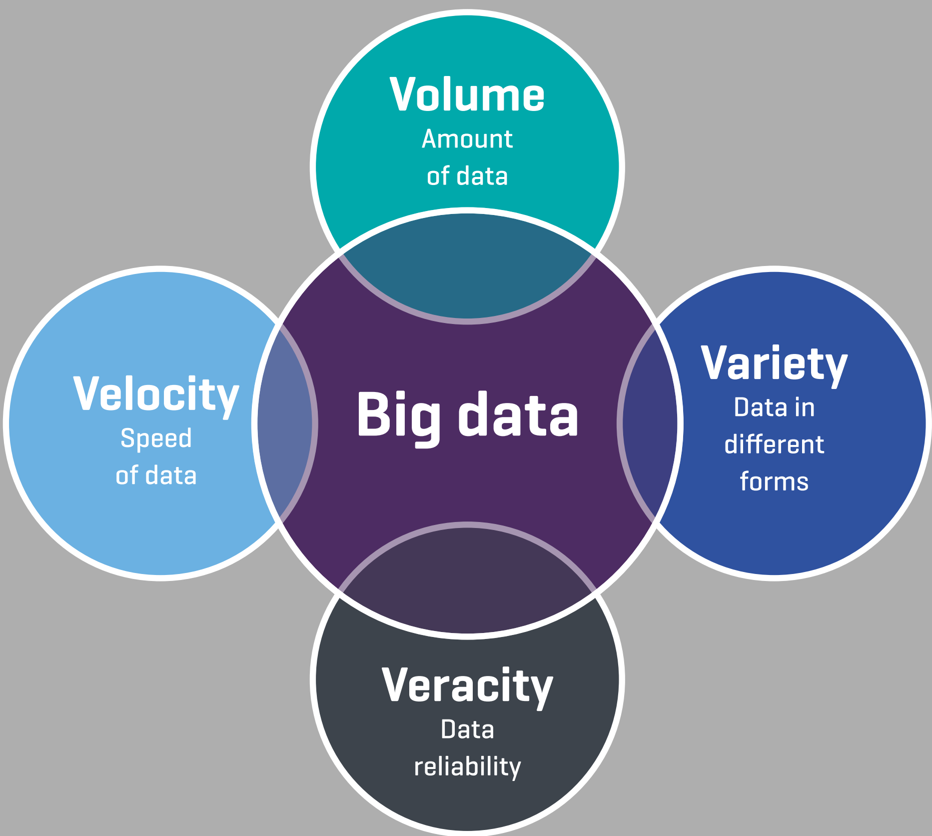
- reliance on inefficient and time-consuming searching interfaces
- a lack of a unified interface for exchange of information
- the inability of the average system to store and process large volumes of data.

The above challenges make clear that applications and technologies based on data analytics are of upmost importance for value creation in the FM sector. Although big data has always been a part of information intensive FM operations, it is only now that companies are investing in applications and technologies that can monitor, produce, systematically gather and make sense of the staggering amount of data available for informed decision making. The development of ubiquitous sensors, information & communication technologies (ICT) and increased computing capacity of systems, allows for affordable storage, transmission and processing of data (Manyika et al., 2011).

Big data is defined as 'datasets whose size is beyond the ability of typical database software tools to capture, store, manage, and analyse' (Manyika et al., 2011). Big data is generated by collecting a wide variety of data both structured (e.g. in a database or spreadsheet) and unstructured (images, videos, emails, transaction data etc.) from different systems to produce actionable knowledge (Bernan, 2013). Gandomi and Haider (2015) characterised big data (See Figure 3) by:

- **volume:** denotes the large magnitude of data that needs to be stored
- **velocity:** denotes the speed at which data is generated and delivered
- **variety:** illustrates the wide variety of sources by which data is generated. They could be in either a structured or unstructured format
- **veracity:** illustrates the integrity of the datasets and focuses on quality of data.

Figure 3 **Characteristics of big data**



Source: Adapted from Gadomi and Haider, 2015

Figure 4 Typical sources of FM operational data

Source: Adapted from Gleeson, 2018

According to Dijcks (2013), big data is multi-dimensional information mined from:

- **traditional enterprise systems** (Customer Relationship Management (CRM), Transactional Enterprise Resource Planning (ERP), web store transactions and ledgers)
- **machines and sensors** (weblogs, smart meters, manufacturing sensors, equipment log)
- **social media** (customer feedback streams, social data from platforms like Facebook, twitter etc.).

The IoT, on the other hand, is where network connectivity and computing capabilities are extended to objects, sensors and items allowing these devices to produce, exchange and consume data with minimal human involvement (Rose et al., 2015).

Although big data and IoT are completely different concepts, they are closely interrelated: essentially, IoT is a means of collecting and sending big data. In an FM set-up, this would typically involve installing meters, sensors, systems and devices that measure the actual behaviour of assets, equipment and components, and interact with other systems, to create a data pipeline (Figure 4).

Following data collection, data analytics involves applying an algorithmic process to provide insights of significant value to organisations (Richards, 2017). As per IBM (2013), analytics is further categorised into:

1. **Descriptive analytics:** this involves data mining to understand what happened; to unearth the root causes of asset failures, the frequency of failures that are occurring, and the cost of these failures to the organisation's operations. This information is presented as charts, graphs, statistical trend analysis and digital dashboards.
2. **Predictive analytics:** this provides decision makers with tools and techniques to predict future conditions i.e. what could happen based on trends identified in current datasets. Most importantly, it facilitates a proactive rather than reactive approach.
3. **Prescriptive analytics:** this involves data processing to propose what should be done. Techniques within this domain explore a number of viable actions and precisely identify what actions need to be taken to achieve an outcome based on the above mentioned analytics.

In the context of FM, BDA provides an opportunity to streamline existing labour-intensive maintenance functions and extend the operations of the sector into higher value-added activities. Although organisational information and knowledge forms an inextricable part of both short-term and long-term decision making, most of the current digital initiatives are targeted to address issues at operational level (Ahonen et al., 2017). As such, early adopters of BDA are automating maintenance activities, work orders and energy management (which represents a major portion of costs for FM companies). Specifically, condition-based and predictive maintenance are emerging trends in the digitised FM industry. These strategies, enabled by IoT, offer the remote monitoring of an asset or facility's condition and intelligent data analytics.

Condition-Based Maintenance (CBM), a subset of predictive maintenance strategy, is defined as a 'reliable, cost effective method of monitoring selected working characteristics of plant items, thus reducing failure rates and costs' (BSRIA, 2001). CBM strategies aim to minimise unnecessary interventions and take action only when the asset behaviour deviates from the normal (Jardine et al., 2006). Under CBM the ideal time to perform maintenance activities is determined from closely monitoring an asset, or its subcomponent (Horner et al., 1997). Therefore, CBM programmes provide a host of predictive measures that assess the state of assets, including (Jardine et al., 2006):

- vibration data
- acoustic data
- oil analysis data
- temperature
- pressure
- moisture levels
- humidity
- weather or environment data etc.

This approach could be further scaled-up to embed sensors in the typical FM clusters (HVAC, power, air quality, temperature, lighting etc.) to achieve more detailed monitoring, measurement and control. This data can then be streamed into an overarching system for aggregation (Patel, 2015).

The FM operations rely on a multitude of Information Management Technologies (IMTs) and systems which hold the potential to supply raw data for BDA initiatives. Ebbesen (2016) further categorised these different systems into:

- data and information repositories that include file servers, Building Information Management (BIM) models and Geographic Information Systems (GIS)
- workflow systems include Computer Aided Facilities Management (CAFM), Computerised Maintenance Management Systems (CMMS) and Integrated Workplace Management Systems (IWMS)
- sensor and mobile technologies include Radio Frequency Identification (RFID), Virtual Reality (VR) and Augmented Reality (AR)
- Field Data Capture Systems (FDCS) include remote sensing, photogrammetry, drones, laser scans
- data standardisation and interoperability
- facilities intelligence systems like Building Automation System (BAS), Building Energy Management Systems (BEMS) and Building Management Services (BMS)
- communication systems like, websites, social media and applications.

As such, a combination of structured, unstructured and semi-structured data are produced by the FM systems (See Table 1). Capturing and integrating datasets from these disparate systems can greatly improve FM services by reaping synergy-related benefits.

Table 1 Sources of big data in FM

Information Management Systems Categories	
Interoperability	IFC, COBie, Protocols, Exchange Methods
Sensor Mobile and Real-time Location Systems	GPS, Mobile Data, NFC, Wi-Fi, LAN, WSN, Optical Fibre, Tablets, RFID Bar Codes, SMS, CCTV, PIR, AR/MAR.
Work-Flow Systems	ERP, CMMS, CAFM, IWMS
Field Data Capture System	Remote Sensing, Photo-grammetry, Drones, Laser Scan
Facilities Intelligence Systems	BAS, BMS, BEMS
Communication Systems	Websites, Intranet, Applications, Social Media, Services
Data Repositories	DataBase, Digital Archives, Spreadsheets, BIM Models, VR/VE, CAD, GIS

Source: Adapted from Ebbesen, 2016

2.3 Absorptive capacity and the competence-based view of a firm

Of the various dynamic capability theories, absorptive capacity and competence-based view (CBV) theories emerge to be the most pertinent to understand how organisations innovate and respond to changing market conditions. Collectively, these theories provide a deeper understanding into the phenomenon of big data (Braganza et al., 2017) and how complex knowledge is explored and exploited in organisational settings.

Absorptive capacity is defined as 'the ability of a firm to recognise the value of new, external information, assimilate it, and apply it to commercial ends' (Cohen and Levinthal, 1990). It capitalises on employees' existing knowledge, understanding of technologies and markets to support key activities and augment organisational performance (Boynton et al., 1994). Absorptive capacity is essential for organisations that seek to extract value from technology and to maximise profits (Nelson and Winter, 1982). In recent times Zahra and George (2002) reconceptualised this theory as 'organisational routines by which a firm acquires, assimilates, transforms, and applies knowledge to create dynamic capability'. Accordingly, Zahra and George (2002) further distinguished absorptive capacity concept into:

- potential absorptive capacity, which refers to the firm's capability to acquire and assimilate
- realised absorptive capacity refers to a firm's capability to transform and exploit that knowledge.

According to McAfee and Brynjolfsson (2012), organisations must focus on leadership, personnel management, technology, decision making and company culture for effective management of big data. BDA initiatives more than anything require collaboration between key stakeholders to creatively identify ways to combine datasets from various enterprise systems and to create new opportunities for staying ahead of the competition (Chen et al., 2012; Camisón and Forés, 2010).

CBV, on the other hand, examines the organisation's key resources (tangible and intangible) and the organisation's capabilities in delivering competitive advantage (Prahalad and Hamel, 1990; Teece et al., 1997; Winter, 2003). CBV differentiates between different companies based on these competencies (Eisenhardt and Martin, 2000).

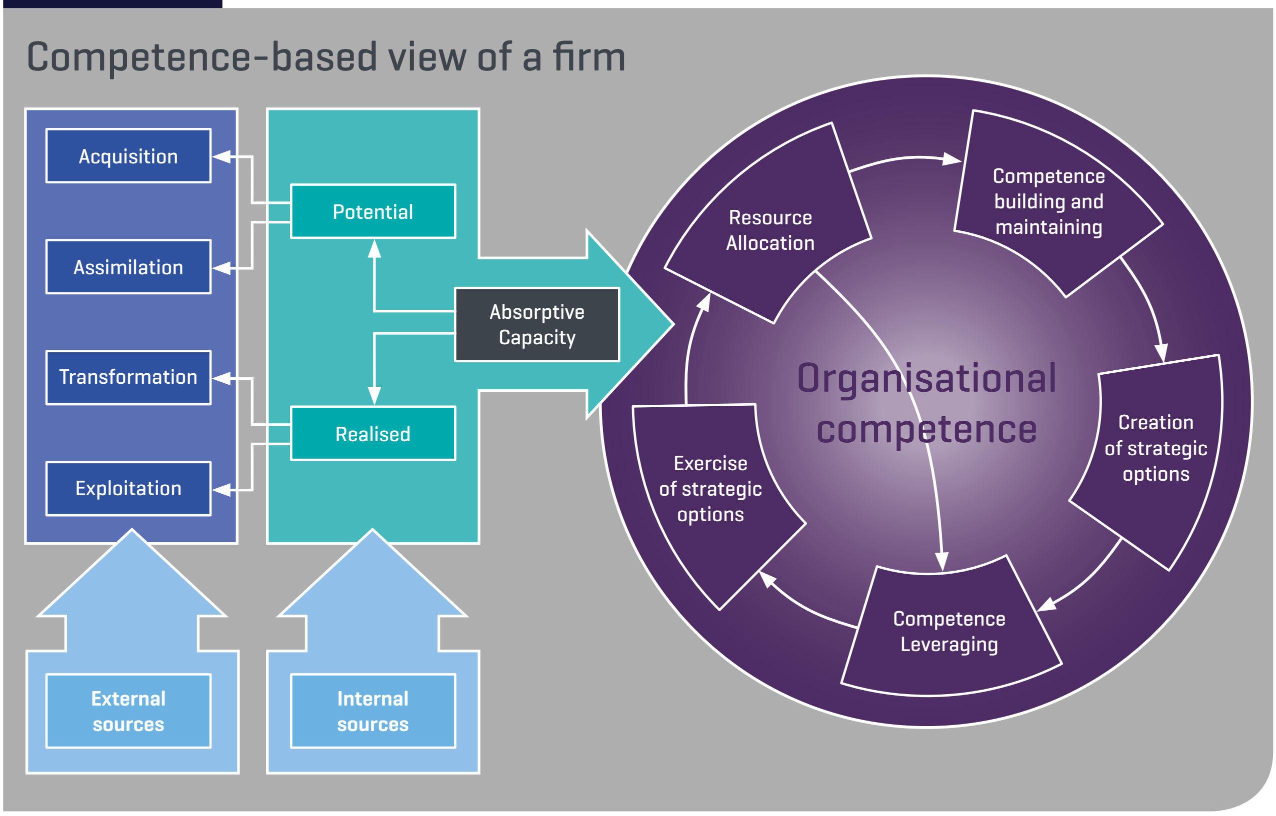
In this context, organisational competence refers to the organisation's ability to effectively align its resources for value creation, addressing client requirements and delivering superior performance (Coombs, 1996). CBV makes a distinction between competence leveraging and competence building. According to Sanchez and Heene (2004) competence leveraging is all about using existing competences to exploit current or new market opportunities without making any qualitative modifications to the firm's assets or capabilities. In contrast, competence building is where a firm makes qualitative modifications to its existing capabilities and asset stocks, including developing new abilities to coordinate and deploy new or existing assets to facilitate the attainment of organisational goals.

Since 'achieving competence involves both knowledge and effective processes for deploying knowledge within and across an organisation's boundaries' (Sanchez, 1997), the absorptive capacity of a firm is a critical precursor to attaining organisational competence (Cohen and Levinthal, 1990; Kogut and Zander, 1992) (Figure 5).

To capture learning, organisations need to develop an awareness of what these technological trends mean for their business and to develop the means to exploit the potential within an organisational context (Kwon et al., 2014) through incremental implementation (Fichman, 2004) (smaller pilot projects). Capgemini Consulting (2014) proposes four building blocks for achieving this data-driven transformation:

- **Strong technological foundation** – this involves investing in big data infrastructure, and tools for data governance, master data and metadata management.
- **Robust governance framework** – this deals with the need for organisations to develop robust organisational structures to support data analytics initiatives.
- **Data management capabilities** – this involves the organisation, management and control of data to ensure high level reliable data effectively deliver insights.
- **Clear strategy to build analytics skill set** – this focuses on strategies to recruit fresh analytics talent and up-skill existing workforce.

Figure 5 **Competence building and leveraging in organisations**



Source: Adapted from Sanchez and Heene, 2004 and Zahra and George, 2002

3.0 Qualitative research

3.1 Research methodology

This study aimed to explore how a group of leading FM organisations in the UK are currently capitalising on BDA and IoT to drive innovation and efficiency in their operations. Given that very little is known about this topic, a multiple case study approach, as recommended by Yin (2009), was adopted. Qualitative data was collected through intensive examination of the current practices of the FM organisations selected, which were chosen because they are exploring the applications of BDA technologies. Multiple sources of data were used (Yin, 2009; Leedy and Ormrod, 2005). A case study research is an empirical inquiry that investigates a contemporary phenomenon within its real-life context when the boundaries between phenomenon and context are not clearly evident (Yin, 1984).

The case studies used in this research were selected based upon:

1. the accessibility and willingness of individuals within the organisations to co-operate and share their experiences
2. the nature of the work they are engaged with i.e. facilities management
3. the company's geographical location – the UK, being the most mature FM market in the world (PWC, 2014), was selected as the region for conducting the research
4. palpable evidence that the organisations were in the process or had already implemented BDA initiatives within their FM operations.

Qualitative data collection involved semi-structured interviews guided by a protocol (see Appendix A). Ethics approval was obtained from the research ethics board at the University of West of Scotland. Three participants were selected from each organisation using both purposive and snowball sampling to ensure the inclusion of individuals who were actively involved in BDA implementation. Participants included:

- directors from senior management
- on the ground FM managers
- technical/innovation managers (See Table 2).

Table 2 **Interviewee profile**

Organisation	Code	Job Title
Case study A (800+ employees)	INT-A-FM1	Head of Technical Services
	INT-A-FM2	Smart Hub Manager
	INT-A-FM3	Technical Performance Engineer
	INT-A-FM4	Capital Operations Specialist (Validation)
Case study B (20,000+ employees)	INT-B-FM1	Strategy Director
	INT-B-FM2	Digital Energy Development Director
	INT-B-FM3	Transformation Manager
	INT-B-FM4	Partnership Director (Validation)
Case study C (800+ employees)	INT-C-FM1	Managing Director of Facilities Services
	INT-C-FM2	Operations Director
	INT-C-FM3	Innovation Manager
	INT-C-FM4	Operations Excellence Manager (Validation)

The interview information protocol was circulated among all the three participants in each of the case studies prior to the interview. Of the nine semi-structured interviews conducted, five were conducted in person and four were conducted online using voice over IP technology (Skype). The interview questions were primarily designed to capture the participants' views of the following:

- the critical factors that enabled their organisation to successfully extract value and benefits from BDA implementation
- the managerial, cultural and technical challenges associated with BDA adoption.

All the interviews were transcribed and analysed using a qualitative analysis software package (NVivo 11.0). A cognitive map was developed for each case study (using NVivo) to indicate participants' experiences of their FM organisation's BDA implementation process (See Figures 6, 7 and 8). A cognitive map is a graphical representation of causes and effects (or means to ends) concerning a determined situation. This map is constructed from dialogues with an agent involved in the process (Rosenhead and Mingers, 2008). It is a very simple and intuitive way of highlighting important strands of thoughts. In this research sentences are broken into distinct phrases known as concepts, which are then categorised as drivers, challenges, strategies and outcomes. The hierarchy is established in the map by placing the outcomes at the top supported by strategies, which are in turn driven by challenges and initiated by drivers.

Since the terms, drivers, challenges, strategies and outcomes are frequently used in this study, it becomes necessary to explain their exact meaning. Consistent with the terminology adopted by Mignon (2016), drivers refer to the rationale that influence and encourage organisations to adopt novel technology (in this case BDA); challenges are the obstacles/barriers organisations face during implementation; strategies are the steps taken by organisations to deal with challenges and the policies that facilitate the implementation process, and outcomes are the end results of the implementation or adoption process.

To design the current project, the researchers first defined the 'unit of study' (UoS) or the 'unit of analysis' (UoA) since they tend to influence the decision pertaining to sample selection and the type of conclusion that can be drawn from the study (Rubin and Babbie, 2010). In this context, the UoS/UoA are the FM organisations.

3.2 Case study A

Case study A is a facilities services provider for a major UK retailer. It has recently extended its contract with the retailer to provide FM services across all the retailer's UK estate, including supermarkets, convenience stores, petrol stations and depots. The FM company's responsibilities include:

- refrigeration remote monitoring
- energy management
- compliance management
- mechanical & electrical maintenance
- building fabric maintenance
- lighting services.

The driving force behind the uptake of BDA and IoT is to leverage technology to reduce the client's energy consumption, deliver contracts efficiently and serve lifecycle information for asset procurement. As such, the Key Performance Indicators (KPIs) are:

- to reduce refrigerant losses
- monitor energy usage of estates
- achieve smooth asset replacement.

Driven by these KPIs, case study A investigated its maintenance practices across the organisation to determine its most critical assets, which were then setup into its asset management system for tracking. Since refrigeration is the largest consumer of electricity and given that a grocery chain has thousands of refrigeration cabinets, each with their own controller, case study A adopted the strategy to integrate its CAFM (Verisae) with their Remote Temperature Monitoring System (RTMS) and establish a global platform to access data in a usable format.

Currently, case study A is in early stages of BDA implementation. The company has been working on building a strong technological foundation for about seven years. The main aims are to:

1. embed the sensors in the right place
2. consolidate the naming conventions.

The sensor verification aspect, i.e. making sure that the sensors are in the right place to capture right granulation of data, has been highlighted as crucial. To deal with data identification, 'Project Haystack' semantic tagging is being used to streamline the interchange of data among different systems, devices and equipment. However, a pre-requisite for getting the best out of these technological applications is ensuring that the data is of sufficient quality.

Case study A currently use an RTMS for refrigeration. This data handling system provides access to continuous live telemetry coming through from each store and equipment (cabinets, packs, engine rooms). The RTMS allows the users to define rules that, once set, automatically generate a ‘flagged condition’, such as temperature spikes or refrigeration leaks, which then go through a couple of different options within the system to automate a response. The flagged conditions or alarms are then categorised and passed on to the appropriate business units in the form of work orders to sub-contractors, email notification or even telephone calls to the store manager. This integration of CAFM with RTMS enables assimilation of data from disparate systems which, combined with external data such as weather data, live telemetry data, energy, alarm and refrigerant usage, is analysed within the system to derive new insights. These insights are used to then alert corrective and preventive actions. The RTMS also notifies and immediately reacts in circumstances such as:

- continuous temperature variation for a certain period
- temperature thresholds being exceeded
- an asset shutting down.

With the development of suitable predictive rules, the company has begun to identify different ways to save energy, since the predictive rules are able to pick on asset inefficiencies that would never have been identified otherwise. For example, all the refrigeration units are equipped with a remote engine which, in the case of an increased load, makes the central refrigeration plant run for longer than required. Predictive rules such as these can identify and notify system users about inefficiencies on each individual asset, highlighting the need to reduce the load on the system. By doing so, the system can, for example, facilitate better performance during the summer by the activating greater capacity to cope with the warmer weather when the load on the system is higher.

Just on energy, the FM company has managed to save around £1.6m to the business. The key contributor is saving on resources: problems can be resolved remotely, technicians don’t have to be on-site and since problems can be predicted, scheduled preventive maintenance has been made redundant and the number of emergencies have been significantly reduced. In addition, this approach is helping the company to accurately capture sub-contractors’ performance on various jobs and identify the characteristics of top performers, which are then used to train those performing poorly.

Most importantly, using a predictive maintenance regime allows case study A to condense most of the repairs into a single time slot when it is not only cheaper to repair (by avoiding out of hour rates) but also creates minimal disruption to usual business activities. Additionally, having more data means that it is able to change the way refrigeration units work in supermarkets thereby increasing the shelf life of products. This eventually provides a big payback for the client. By taking action to become equipped with this analytics capability and the subsequent improved understanding of equipment and component behaviour, case study A is best placed to advise client and manufacturers on procurement and performance issues.

The main challenge currently facing the company is the integration of data coming from various systems. The company uses multiple systems, which often do not easily communicate with one another. The CAFM software currently being used has a limited capacity to deal with different kinds of data; only energy and refrigeration data are being analysed. Therefore, the company is now collaborating with an IoT technology expert to develop a comprehensive platform that allows vast amounts of diverse devices and systems to be connected and to build accurate, testable and predictive models for wider asset portfolios.

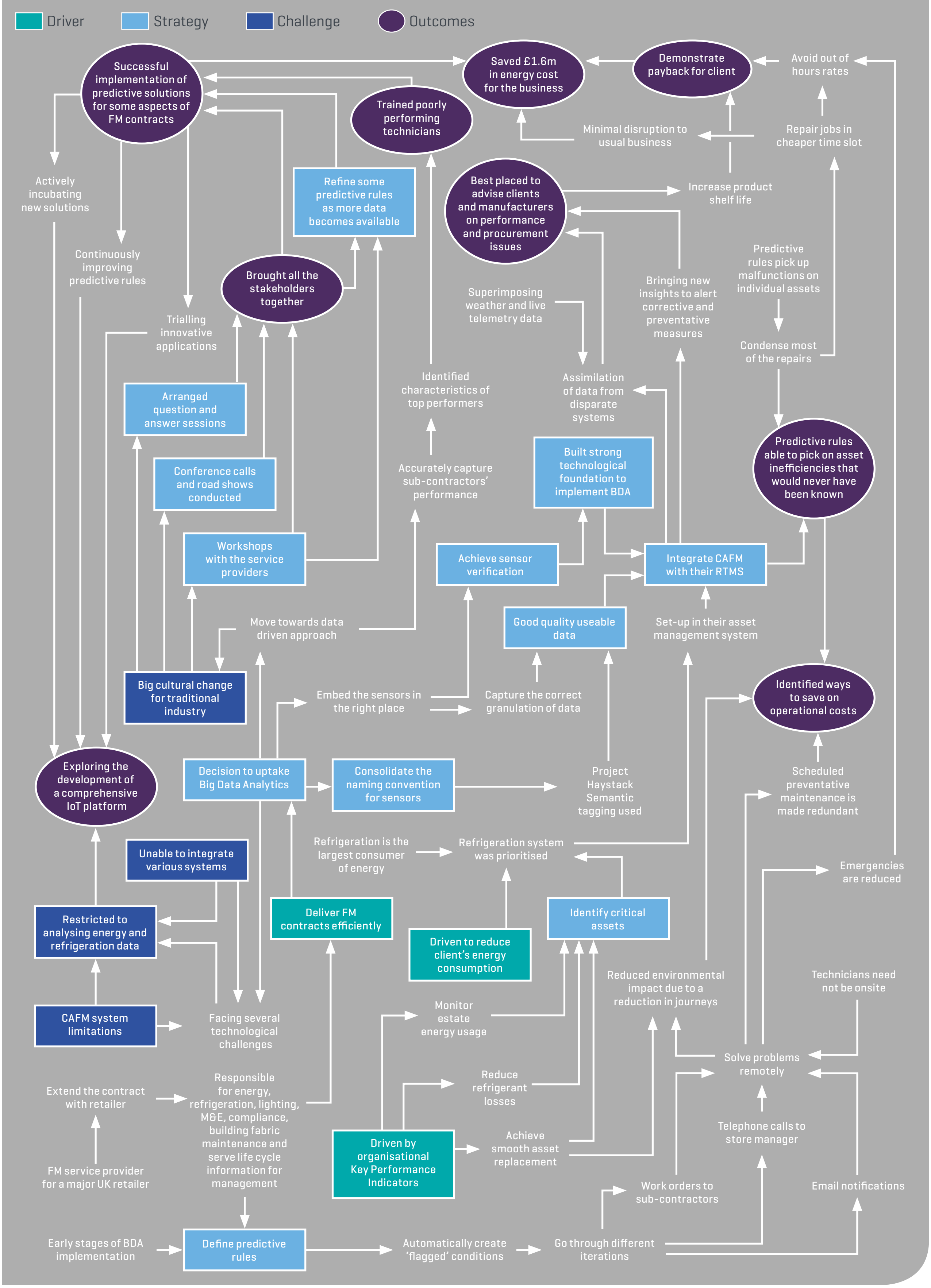
This data-driven approach requires a big cultural change for those involved on the FM side, especially for sub-contractors not accustomed to examining operating assets with no obvious problems. In this context, the successful implementation of predictive analytical solutions in FM contracts has required bringing the sub-contractors/stakeholders on board. To improve implementation quality, the company has organised road shows around the country, workshops with all the different service providers, question and answer sessions and conference calls. This interaction with various parties has also helped to redevelop or redesign some of the predictive rules.

A key lesson that the company has learnt from BDA adoption is that implementing new technologies will not always be a smooth ride. However, case study A has been actively developing new solutions, trialling innovative applications and continuously improving the predictive rules as more data emerges. As one interviewee stated:

‘[the] strategy for … [case study A] is making sure they have got the right people, the right technology, the right rules, to give you the right benefits’.

See Figure 6 for the combined cognitive mapping of case study A interviews.

Figure 6 Cognitive map for case study A



3.3 Case study B

Case study B is a large multinational energy organisation (20,000 employees in the UK and 120,000 worldwide) active in the energy, retail and business services market. The UK business has three divisions:

1. energy infrastructure
2. energy solution
3. business services, which involves facilities management.

Case study B has recently acquired a UK-based digital energy management specialist company to complement its energy and carbon management services and promote digital technologies and connected business.

The IoT platform developed by the newly acquired company enables FM teams to predict energy usage and take proactive measures to control it. It allows data feeds from various sources, such as a building's utility meter, equipment meter, HVAC system and BMS system. Performing analytics on these large data sets not only offers deeper insights but also helps to understand how a particular piece of equipment is operating in conjunction with other equipment in the building.

With emphasis placed on energy efficiency, the first phase of BDA and IoT adoption has involved the integration of the BMS and energy data. The company is also able to integrate client datasets like occupancy data, production volumes, side air temperature and market prices. The first phase of implementation has delivered substantial success. The company has been able to lower the cost of ownership for its clients, deliver best service for customers and stay ahead of the competition by becoming an innovator in BDA services.

In a move towards CBM and an analytical approach to asset lifecycle, the company plan in the second phase of implementation is to merge data from its CAFM system to existing schemes. With abundant data come the challenges associated with standardisation and nomenclature. Given that the FM systems and applications used by the company were originally designed to be stand-alone installations, the company recognised the importance of developing a standard, rational method of managing and organising information during the building's lifecycle. Standardisation has also enabled data mobilisation; the company was able transfer a standardised dataset from previous contracts to the following ones.

However, the starting point to producing comprehensive insights and reducing false positives is ensuring that the collected data is of a high quality. Integrating poor quality data can produce false correlations, false conclusions and can consequently affect stakeholder engagement, trust and buy-in. Alongside these considerations, respondents from case study 2 stated that establishing a comprehensive and robust ontology concerning 'asset hierarchy' (how assets and devices should be grouped or related within a hierarchical structure) was one of the challenges to leverage technology to collect asset data. To flawlessly identify the assets and components, the company has come up with a bespoke secondary labelling system that tags asset points. The key advantage of this approach is that data can be taken in whatever format it currently is without going back and reworking. Though data mobilisation has been a laborious manual process, it was highlighted to be a key cornerstone for the uptake of technology. A priority issue for case study B is to reduce the cost of data mobilisation.

Having appropriately classified assets and prioritised quality data, correlation analytics have been helping to identify the root-cause of equipment faults leading to energy waste in real time. For instance, in one of the university premises monitored by case study B, data analytics highlighted an additional increase in gas consumption at a rate of £60 per day. The team were also able to precisely identify the particular heating valve for the particular air handler that was causing the problem. A technician then investigated and confirmed that the valve wasn't working and needed replacement.

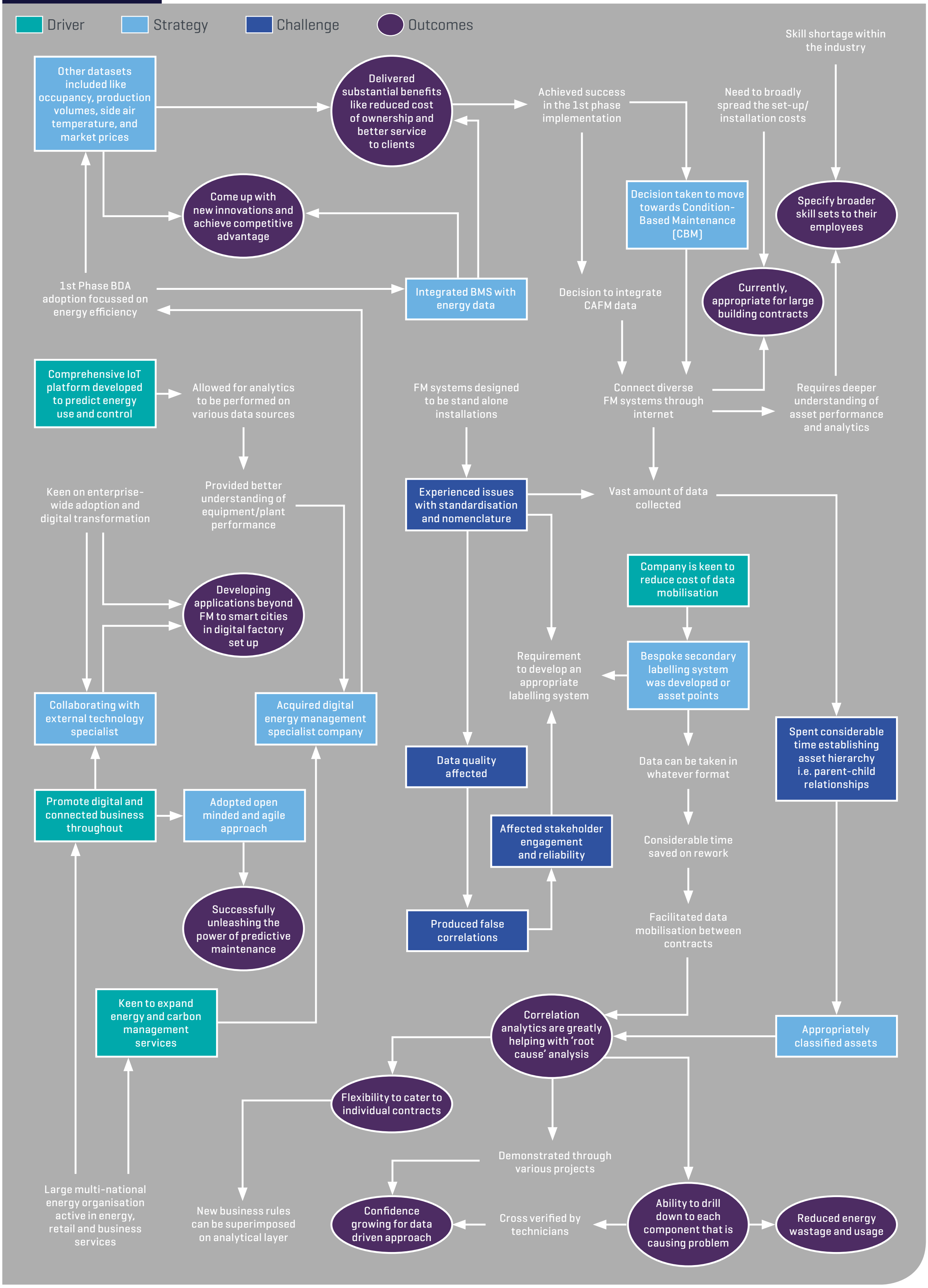
New business rules can also be superimposed over the analytics layer to cater to specific contracts. Current initiatives were highlighted to be appropriate for larger building contracts because it was possible to spread the set-up costs over a broader base. Nonetheless, these systems have provided cost savings and have reduced the buildings' overall energy usage.

Given the disruptive nature of technology implementation, facility managers are required to not only have a deeper understanding of asset performance but also an appreciation of data analytics. The organisation is challenged to either find employees with broader skill sets or to invest in re-training its employees.

The company has been able to revolutionise the way it maintains its facilities by incorporating a data-driven analytical approach. By collaborating with an external technology (IoT) specialist, the company aims to further harness the power of cloud computing, big data, analytics, machine learning and the IoT to enhance and accelerate enterprise-wide transformation. The FM company is also being supported by a digital factory based in Europe as a means to develop applications on a larger scale, spanning beyond predictive maintenance facilities to cover smart cities. Case study B has been able to reap the rewards of an open-minded and agile approach to disruptive technology by unleashing the power of predictive maintenance. However, the industry as such is far from realising the true potential of connectivity.

See Figure 7 for the combined cognitive mapping of case study B interviews.

Figure 7 Cognitive map for case study B



3.4 Case study C

Case study C is a large facilities management company offering a full range of hard FM services (electrical, mechanical, ventilation, fabric maintenance, property and energy services) to various sectors including defence, education, office buildings and local authorities. In 2010, the company decided to move away from a planned preventative maintenance (PPM) approach to facilities management and adopt a proactive CBM paradigm. To initiate this adoption of BDA within its FM operations, the company collaborated with academia. The company sponsored a doctoral studentship to investigate the potential benefits from CBM of critical assets. Specifically, the project was undertaken as part of a four-year (2012–2016) partnership between case study C, the client organisation and a university.

The project concerned the real-time monitoring of the condition of 83 critical rotary assets, including pumps, motors and fans. These rotating assets are essential to the daily operations of the building; they feed into fundamental building systems such as chillers, cooling towers and air handling units. Data collection for CBM called for the development of a sensors-enabled platform to gather vibration, temperature, humidity, energy and operational data. The main focus was placed on vibration analysis, since the vibration levels can provide an indication of condition as well as the differentiation of normal acceptable variations from harmful levels. The CBM detected faults to 48% of the assets and increased asset operational life by up to 75%. In the context of the developed maintenance paradigm, bi-monthly planned maintenance intervention was considered to rectify faults identified by continuous monitoring. This has enabled the removal of monthly and three-monthly PPM routines. CBM has also minimised unplanned failures, thus reducing reactive maintenance by around 10%.

The comprehensive technical feasibility and business case identified potential savings in excess of £790,000 over the remaining duration of the concession period (16 years) and various operational benefits such as:

- mitigation of unplanned failure risk
- increased asset life
- enhanced analysis and reporting relating to asset maintenance and operations.

Through maximising the asset life via continuous monitoring and proactive intervention, CBM provided a significant reduction to asset lifecycle expenditure while improving the asset's performance and reliability.

Case study C's priority is to exploit the opportunities offered by systems integration with the aim to reduce the inherent risks associated with FM business while delivering superior client experience. With the initial focus on establishing critical business systems and laying sustainable foundations for successful analytics, the company worked on:

- establishing asset parent-child relationships
- developing a uniform coding structure to standardise data for the CAFM system
- identifying locations for asset tags etc., which were then piloted in a live project environment.

The FM organisation is working to overcome several challenges, which include:

- getting the right interoperable platform
- establishing bi-directional communication between systems
- providing wifi internet connectivity/avoiding black spots in buildings
- improving data security, data ownership and data aggregation
- providing remote access to BMS systems for certain clientele.

The initial use of BDA has been restricted to its longer length FM contracts (i.e. private finance initiative FM contracts). As such, the company has been able to achieve pockets of excellence by rolling out small trials and funding pilot projects. It is still working towards its vision for a full-fledged roll out on wider scale.

These innovative pilot projects have demonstrated value for its customers. The CBM/vibration monitoring approach is able to detect symptoms and to uncover the causes of faults in pumps, bearings, gearboxes etc. up to a year in advance of the part becoming a problem. For instance, if the desired functionality is to grease a bearing, analytics data could exactly specify the quantity of greasing required to avoid over or under greasing components. By being able to detect component faults in advance, the company can schedule maintenance activities around production schedules and avoid causing disruptive downtime. This preventative approach effectively eliminates the servicing or routine interventions, typical of reactive maintenance programmes and ensures improved machine availability. Asset performance data is regularly presented as a series of dashboards available for the relevant stakeholders; data on these dashboards are tailored to the interests and overall goals of parties involved.

As a result of these BDA and digitisation initiatives, the company has been able to achieve wide-ranging benefits, which include:

- informed decision making
- better transparency with customers
- evidence of engineering compliance
- enhanced productivity in workflow management
- improved stock management.

Furthermore, BDA has enabled the company to:

- develop targeted as well as flexible information management
- achieve better route planning for jobs
- precisely record the time taken to complete a particular job
- improve tender pricing accuracy
- achieve better functionality for older buildings
- better resource management.

In one of the pilot projects, the client achieved payback in one year as opposed to ten years set out in the business case. Adopting BDA and IoT technologies has also transformed the FM services offered by the organisation. Having spent several years establishing technical expertise in BDA and IoT, the company is now keen to expand its services portfolio by offering digital set-up contracts.

Sensor selection (i.e. intrusive vs non-intrusive) has been critical to achieving data accuracy and to reducing the number of false alarms. The interviewees stated that the partnership with academia had been hugely beneficial in helping them understand the broad academic knowledge base. Case study C plans to take its BDA capability one step further by moving beyond its current focus on critical assets towards applications within utilities, the wider construction arena and smart city infrastructure. Armed with these capabilities, the company aims to utilise artificial neural networks to understand patterns and test academic research in this area in the future. Although at the early stages of implementation, these steps are demonstrating significant performance improvements and potential. See Figure 8 for the combined cognitive mapping of case study C interviews.

3.5 Factors extracted from case studies

Significant statements were extracted from main interview transcripts and clustered into themes. The statements that explain the same issues were then clustered into various themes of drivers, strategies, challenges and outcomes in an attempt to answer the research questions posed. The findings were further analysed and discussed among the co-investigators. Results from the qualitative analysis (see Table 3) and literature review were used as a foundation to support the development of a theoretical framework. This framework captured the drivers, implementation strategies, challenges and processes that forward-looking FM organisations are putting in place to embrace digital innovation and identify new potential business models. By using a multiple case study approach, the research provided rich contextual data that was appropriate for studying technological implementations within FM organisations and allowed for cross-analysis and comparison between the three organisations to establish key challenges and elements of good practices.





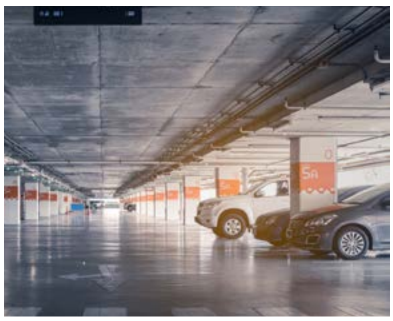



Figure 8 Cognitive map for case study C

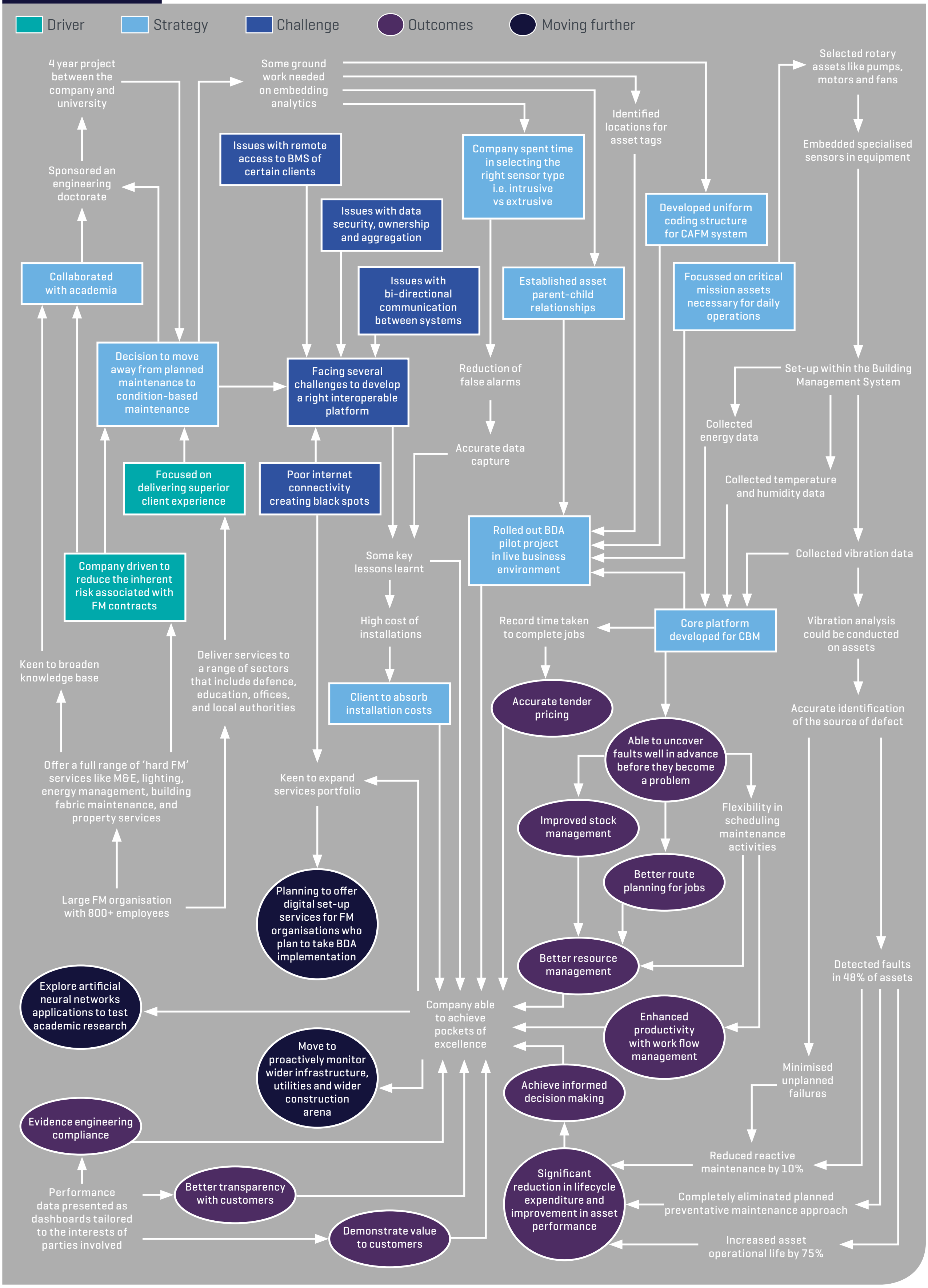


Table 3 Factors extracted from case studies

	Case study A	Case study B	Case study C
Drivers	• Deliver FM contracts efficiently • Reduce client's energy consumption • Organisational KPIs	• Expand energy & carbon management services • Promote digital and connected business • Comprehensive IoT platform developed to predict energy use and control	• Company driven to reduce the inherent risks associated with FM contract • Focused on delivering superior client experience
Strategies	• Decision to uptake BDA • Consolidated naming convention for sensors • Achieved sensor verification • Defined and refined predictive rules • Identified critical assets • Integrated CAFM with RTMS • Built strong technological foundation • Arranged for Q&A sessions • Organised conference calls and road shows • Organised workshops with service provider	• Collaborated with external technology specialist • Adopted open minded and agile approach • Acquired digital energy management specialist company • Other datasets included like occupancy, production volumes etc. • Integrated BMS with energy data • Bespoke secondary labelling system developed for asset points • Appropriately classified assets	• Collaborated with academics • Decision to move from PPM to CBM • Company spent time in selecting the right sensor type i.e. intrusive vs extrusive • Developed uniform coding structure for CAFM system • Client to absorb installation costs • Rolled out BDA pilot project in live business environment • Established parent-child relationships • Core platform developed for CBM
Challenges	• Big cultural change for traditional industry • Unable to integrate various systems • Restricted to analysing energy and refrigeration data • CAFM system limitations	• Experienced issues with standardisation and nomenclature • Data quality affected • Produced false correlations • Affected stakeholder engagement and reliability	• Poor internet connectivity creating black spots • Faced several challenges to develop a right interoperable platform • Issues with data security, ownership and aggregation • Issues with bi-directional communication • Issues with remote access to BMS of certain clients
Outcomes	• Identified ways to save on operational costs • Predictive rules able to pick up asset inefficiencies • Demonstrated pay back for client • Saved £1.6m in energy costs for business • Trained poorly performing technicians • Brought all stakeholders on board • Successfully implemented predictive solutions for some aspects of FM contracts • Exploring development of comprehensive IoT platform	• Developed applications beyond FM to smart cities • Successfully unleashed the power of predictive maintenance • Flexibility to cater to individual contracts • Confidence growing for data driven approach • Came up with new innovations and achieved competitive advantage • Delivered substantial benefits like reduced cost of ownership and better service to clients • Correlation analytics greatly helped 'root cause' analysis • Ability to drill down to each component that is causing problem • Current capability appropriate for large building contracts • Specified broader skill sets to their employees • Reduced energy wastage and usage	• Accurate tender pricing • Enhanced productivity with work flow management • Better resource management • Demonstrated value to customers • Better transparency with customers • Evidenced engineering compliance • Achieved informed decision making • Improved stock management • Better route planning for jobs • Able to uncover faults before they become a problem **Moving Further** • Planning to offer digital set-up services for FM organisations who plan to take BDA implementation • Exploring artificial neural networks applications to test academic research • Move to proactively monitor wider infrastructure, utilities and wider construction arena

4.0 Theoretical framework development

The study aims to achieve a better understanding of BDA adoption in the UK FM sector through exploring various drivers, challenges, strategies and outcomes associated with its implementation process. The theoretical framework (Figure 9), developed from a review of literature and from the findings of three in-depth case studies, indicates the full benefits expected from utilising BDA capabilities have yet to be achieved within the industry, which is in the early stages of adoption. It has taken the case study organisations several years to amble forward with BDA initiatives; to put an infrastructure in before any potential value outcome could be realised. However, the associated challenges are far too many and without a strategic implementation plan it is hard to get a holistic view of the financial and business benefits.

Broadly based on absorptive capacity theory and the competence-based view, the proposed integrated conceptual framework distinguishes between various stages (i.e. pre-adoption, implementation and post-adoption) and identifies the key elements of the conceptual framework as drivers, challenges, strategies and outcomes. The main intention behind developing this conceptual framework is to outline the process by which organisations learn and integrate new knowledge into their operations through the data-driven analytical approach to FM, thereby achieving valuable outcomes and insights.

4.1 Drivers

The complex journey into BDA implementation for the FM organisations begins with clearly establishing and defining the business goals (i.e. KPIs) (Engelbrecht and Willis, 2015). Organisational maturity plays an important role in this process, as it has tremendous influence on the ability to pursue such initiatives (Dhanuka, 2016), which are currently restricted to large FM businesses.

As energy prices rise, the pressure on FM organisations to provide energy management solutions and reduce their client's operating costs has increased. While the attention has predominantly centered on energy efficiency, clients realising the benefits of improving the facilities require FM professionals to offer a seamless package of services to include water conservation, improve occupant comfort and air quality levels. These are the factors that are driving organisations to adopt novel technologies to accelerate innovation, drive optimisation, and improve compliance (Carnelley and Schwenk, 2016). New data-management platforms with sophisticated analytical capabilities hold the potential to accurately quantify energy saved, operational costs reduced, and water conserved. In response to raised client expectations, the FM organisations in the early stages of the BDA implementation are targeting 'energy analytics' which seems to be the most straightforward way to address client objectives.

FM companies are increasingly looking for smarter ways to deliver contracts, stay ahead of their competitors, find new revenue opportunities and (most importantly) minimise any inherent risks associated with FM contracts. The majority of the interviewees stated that capitalising on BDA initiatives provides their company with an opportunity to gain competitive advantage and to stay ahead of the competition. Although the companies investigated are in the early stages of adoption, the benefits derived from BDA initiatives so far have considerably improved the quality of their service. For example, FM professionals are able to advise their clients and manufacturers on asset performance issues. These benefits substantiate the business case for enterprise-wide adoption and the move from descriptive analytics approach to predictive analytics capabilities.

4.2 Challenges

With organisations recognising the importance of BDA and making significant investments, there are several challenges that need to be addressed. Even before FM organisations embark on the journey towards digital transformation they first need to 'unpack' the concept of data governance. Given that technology has recently made inroads into the FM sector, companies are challenged to bring the appropriate policies and procedures into place to address the relevant governance and management issues surrounding data ownership, aggregation, ethical issues, security, remote access, closed protocols etc. These concerns are also expressed by Colas, et al. (2014) and Bilal et. al. (2016) while Zhou et al. (2016) add that energy systems containing energy big data and privacy information are particularly vulnerable to cyber theft or attacks.

Since FM big data is obtained from many different systems and sources (BMS, BIM, CAFM, ERP, Space Planning, Waste Management Systems, Air Quality to name a few), the quality or 'fitness' of the data is posing to be a significant challenge to companies wishing to capitalise on this big data. Inferences drawn from inconsistent datasets are increasingly leading to inaccurate analytical results that are shared with downstream technicians and field crew. This leads to scepticism about organisational capability. Bilal, et. al. (2016) confirm that the prevalence of poor quality data in the building industry is significantly affecting the production of high value analytics.

Along with the data quality, there are challenges associated with communications, for example, transmitting data from sensor to storage facilities, especially in hard to access locations like basements, plant rooms etc. Establishing or investing in pervasive connectivity, BDA tools and infrastructure, data centres and software licenses have very high cost and investment implications (Abu-Elkheir et al., 2013; Bilal, et. al., 2016), which is also listed as one of the inhibitors.

The process of setting up systems for smart asset management is very convoluted. The very first step involves establishing an asset hierarchy to facilitate data capture, processing, storage, use and analysis (Lin et al., 2006). For FM organisations accustomed to working with informal hierarchical structures, classifying assets into primary, secondary and tertiary tiers is proving to be a time-consuming exercise. Additionally, this technology aspect is aggravated by the inability to accumulate accurate real-time information from multiple sources. Although most of the existing FM legacy systems are a potential source of valid and reliable information, the architectures of these systems are not necessarily designed to facilitate data integration and business growth. As such they require significant interventions to support new business perspectives.

Other than IT, BDA initiatives more than anything require investment in human capital (skilled personnel in data management and analytics). The challenge currently crimping the uptake within the FM market is the lack of skilled talent with a good understanding of the FM business to identify big data opportunities and clearly articulate the business case for funding. Colas, et al., (2014) confirm that the big data talent gap is something that organisations are increasingly coming face-to-face with. Similarly, Zhou et al. (2016) argue that specialised courses and programmes in management science, data science and computer science should be developed to offer comprehensive training and develop suitable skills for the various jobs of big data era.

Another aspect of the human element pushing back BDA adoption is the stakeholders' resistance to change. Adopting a data-driven approach requires changing the mind-set of key stakeholders who are traditionally accustomed to reactive approaches. Addressing all these challenges, along with effective leadership, could help achieve stakeholder buy-in.

4.3 Strategies

Given the vast challenges associated with embedding BDA, FM organisations are embarking on data-driven strategies that can deliver genuine value and provide competitive business advantage. The case study interviews placed particular emphasis on developing a robust technological foundation for coordinated and comprehensive analytics. This includes addressing a host of issues to achieve end-to-end technological integration such as:

- standardising naming conventions
- positioning asset tags
- selection of appropriate sensor types
- consolidating the data in a consistent and comparable format.

A technical strategy should involve:

- establishing hierarchical dependencies between assets
- sensor verification
- prioritising key assets/systems
- working towards continuously defining and refining algorithms/rules engine
- choosing a technologically robust asset management system.

CAFM systems undoubtedly play a key role – as a central database processing and managing all the data from various systems in a unified and cost efficient way (Verisae, 2015).

The case studies confirm that FM companies are moving from traditional PPM strategies to CBM as a result of the BDA initiatives. The move away from the standard maintenance approach involves a protracted process of integrating various critical systems. The case studies indicate BDA implementation is therefore restricted to longer length FM contracts, where installation costs can be spread out and passed onto the client.

At an organisational level, it is crucial that the management possess the ability to transform the organisation by having a clear strategy (i.e. how to use data and analytics to yield better decisions and the deployment of the right technology and capabilities). The most successful initiatives in the FM arena are a result of collaborative efforts with external specialists and academia to incrementally improve capabilities. Colas et al. (2014) also favour the opinion that besides technology, the single biggest factor affecting the uptake of BDA in FM organisations is the development of a strong operating model based on:

- a well-defined organisational structure
- a systematic implementation plan (aligning managers across the organisation)
- strong leadership support.

They also argue that a centralised approach is much more likely to bring together technology and business executives to conceptualise new use cases and define best practices (ibid.).

At a practical level, organisations are integrating new analytics into their routine processes through small trials and pilot projects suitable to demonstrate the practical potential of BDA i.e. to act as proof-of-concepts (PoCs). This practice is in line with Colas et al.'s (2014) recommendation that organisations should implement an agile methodology that can identify optimal use and filter out use-cases where BDA is not practically feasible. However, the key to fully exploiting data and analytics lies in up-skilling and engaging facilities managers and staff; those who will work with these systems on a daily basis. FM companies are taking a multi-faceted approach to organisational change; strategies include organising training and workshops with key front line stakeholders to reinforce behaviour and ensure it permeates across the organisation.

4.4 Outcomes

The empirical findings and insights gained from case studies and cross-case analysis reveal the initial adoption of data analytics and real time monitoring of assets has brought a host of value enhancing benefits to FM organisations. Data analytics is becoming a critical capability which is drastically transforming routine FM processes and decision-making norms. Initial consultation with highly experienced FM industry professionals noted that the current initiatives are reinventing the customer experience, as insights derived from data are bringing unprecedented visibility and optimisation to FM operations.

This newly acquired digital capability is presenting FM organisations with new opportunities to engage with their clients and reinvent the end-user experience. Being equipped with intelligent reporting capability means that FM organisations are able to offer greater transparency into an equipment or asset's history. This promotes engineering and statutory compliance and the availability of evidence to justify decision making and refine business processes. The resulting improvements in information management have also supported the development of effective and targeted training programmes for field crew, based on the best performance practices.

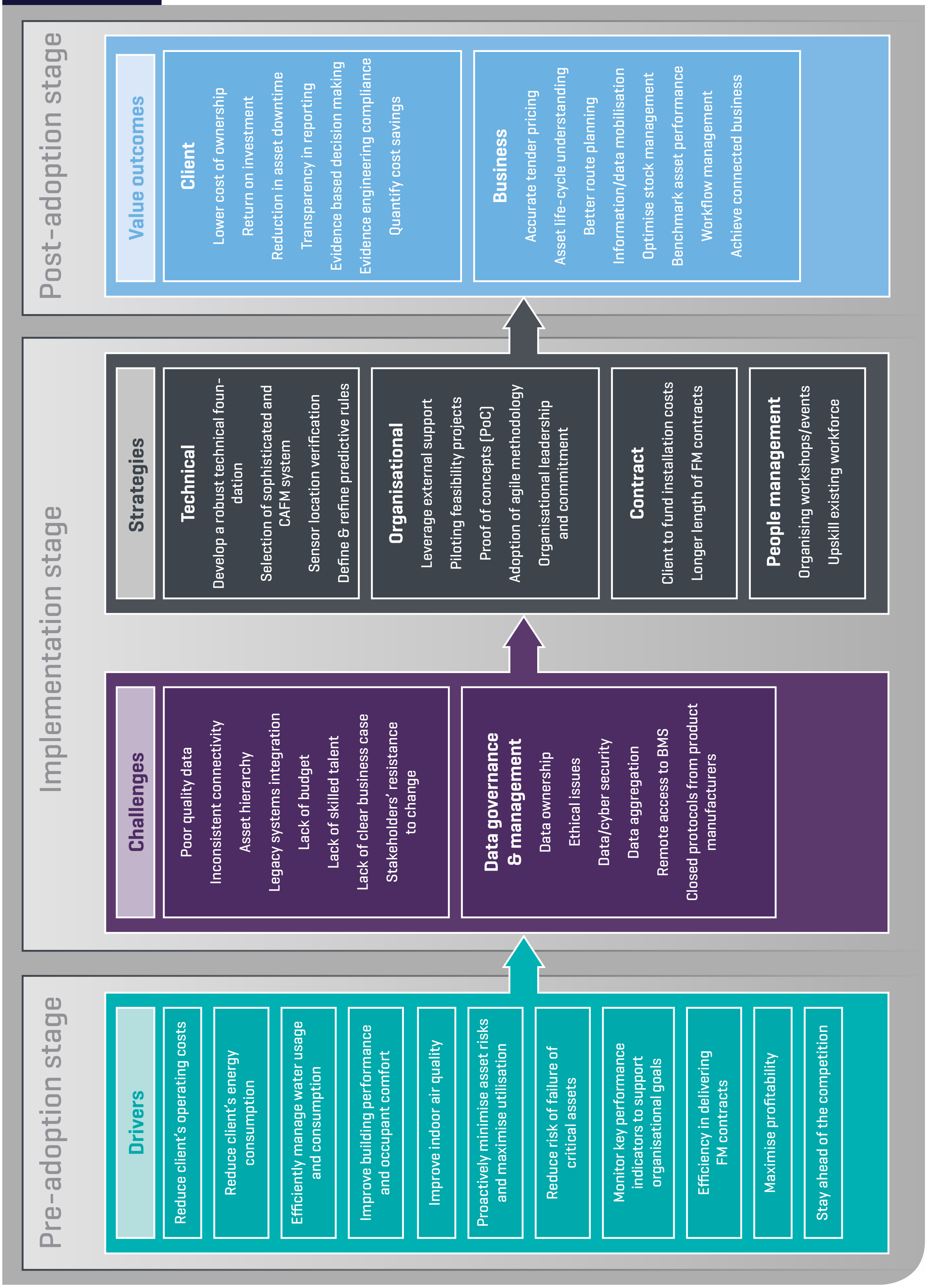
This early phase of the analytics journey is completely transforming traditional FM; delivering significant business benefits such as:

- shorter payback periods
- enhanced productivity in workflow management
- improved resource and stock management
- greater accuracy in tender pricing.

Powered by the predictive analytics, IoT and data-driven insights, novel asset management practices are adeptly eliminating unplanned failure risk, increasing asset life and optimising maintenance scheduling (i.e. organising maintenance at times when the minimum cost and disruption to business occurs). BDA has supported the minimisation of downtime and consequent maximisation of asset and equipment availability while significantly reducing lifecycle expenditure.

BDA is driving the most marked innovation and increased efficiency in the area of energy management. Having access to a system's complete dataset, right down to the individual pieces of equipment, is allowing facilities managers to identify energy saving opportunities and provide valuable insights on client's energy usage. This can substantially reduce the costs associated with owning an asset and most importantly eliminating the resource-intensive preventive maintenance activities. Bilal et al. (2016) have also stated the potential benefits to FM organisations from lowered operating expenses, higher profit margins and enhanced service availability.

Figure 9 Theoretical framework for BDA implementation within FM



5.0 Quantitative research

5.1 Research methodology

A questionnaire survey was the second stage of data collection method used in this study. The primary objective behind developing the research instrument was to quantify the drivers, challenges, strategies and value outcomes (both for the client and the business). As such, the findings from the empirical investigation via semi-structured interviews and the literature review informed the questionnaire, making it more comprehensive.

The questionnaire was divided into four sections; Sections A and B were designed to gather demographic information and general BDA implementation status, whereas Section C, (the main body of the questionnaire) consisted of 60 variables used to measure drivers, challenges, strategies, outcomes and future initiatives associated with BDA implementation and applications. The respondents were invited to rate their level of agreement on various statements on a Likert scale of 1 to 5 where; 1- Strongly Disagree, 2- Disagree, 3- Neither Agree nor Disagree, 4- Agree, and 5- Strongly Agree. The final section of the questionnaire aimed to gather additional comments from the respondents (See Appendix B).

The developed questionnaire was piloted with academics and co-investigators in order to assure its clarity, validity and reliability. A purposive sampling technique was used to choose respondents who were relevant to the research topic (Hall, 2008). The sample was chosen based on their rich experience of being involved with BDA implementation of their organisation. Therefore, only those companies who were or had implemented BDA were invited for the survey. This also dictated the response rate for the survey which depended on the respondent's knowledge about the subject area (Yates, 2004).

A validity check of the quantitative results was also conducted. Triangulation of survey findings with qualitative interview data (one interview each with the three case study organisations) provided a deeper understanding of how participants viewed the statistics.

5.2 Quantitative analyses

Of the 150 email requests sent, a total of 52 responses were returned, yielding an effective response rate of around 35%. This is considered to be a fair number of responses for a novel research area. Descriptive analyses were performed on the Section A and B of the questionnaire to analyse the respondents' background and generate confidence in the credibility of data collected.

As highlighted in Table 4, the largest proportion of the sample (40%) that participated in this study were directors with a considerable number of years of experience. They were followed by project managers and technical managers at 15% and 14% respectively. The rest of the respondents (23%), encompassed a wide spread of job titles that included Innovation Manager, Bid Manager, IT Partner, Sales Manager, Marketing Manager and Head of Data Governance. Since the majority of the respondents (56%) had industry experience of over 15 years, the responses offer a useful and accurate insight into the current state of thinking within the FM sector and its engagement with BDA.

Given the level of investment required both in terms of time and money, it is not surprising that the larger FM organisations (those with 5000+ employees) seemed to be the early adopters of this technology; 65% of the people who participated in the study came from larger organisations. The number of small businesses (less than 50 employees) was restricted to 8%.

With regards to the respondents' education and qualifications, around 27% reported pre-degree qualifications, over 33% held a first degree in some discipline and 15% held a masters. Seventeen per cent had various other qualifications that included DTI, City and Guilds, RICS, Higher National Certificate to name a few. Additionally, the percentage of respondents holding a doctorate (4%) was similar to those holding BIFM qualification.

Almost half (47%) of the respondents had no professional memberships, while approximately 29% of them held the BIFM membership. It should be noted that few of the BIFM members held multiple memberships with other professional bodies such as RICS, International Facility Management Association and Chartered Institution of Building Services Engineers. Just over a quarter (26%) of the respondents belonged to other professional bodies that were not listed. These included: Chartered Engineer, Institute of Refrigeration, British Computer Society, Association of Project Management, British Pest Control Association, Institute of Chartered Accountants in England and Wales, Institute of Environmental Management and Assessment (See Figure 10).

Table 4 Respondent profile

Section A: Particulars of the respondents			
Items	**Categories**	**Frequency**	**Percentage**
Qualifications	Pre-Degree Qualification	14	27%
	Degree Qualification	17	33%
	Master's Qualification	8	15%
	Doctorate	2	4%
	BIFM Qualifications	2	4%
	Others	9	17%
Job Title	FM Consultant	3	6%
	Facilities Manager	1	2%
	Project Manager	8	15%
	Director	21	40%
	Technical Manager	7	14%
	Other	12	23%
Experience	Less than 1 Year	0	0%
	1 to 5 Years	8	15%
	6 to 10 Years	6	12%
	11 to 15 Years	9	17%
	More than 15 Years	29	56%
Company Turnover	Unknown	2	4%
	Less than £10m	6	12%
	£10 - 50m	1	2%
	£51 - 250m	8	16%
	£251 - 500m	6	12%
	£501 - 1 billion	12	23%
	>£1 billion	16	31%
Organisation Size	1 - 9	0	0%
	10 - 49	4	8%
	50 – 99	2	2%
	100 - 249	1	2%
	250-499	2	4%
	500 - 999	5	10%
	1000 - 4999	4	8%
	5000+ Employees	33	65%

Figure 10 **Professional membership of respondents**

5.3 Results of section B: BDA implementation status

The majority of respondents regarded BDA as a huge disrupter to the FM sector. Nearly 98% of respondents confirmed BDA as important or extremely important to their organisation (Figure 11). The participants overwhelmingly supported the BDA approach as a more intuitive and intelligent way to provide FM services. This should not be surprising, as big data is becoming crucial for businesses in general. Despite acknowledging the benefits and importance of BDA to the FM sector, the responses also indicated that BDA engagement has been lagging. These questionnaire responses are broadly similar to trends within other industries like healthcare, banking, aviation, medical diagnosis and manufacturing.

Early FM adopters of BDA are using data to be more proactive and to deliver their services on a more intelligent basis, which means challenging some of the established thinking in FM. Through IoT and connected devices, organisations are able to come up with a much more tailored approach to a specific asset or portfolio; more aptly supporting the clients in their environment.

Of the five stages of big data maturity levels (nascent, pre-adoption, early adoption, corporate adoption, and mature/visionary), the majority of the respondents (72%) were at the beginning stages (i.e. pre-adoption 37% and early adoption 35%) at the time of survey. Since the majority of the industry is in the early stages of BDA adoption, maturity models could not only be used to assess the current level of technology capability, but also to prescribe the steps required to build on current level of expertise (Comuzzi and Patel, 2016). Figure 12 depicts the percentage of respondents in each stage of maturity. Around 13% reported corporate adoption, whereas a meagre 2% considered themselves to be at visionary level with well-established data governance strategies.

As highlighted in Figure 13, the survey results suggest that the industry has only just begun to implement BDA, with 38% of the respondents and companies having spent less than one year on BDA initiatives. Around 56% of the companies have spent between 1 to 4 years on BDA initiatives. However, a reasonable 17% of individuals reported having spent over five years on BDA initiatives; the time reported by the case study companies required to introduce analytics and leverage technology. This transformation to an insight-driven organisation is a continuous learning process, which explains why organisations vary in their analytics capabilities. When asked to highlight data sources for BDA projects, FM professionals selected operational systems such as CAFM, BMS, EMS and BIM to be key for data collection (see Figure 14). Other sources of data, such as ERP, space planning, security, waste management, air quality and refrigeration were also mentioned. Some respondents also reported using of light detection and ranging (LiDAR) and videos.

Figure 11 Importance of BDA for information intensive industry like FM

How would you rate the importance of BDA and Internet of Things (IoT) for an information intensive industry like facilities management?

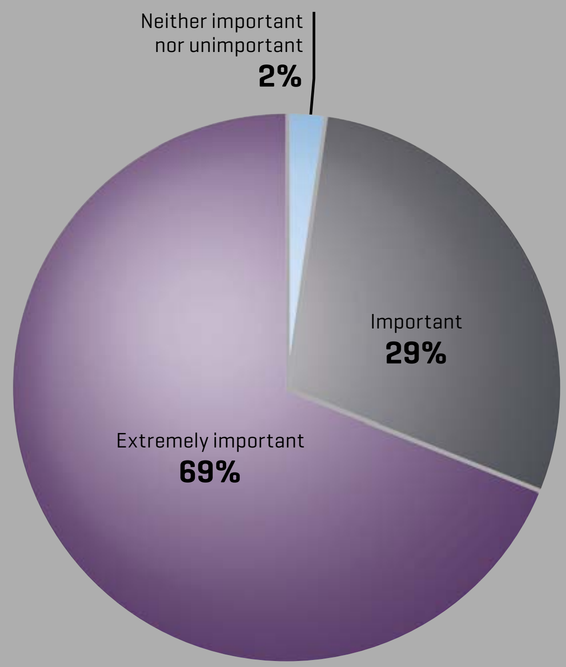


Figure 12 BDA implementation status

Please specify the current status of BDA implementation within your organisation?

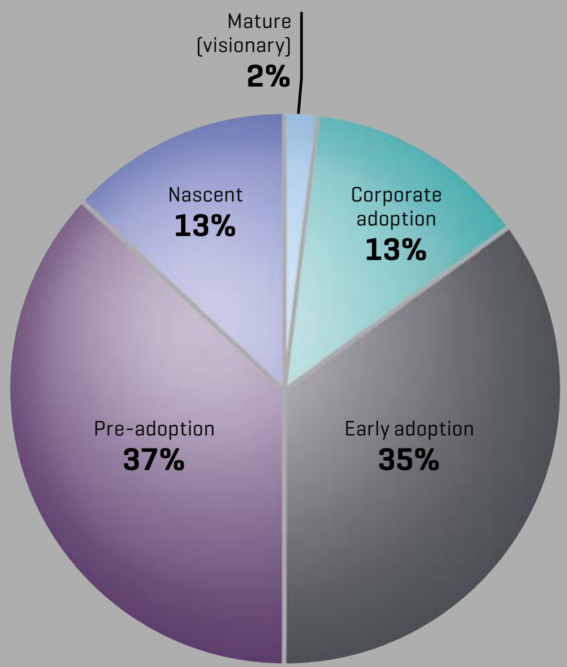
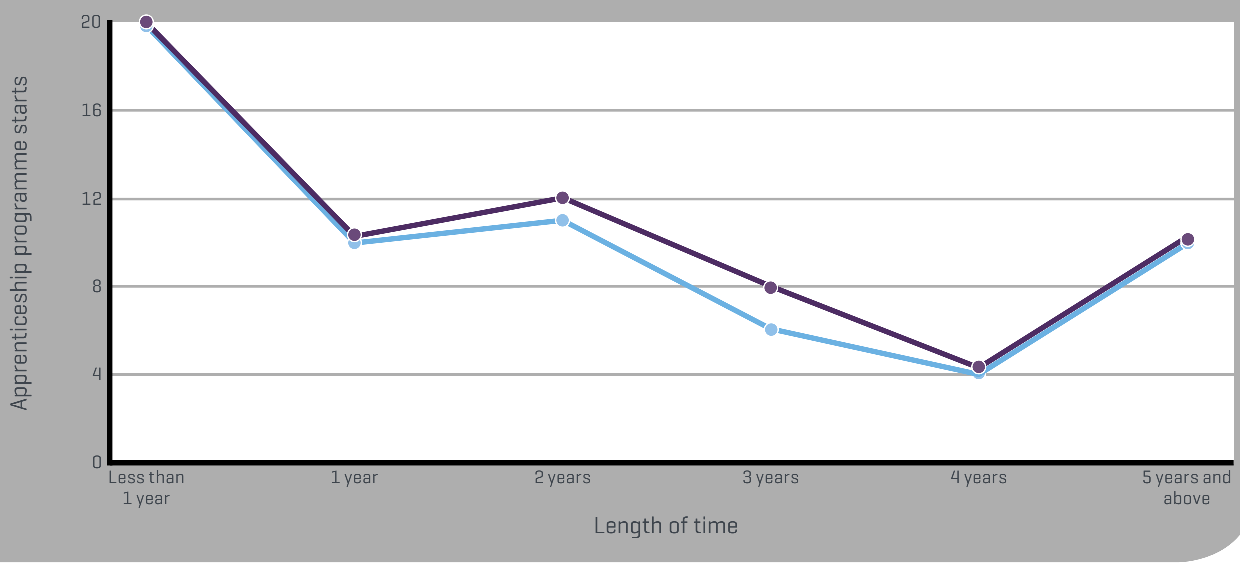


Figure 13 Individual and company involvement with BDA implementation

How long have you personally been involved with BDA initiatives?

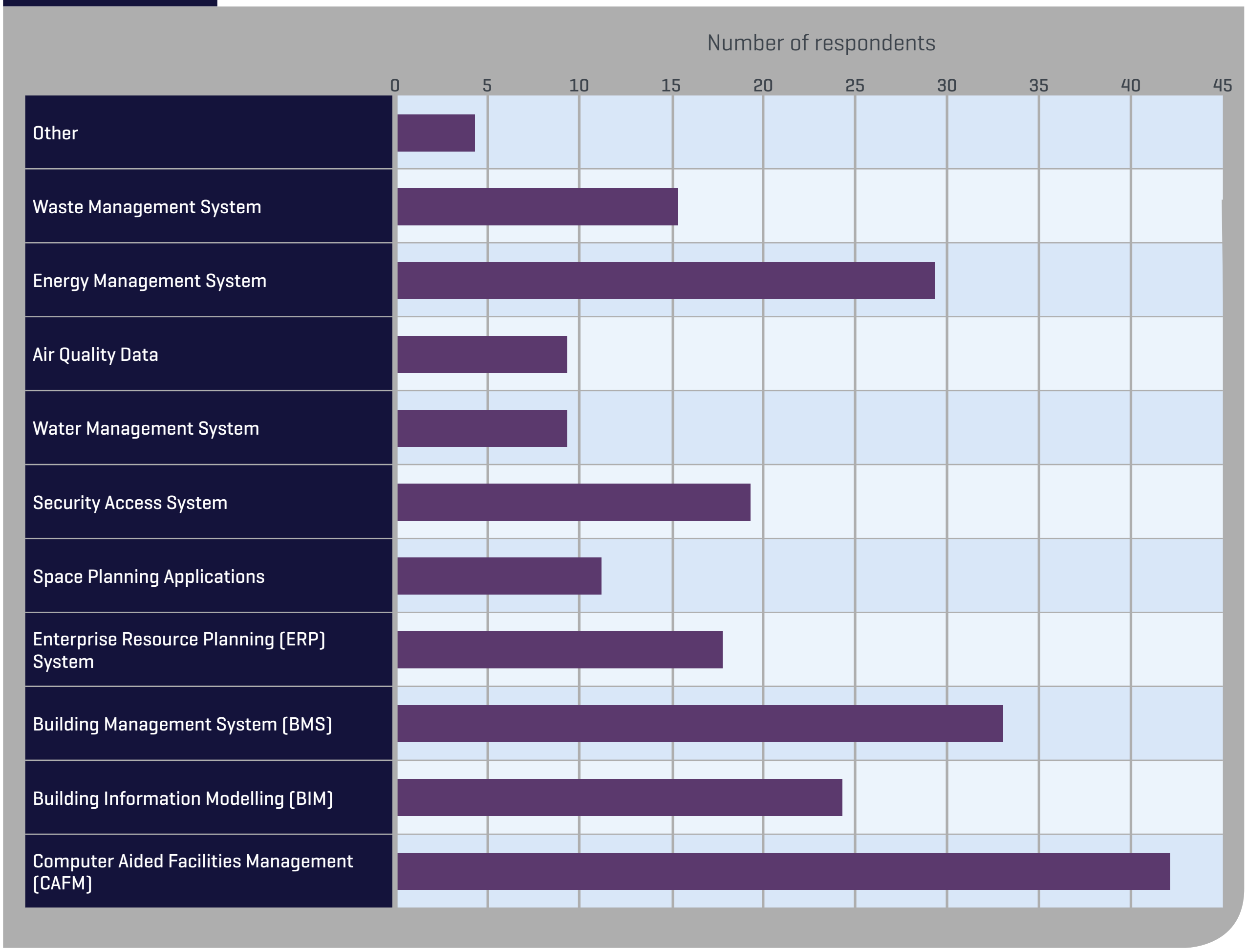
How long has your company been involved with using BDA for FM operations?



The advent of BIM for FM and its enhanced capability to support data mining and deal with large volumes of heterogeneous data is increasing its popularity as a key data platform.

Most respondents (81%) reported using more than two systems in FM management. Seamlessly merging and integrating different operational systems with information technology requires significant investment in terms of time and money, as revealed during the case study interviews. Nevertheless, the survey results indicate a growing interest in acquiring and analysing a wide variety of data (both structured and unstructured) within the asset-intensive sector.

Figure 14 **Sources of FM big data**



6.0 Analysis and discussion

The data extracted from the questionnaire survey were computed in SPSS software to establish a database. Descriptive statistics were conducted to tabulate the mean values for the five groups (drivers, challenges, strategies, outcomes and future direction) and rank the variables in each respective group. Figures 15 to 19 show the top five variables of each group. Early adopters of BDA believe that it holds the potential to steer the business towards sustainable performance while capitalising on data advantage. The sub-sections below detail and discuss the findings.

6.1 Drivers for embedding BDA and IoT in FM operation

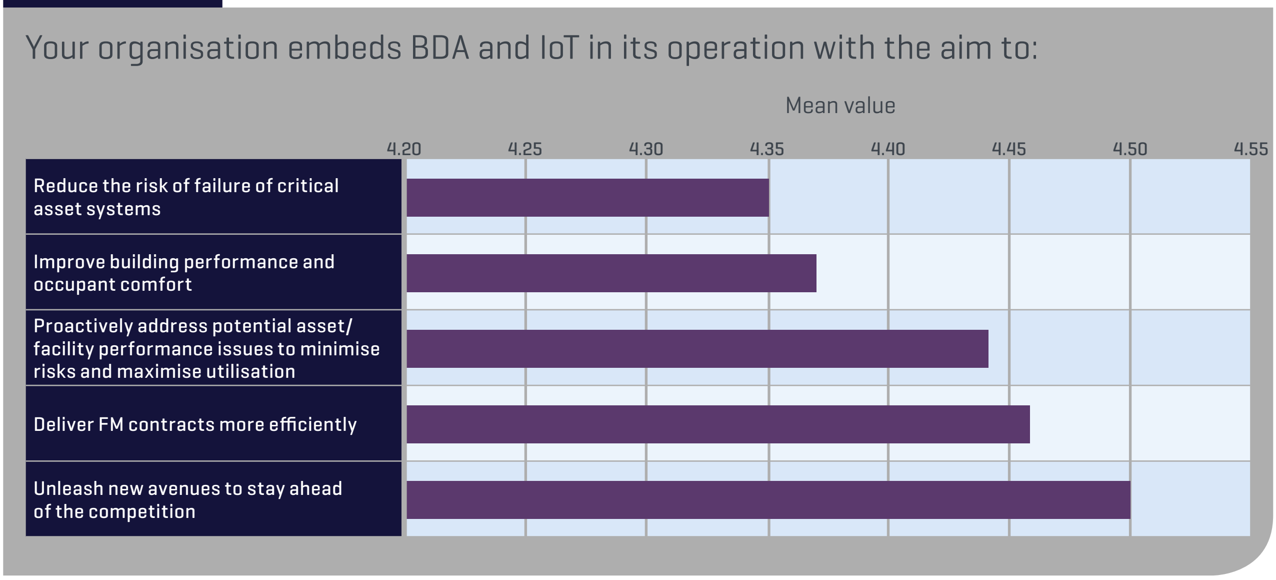
The competitive business landscape coupled with rising levels of risks associated with FM contracts are driving organisations to explore BDA as a means to broaden their business reach and increase profits. BDA offers companies the capability to explore the service footprint within historical datasets, extract meaningful insights and make predictions. Against this backdrop, participants of the study indicated that their company's adoption of BDA and IoT technology was overwhelmingly driven by competitive pressure. Based on the mean values in Figure 15, 'Unleash new avenues to stay ahead of the competition' emerged as the most influential driver (mean value = 4.50) followed closely by 'Deliver FM contracts more efficiently' at 4.46.

By leveraging this data technology, companies have been able to streamline their contract pricing strategy and deliver contracts more efficiently. The availability of robust historical data means that pricing for contracts could be based on actual modelled costs as opposed to the industry standard (SFG20), which tends to be an estimate (on the higher side). There are therefore clear commercial advantages to BDA adoption.

The drivers ranked third (Proactively address potential asset/facility performance issues to minimise risks and maximise utilisation), fourth (Improve building performance and occupant comfort) and fifth (Reduce the risk of failure of critical asset systems) indicate that the participants recognise the business value to be achieved in taking a proactive maintenance approach. Automating the entire maintenance process allows FM companies to maximise asset and building utilisation and identify any potential issues before failure occurs. The early warning notifications typical of predictive maintenance regimes help managers to prioritise and allow more lead time during which managers can strategically plan maintenance activities. However, it is essential to note that the potential value of big data is only realised if one has the ability to act in response to what the data shows. Increasingly, FM organisations prioritise the maintenance of critical assets and business systems whose performance on the 'front-line' is critical. The importance of a meaningful maintenance programme for critical assets is captured in the following excerpt from INT-B-FM4:

'With regards to critical assets, you can do a lot more than statutory maintenance. In fact, data analytics gives you a lot more depth and ability to justify how you differentiate and moreover you are not exposing yourself or customer to unquantified risk'.

Figure 15 **Drivers associated with BDA implementation**



6.2 Challenges associated with BDA and IoT implementation

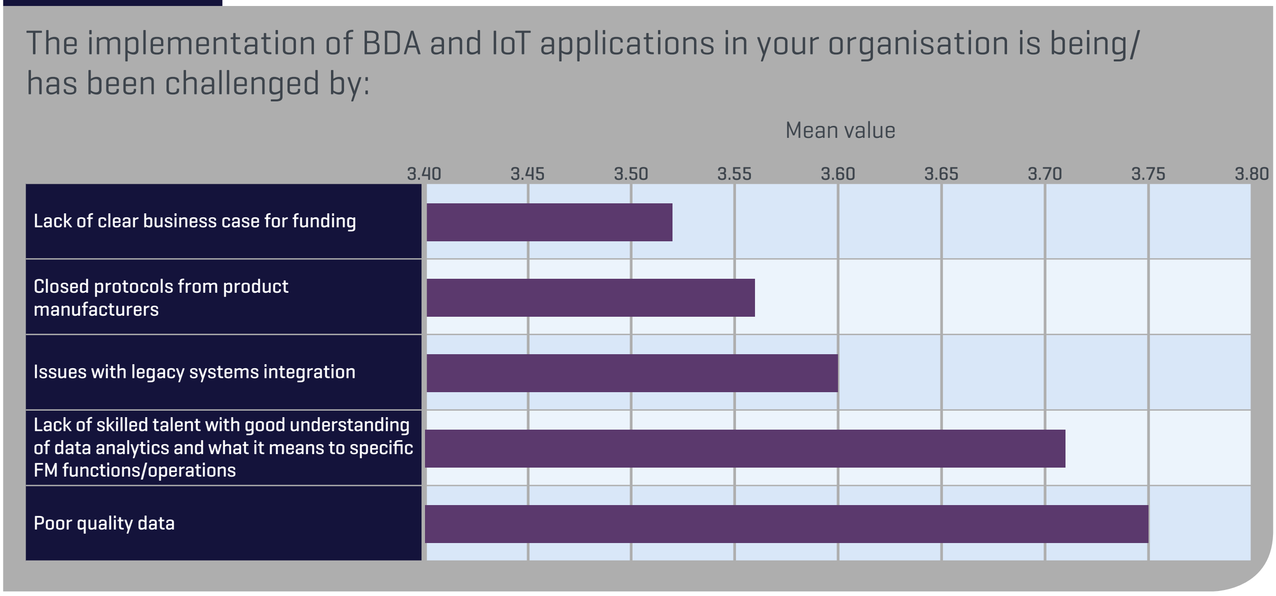
With data quality being a fundamental prerequisite to effective analytics, organisations need to divert substantial resources to establish the verification aspects of big data (Moyne and Iskandar 2017); companies need to invest resources (time and tools) to ensure the accuracy of the input data. This process of creating clean and reliable data is very time consuming. Consistent with the findings of Shin (2013) and Gandomi and Haider (2015), the participants of this study agree that high quality data is a valuable asset. High quality data is critical for increasing customer demands, improving revenue streams, and offering competitive differentiation.

The second biggest challenge facing FM businesses as data volumes and sources continue to grow is the lack of staff capability to support the company's adoption of this novel technology. Since data can be analysed in many different ways, the current market demands multi-disciplinary professionals who are capable of determining sector-relevant and actionable insights from the new data available (Accenture, 2014).

On the architecture front, BDA implementation is restricted by systems and technologies that have not been designed to facilitate open access to data. FM organisations are therefore not able to take full advantage of available datasets because these cannot be integrated into existing systems. As highlighted by Carnelley and Schwenk (2016), the problems associated with the proliferation of data sources could be addressed by developing an information management strategy that facilitates the integration of diverse technologies.

Securing funding for BDA and IoT implementation from senior leadership requires a clear link to be drawn between BDA implementation and the achievement of a company's business goals i.e. understanding what exactly needs to be accomplished and how this addresses their company's problem. FM companies are struggling to clearly establish the scope of proof-of–concept – a realistic attainable goal with a clear time parameter. These results indicate that businesses need to holistically assess the potential impact that BDA-related practices and applications could have for their business in order to broadly roll out and realise the full potential and innovation opportunities.

Figure 16 **Challenges associated with BDA implementation**



6.3 Strategies for realisation/ achievement to BDA implementation

The participants of the survey highlighted that the best strategy for FM organisations to integrate analytics into their decision-making process would be to take an incremental approach (see Figure 17). Essentially, the big data journey commences with clearly understanding the pinch points (challenges) and formulating holistic strategies to address a range of issues around methodology, people, technologies and best practices.

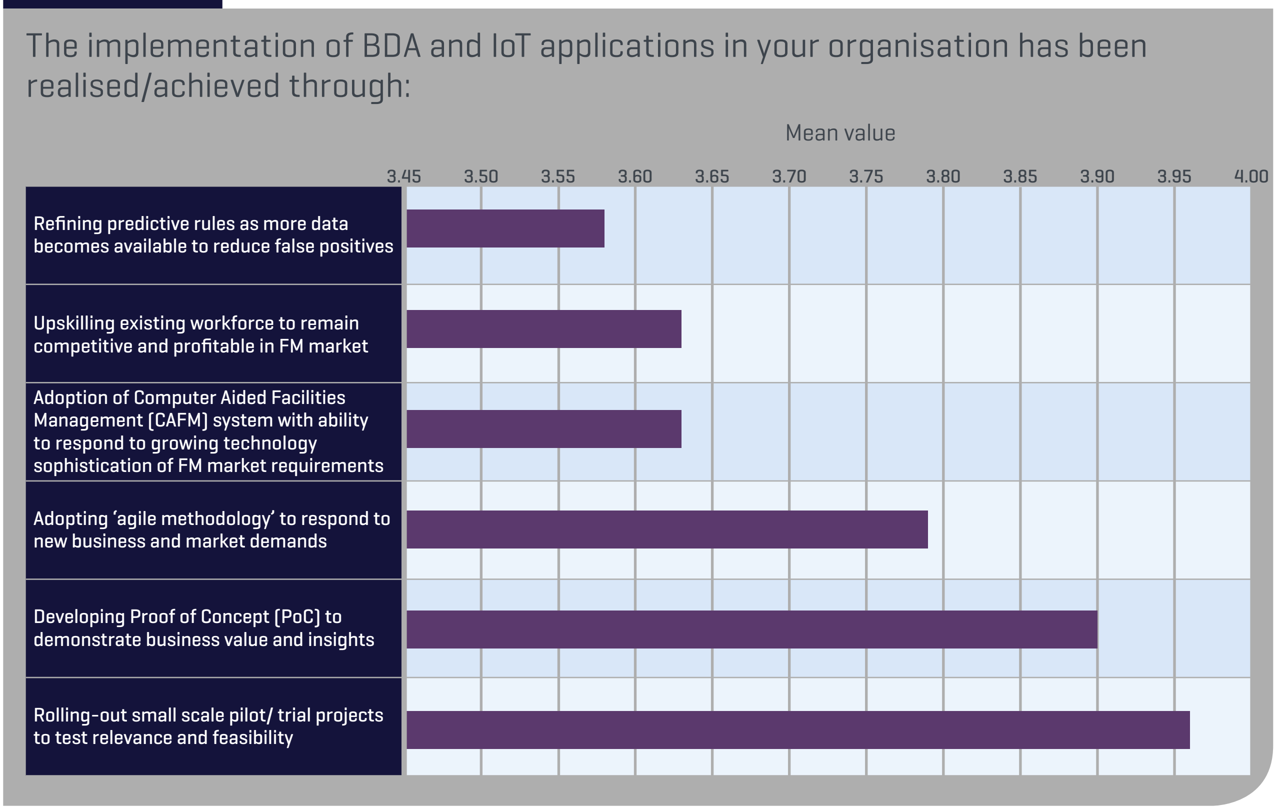
BDA implementation in a live FM environment where there are a number of stakeholders can be challenging. The survey participants believed that the best method for achieving successful implementation of new, innovative techniques, is through small scale, highly focused pilot projects that can be assessed for their feasibility and success.

The development of a proof-of-concept, i.e. choosing/ focusing on a right area that has the potential to answer pressing business problems and generate value, was also a popular strategy. Much of the industry is currently focusing on energy efficiency solutions, which is the low hanging fruit.

Rolling out smaller pilots has several benefits, including that it is easier to prove the business case, it allows decision makers to gauge the actual work required and to identify the issues associated with integrating new with existing systems. In contrast, large-scale projects generally tend to take longer.

Starting small is also part of the agile project management methodology, which focuses on the ‘rapid release’ approach, i.e. delivering quick solutions based on current requirements rather than big bang applications (Frankováa et al., 2016).

Figure 17 **Big data implementation strategies**



To extract the most value from the big data initiatives and develop data-driven culture in their operations, FM companies will need to focus on:

a) upskilling the existing workforce (to deal with shift in organisational culture – move towards proactive rather than reactive approach)

b) digitise their facilities/asset portfolio by investing in a flexible and sophisticated CAFM system to ensure data transparency and facilitate data exchange between systems.

Case study A invested in training service providers by organising workshops, question and answer sessions and conference calls in order to develop the predictive rules needed to attain data advantage and efficiently and cost-effectively operate assets. With this kind of action companies can eventually move towards the automation of work orders to technicians, removing any human intervention.

6.4 Initial outcomes of BDA implementation

Even though the industry has barely scratched the surface of predictive analytics, it is evident from the responses that data-driven decision making is quickly becoming a necessity within the FM industry. BDA is considered to be essential to condition-based maintenance. A respondent reiterated this importance:

'As buildings become more complex in terms of equipment it becomes equally important to understand how a plant is operating in conjunction with other pieces of equipment within the building.'

The means-testing results reveal that successful applications of big data are prompting real-time evidence based decision making. Facilities managers can now see the big picture and use evidence to defend their decisions. This data transparency minimises risks for both the parties. Needless to say, the variable 'Greater transparency in reporting to the client' emerged to top the list of outcomes with a mean value of 4.02 (see Figure 18).

The other variables in this group were all the outcomes associated with acquiring comprehensive understanding of an asset/equipment's profile, signature, performance and behaviour. These outcomes included 'Evidence-based decision making' (mean=3.89), 'Better understanding of asset life-cycle' (mean=3.81) (includes, equipment replacement, capital decisions etc.) and 'Set new benchmarks for asset/facility performance' (mean = 3.75).

The continuous monitoring and recording of asset information through sensors and prediction engines not only provides a solid database but also provides a digital trail that could be used as evidence of the legal engineering compliance of assets and equipment. Predictive analytics are able to spot minor changes to equipment behaviour by comparing the historical operational signature of an asset to its real-time operating data (Reed, 2015). One respondent, commenting on the outcomes of increased measurement and analysis, stated:

'We are better understanding the equipment that we buy, the type, the model, so we really are able to challenge ourselves to buy the right equipment not only from performance perspective, reliability but in terms of energy. We are absolutely moving in that direction – what we buy'.

Figure 18 **Outcomes of big data analytics initiatives**

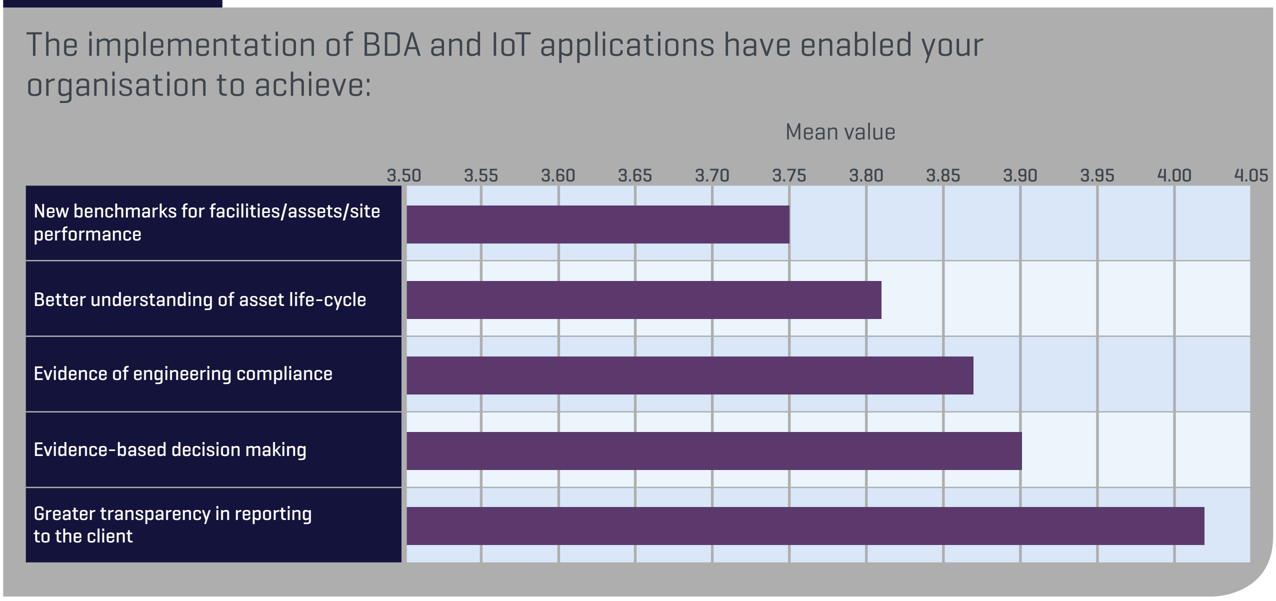
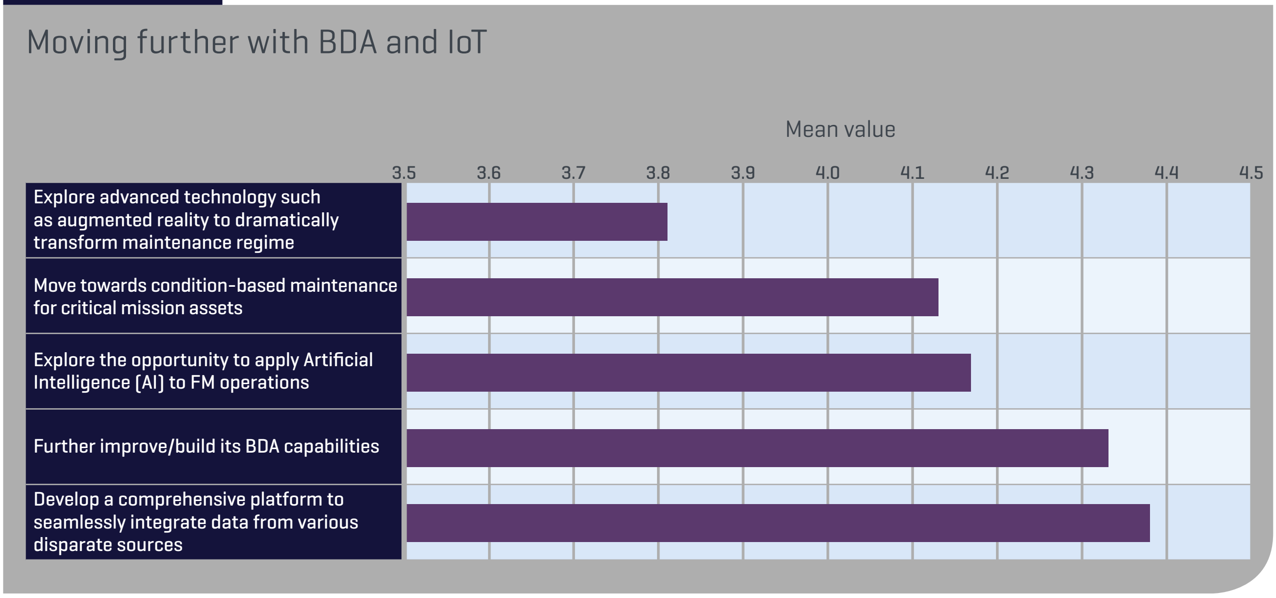


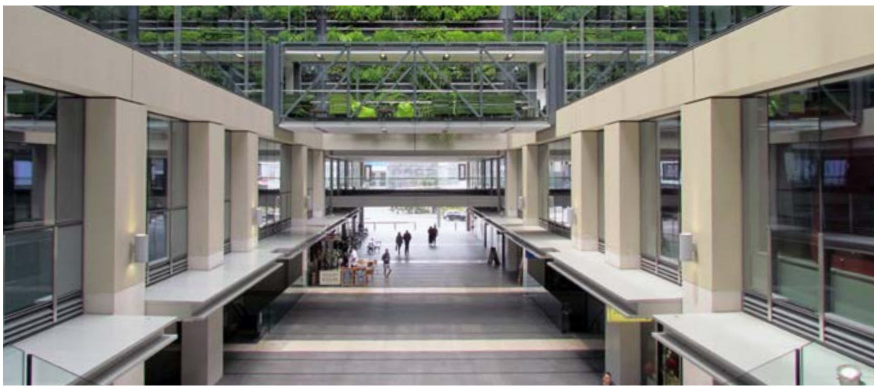
Figure 19 Moving further with BDA and IoT



6.5 Moving further with BDA and IoT

As highlighted in Figure 19, FM organisations are looking to improve and extend their current capabilities, develop comprehensive IoT platforms to facilitate the assimilation of data from various sources and use emerging technologies to facilitate an analytics-driven approach.

Achieving buy-in and support from top management is vital to ensuring companies continue to adapt to new technology and realise their future plans. To this end, the support from external consultants or higher education institutions in the implementation of pilot projects could help to clearly demonstrate business results from investment in BDA implementation.



7.0 Conclusion

Though BDA technology has emerged to be a real game changer that can deliver on both strategic and operational aspects, it is yet to see significant uptake in the FM world. This research attempted to explore a host of determinant factors that have enabled FM organisations to transition from a reactive to an insight-driven approach.

Viewing the BDA implementation process through the lens of absorptive capacity theory and the competence-based view, the study systematically reviewed the strategies used by the three case study organisations to explore, exploit and capitalise on external and internal knowledge bases. A methodological framework was developed, based on the case study discussions. This framework provides an outline of the strategies used by the case study organisations to comprehensively engage, integrate and understand the ever-growing amounts of FM big data (see Figure 9). Given that many within the sector are actively moving towards BDA adoption, this framework provides a good starting point for potential adopters to learn from the experiences of their peers and successfully engage with the information deluge. Following the development of the methodological framework, an industry-wide survey was conducted, soliciting 52 responses from people who were heavily involved with BDA and IoT implementation.

The research found that in a price-constrained market, BDA and IoT applications are deployed to:

- stay competitive
- reduce business risks
- maximise asset and equipment performance
- enhance customer-oriented services.

The results of the study also show that the FM big data market is primarily at the pre- or early adoption stage. However, the FM sector is only expected to mature as more and more firms seek to enhance their organisational effectiveness and efficiency. Unsurprisingly, due to the complexity and challenges associated with BDA, larger FM businesses – those equipped with the right human resources and established innovation-supporting structures – emerged to be front-runners.

As BDA becomes more commonly used in asset, facility and building maintenance, a host of issues associated with data quality, governance and management need to be addressed. The crucial point raised by respondents is to systematically verify and substantiate the collection and measurement of information.

BDA implementation and adoption is dependent on various organisational factors that include:

- The organisation's readiness to deal with challenges (poor quality data, the talent gap, dealing with closed protocols, integrating legacy systems, defining the business case for funding etc.).
- The organisation's maturity and business objectives: to navigate the implementation process, organisations need to make significant changes to existing practices, structures and most importantly to internal mindsets.

Businesses must address this challenge holistically, by:

- investing in appropriate training
- ensuring they focus on multidisciplinary skills in their FM recruitment
- acquiring the appropriate IT capability
- developing a strategic implementation plan
- investing in pilot projects to highlight feasible initiatives over the short term that can deliver proof of concept
- engagement with key stakeholders across the value stream.

The results of the study reveal that the FM industry has barely skimmed the surface of, or even captured, the true essence of the term big data. However, BDA has opened up valuable opportunities to leverage data from disparate sources (CAFM/CMMS/IWMS, BMS, BIM, BEMS etc.) and is completely revolutionising the reporting and compliance processes. The transition towards a knowledge-based economy is only set to speed up as businesses strive to move forward to strategically position themselves and monetise big data. Keeping with the evolutionary trajectory, the next step for businesses is to scale-up existing initiatives and introduce new dimensions, such as:

- comprehensive IoT platforms
- artificial intelligence
- augmented reality applications.

If deployed effectively, these applications can transform FM operations, taking them a step closer to the hyper-connected world.

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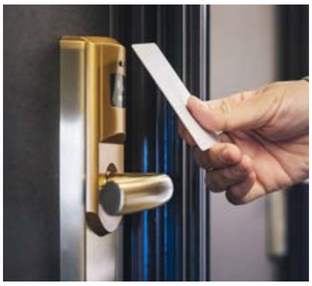

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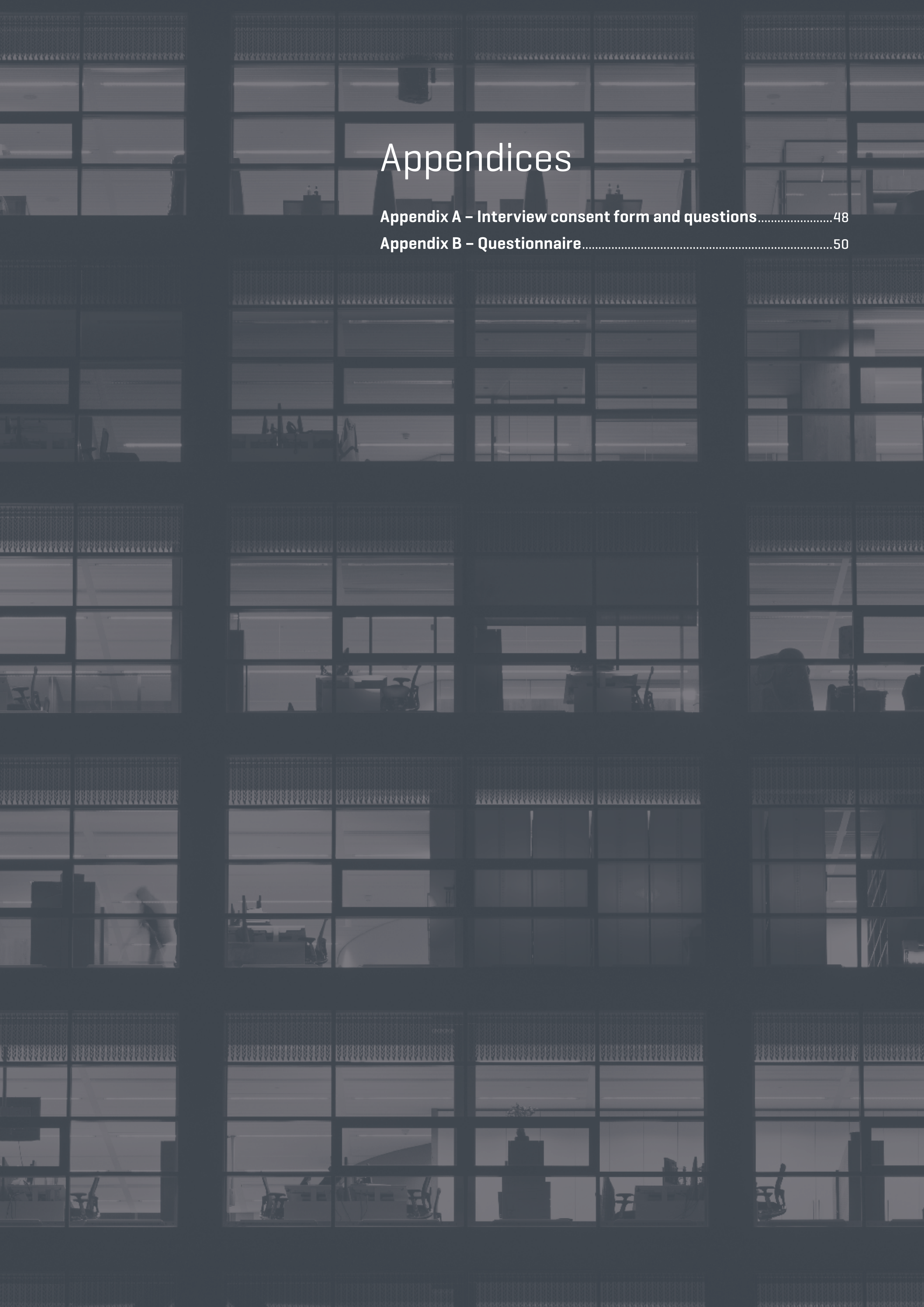

Appendices

Appendix A – Interview consent form and questions

School of Engineering and Computing
Paisley Campus High Street
Paisley PA1 2BE

Interview consent form

Title of the Project: Big data Analytics: A new revolution in the UK Facilities Management Sector

Researchers: Dr Ashwini Konanahalli (University of West of Scotland)
Professor Lukumon Oyedele (University of West of England)
Dr Marina Marinelli (University of Leicester)
Dr Gehan Selim (Queen's University of Belfast)

1	I confirm that I have read and understand the information sheet for the above study. I have had the opportunity to consider the information, ask questions and have these answered satisfactorily	☐
2	I understand that my participation is voluntary and that I am free to withdraw anytime without giving any reason	☐
3	I agree to take part in the above study	☐

Name of Interviewee ______________________ Name of Interviewer ______________________

Date ______________________ Date ______________________

Signature ______________________ Signature ______________________

Interview questions

Introduction

a) Please can you tell me about your position within the company?

b) How long have you worked for this company?

c) How many employees work for your company?

d) What are your current responsibilities within the company?

e) How long have you personally and your company been using Big Data Analytics?

Main interview questions

1. Can you please highlight how important is big data for information intensive industry like facilities management?

2. Can you please explain on the applications of BDA/IoT technologies and how are they driving innovation in your organisation?

3. Can you please elaborate on the main drivers that influenced the implementation BDA initiatives/disruptive technologies?

4. Can you please elaborate on the main risks or problems identified before or at the start of implementation?

5. Can you please elaborate on the systems/processes that are put in place to extract value from the implementation of BDA?

6. Can you please elaborate on the critical success factors (CSFs) for implementation of BDA initiatives in FM organisations?

7. How would you rate the profitability of your BDA initiatives?

8. How would you make sure that the key relevant information is available at the right time?

9. What are your organisations top challenges with respect to operationalizing BDA and turning into trusted business asset?

10. What according to you are the key benefits that your organisation has achieved to date as a result of BDA initiatives? (Improved decision making, improved collaboration,/information sharing, improved productivity, customer satisfaction, reduced costs and operational efficiencies, compliance readiness, increased revenue etc.)

11. What were the main challenges you faced with regards to implementing disruptive technologies like BDA in your company (budget, lack of talent, procurement limitations –big data vendors, enterprise not ready for big data)?

12. How did you overcome these challenges?

13. Did you get external help (consultants, contract employees, technology vendor resources, internal resources) for your BDA installations or was it in-house?

14. Can you please elaborate on the choice for the technical solution used?

15. Were there any other options and if so please elaborate on these?

16. How did you go about with the implementation of BDA initiatives within your organisation?

17. Can you please elaborate on changes in the organisation related to the adoption of Disruptive technologies?

18. Can you please elaborate as to what were the main lessons learned related to this implementation?

19. Have you considered widening the application of BDA/IoT to various other FM operations/aspects?

20. What are the key competencies that you have in-house to deliver BDA for your business?

21. What are the new competencies that you do not have in-house but are hoping to bring from outside your organization?

22. How do you achieve value using BDA?

Appendix B – Questionnaire

Dear Respondent,

This questionnaire is the basis of an ongoing research investigating the technological trends and opportunities currently transforming the Facilities Management (FM) sector in the United Kingdom. Specifically, this research intends to review the uptake of 'Big Data Analytics' (BDA) and the opportunities it offers in terms of operational and business intelligence. We are interested to analyse the FM industry's perception about BDA and the potential it holds to inform facility managers make smarter and quicker decisions.

This questionnaire is aimed at FM professionals with a good understanding of the BDA implementation practices of their organisation and should take not more than 15 minutes to complete. This survey is purely for academic purposes and all responses will be treated in confidence. Should you require further detail or clarification, please feel free to contact us or email Ashwini.Konanahalli@uws.ac.uk or m.marinelli@leicester.ac.uk.

Thank you for your anticipated co-operation.

Dr Ashwini Konanahalli

Prof Lukumon Oyedele

Dr Marina Marinelli, and

Dr Gehan Selim

Section A: Participants' details

a) Please specify the qualifications you hold.

- ☐ Pre- degree Qualification
- ☐ Degree Qualification
- ☐ Master's Qualification
- ☐ Doctorate
- ☐ BIFM Qualifications
- ☐ Other: ______________________

b) Please select from the list below the title which best describes your role.

- ☐ FM Consultant
- ☐ Facilities Manager
- ☐ Project Manager
- ☐ Director
- ☐ Technical Manager
- ☐ Other: ______________________

c) Please specify how many years of experience you have.

- ☐ Less than 1 Year
- ☐ 1 to 5 Years
- ☐ 6 to 10 Years
- ☐ 11 to 15 Years
- ☐ More than 15 Years

d) Please select from the list below the professional membership you hold.

- ☐ British Institute of Facilities Management (BIFM)
- ☐ Chartered Institution of Building Services Engineers (CIBSE)
- ☐ Royal Institution of Chartered Surveyors (RICS)
- ☐ The Chartered Institute of Building (CIOB)
- ☐ International Facility Management Association (IFMA)
- ☐ No Professional Membership
- ☐ Other: ______________________

e) How many people are employed by your organisation?

- ☐ 1–9
- ☐ 10–49
- ☐ 50–99
- ☐ 100–249
- ☐ 250–499
- ☐ 500–999
- ☐ 1000–4999
- ☐ 5000+ employees

f) What is your organisation's annual turnover?

- ☐ Unknown
- ☐ Less than £10 Million
- ☐ £10–50 Million
- ☐ £51–250 Million
- ☐ £251–500 Million
- ☐ £501–1 Billion
- ☐ >£1 Billion

Section B: Big Data Analytics (BDA) implementation

g) How long have you personally been involved with BDA initiatives?

- ☐ Less than 1 year
- ☐ 1 Year
- ☐ 2 Years
- ☐ 3 Years
- ☐ 4 Years
- ☐ 5 Years and Above

h) How long has your company been involved with using BDA for FM operations?

- ☐ Less than 1 year
- ☐ 1 Year
- ☐ 2 Years
- ☐ 3 Years
- ☐ 4 Years
- ☐ 5 Years and Above

i) Please specify the current status of BDA implementation within your organisation.

- ☐ Nascent – low awareness of big data or its value across much of the business
- ☐ Pre- Adoption – starting to do homework regarding big data analytics
- ☐ Early Adoption – characterised by Proofs-of-Concept (PoC) which have become more established and production ready
- ☐ Corporate Adoption – end users typically get involved, gain insights, and transform how they do business
- ☐ Mature (Visionary) – Proficiency in executing big data programs using highly tuned infrastructure and well-established data governance strategies

j) How would you rate the importance of BDA and Internet of Things (IoT) for information intensive industry like Facilities Management?

- ☐ Least Important
- ☐ Not Important
- ☐ Neither Important nor Unimportant
- ☐ Important
- ☐ Extremely Important

k) Which of the following big data sources are currently being analysed by your organisation to bring new insights? (Please select all applicable)

- ☐ Computer Aided Facilities Management (CAFM)
- ☐ Building Information Modelling (BIM)
- ☐ Building Management System (BMS)
- ☐ Enterprise Resource Planning (ERP) System
- ☐ Space Planning Applications
- ☐ Security Access System
- ☐ Waste Management System
- ☐ Air Quality Data
- ☐ Energy Management System
- ☐ Water Management System
- ☐ Other: ______________________________

Drivers associated with BDA implementation

The following are some of the factors potentially driving FM organisations to embed BDA and IoT in their operations. Please consider each driver with relevance to your experience and that of your organisation and rate your level of agreement with each of the statement on a scale of 1 to 5.

Where:

1 – Strongly Disagree

2 – Disagree

3 – Neither Agree nor Disagree

4 – Agree

5 – Strongly Agree

Your Organisation embeds BDA and IoT in its operation with the aim to:

1) Reduce client's operating costs

Strongly Disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 Strongly agree

2) Reduce client's energy consumption

Strongly Disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 Strongly agree

3) Efficiently manage water usage and consumption

Strongly Disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 Strongly agree

4) Improve building performance and occupant comfort

Strongly Disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 Strongly agree

5) Improve the quality of air and environment inside buildings

Strongly Disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 Strongly agree

6) Proactively address potential asset/facility performance issues to minimise risks and maximise utilisation

Strongly Disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 Strongly agree

7) Reduce the risk of failure of critical asset systems

Strongly Disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 Strongly agree

8) Provide an informed basis to successfully monitor Key Performance Indicators (KPIs) and support organisational goals

Strongly Disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 Strongly agree

9) Deliver FM contracts more efficiently

Strongly Disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 Strongly agree

10) Maximise profitability in an increasingly complex market

Strongly Disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 Strongly agree

11) Unleash new avenues to stay ahead of the competition

Strongly Disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 Strongly agree

Challenges associated with BDA implementation

The following are some of the potential challenges currently facing FM organisations implementing BDA and IoT applications. Please consider each challenge with relevance to your experience and that of your organisation and kindly rate your level of agreement with each of the statement on a scale of 1 to 5.

Where:

1 – Strongly Disagree

2 – Disagree

3 – Neither Agree nor Disagree

4 – Agree

5 – Strongly Agree

The implementation of BDA and IoT applications in your organisation is being/has been challenged by:

12) Poor quality data

Strongly Disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 Strongly agree

13) Concerns over security of the data being transmitted over the network

Strongly Disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 Strongly agree

14) Lack of clarity on how assets should be grouped in hierarchical structure (i.e. parent-child relationship)

Strongly Disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 Strongly agree

15) Inconsistent connectivity (both wired and wireless) to handle bandwidth-intensive real-time applications

Strongly Disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 Strongly agree

16) Legal issues associated with aggregating massive amounts of data

Strongly Disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 Strongly agree

17) Ethical issues associated with data storage

Strongly Disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 Strongly agree

18) Ambiguity associated with ownership of 'Big Data'

Strongly Disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 Strongly agree

19) Restricted rights to remotely access and control Building Management Systems (BMS)

Strongly Disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 Strongly agree

20) Closed protocols from product manufactures

Strongly Disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 Strongly agree

21) Issues with legacy systems integration

Strongly Disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 Strongly agree

22) Lack of clear business case for funding

Strongly Disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 Strongly agree

23) **Lack of budget to roll out BDA and IoT initiatives on a larger scale**

Strongly Disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 Strongly agree

24) **Lack of skilled talent with good understanding of data analytics and what it means to specific FM functions/operations**

Strongly Disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 Strongly agree

25) **Stakeholders' resistance to change**

Strongly Disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 Strongly agree

Big data implementation strategies

The following are some of the strategies used by FM organisations to implement BDA and IoT applications. Please consider each strategy with relevance to your experience and that of your organisation and kindly rate your level of agreement with each of the statement on a scale of 1 to 5.

Where:

1 – Strongly Disagree

2 – Disagree

3 – Neither Agree nor Disagree

4 – Agree

5 – Strongly Agree

The implementation of BDA and IoT applications in your organisation has been realised / achieved through:

26) **Development of a robust technological foundation to implement BDA for FM operations**

Strongly Disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 Strongly agree

27) **Establishing sensor verification process i.e. verifying whether the true location of sensor is same as its claimed location**

Strongly Disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 Strongly agree

28) **Adoption of Computer Aided Facilities Management (CAFM) system with ability to respond to growing technological sophistication of FM market requirements**

Strongly Disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 Strongly agree

29) **Clearly defined leadership roles for BDA implementation**

Strongly Disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 Strongly agree

30) **Getting the Client to absorb the set up and installation costs**

Strongly Disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 Strongly agree

31) **Defining predictive rules to leverage and transform intelligence from data**

Strongly Disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 Strongly agree

32) **Promoting predictive maintenance strategies for critical mission assets**

Strongly Disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 Strongly agree

33) Implementing BDA applications for longer length FM Contracts (10 years and above)

Strongly Disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 Strongly agree

34) Leveraging external help (Academia /Acquisition/ Engage with start-ups/ Consultants) to embed data analytics into FM operations

Strongly Disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 Strongly agree

35) Organising events to involve multiple providers and encourage team play

Strongly Disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 Strongly agree

36) Developing Proof of Concept (PoC) to demonstrate business value and insights

Strongly Disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 Strongly agree

37) Rolling-out small scale pilot/ trial projects to test relevance and feasibility

Strongly Disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 Strongly agree

38) Refining predictive rules as more data becomes available to reduce false positives

Strongly Disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 Strongly agree

39) Adopting 'agile methodology' to respond to new business and market demands

Strongly Disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 Strongly agree

40) Upskilling existing workforce to remain competitive and profitable in FM market

Strongly Disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 Strongly agree

Outcomes of big data analytics initiatives

Please rate your level of agreement in terms of the cumulative benefits of implementing BDA and IoT applications in your FM operations on a scale of 1 to 5.

Where:

1 – Strongly Disagree

2 – Disagree

3 – Neither Agree nor Disagree

4 – Agree

5 – Strongly Agree

The implementation of BDA and IoT applications have enabled your organisation to achieve:

41) Evidence-based decision making

Strongly Disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 Strongly agree

42) Better understanding of asset life-cycle

Strongly Disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 Strongly agree

43) Optimisation of stock management

Strongly Disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 Strongly agree

44) Accurate pricing for tenders

Strongly Disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 Strongly agree

45) Accurate quantification of cost savings for the client

Strongly Disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 Strongly agree

46) Seamless data/information mobilisation between contracts

Strongly Disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 Strongly agree

47) Lower the cost of asset ownership for the client

Strongly Disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 Strongly agree

48) Greater transparency in reporting to the client

Strongly Disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 Strongly agree

49) Evidence of engineering compliance

Strongly Disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 Strongly agree

50) Reduced asset downtime

Strongly Disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 Strongly agree

51) New benchmarks for facilities/assets/site performance

Strongly Disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 Strongly agree

52) Demonstrable return on investment for the client

Strongly Disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 Strongly agree

53) Productivity in work flow management

Strongly Disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 Strongly agree

54) Better route planning for sub-contractors i.e. optimisation of field crews

Strongly Disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 Strongly agree

55) Connected business operations

Strongly Disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 Strongly agree

Moving forward with BDA initiatives

As the road-map for data science evolves and matures for facilities management operations, please rate your level of agreement with the following statements as to how your organisation intends to capitalise on the disruptive power of 'Big data' on a scale 1 to 5.

Where:

1 – Strongly Disagree

2 – Disagree

3 – Neither Agree nor Disagree

4 – Agree

5 – Strongly Agree

Your organisation's future initiatives in the field of BDA and IoT applications include plans to:

56) Further improve/build its BDA capabilities

Strongly Disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 Strongly agree

57) Move towards Condition-Based Maintenance for critical mission assets

Strongly Disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 Strongly agree

58) Explore the opportunity to apply Artificial Intelligence (AI) to FM Operations

Strongly Disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 Strongly agree

59) Explore advanced technology such as augmented reality to dramatically transform maintenance regime

Strongly Disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 Strongly agree

60) Develop a comprehensive platform to seamlessly integrate data from various disparate sources

Strongly Disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 Strongly agree

Additional comments

Please provide any additional comments or suggestions you may have in relation to the topic covered in the questionnaire

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RICS promotes and enforces the highest professional qualifications and standards in the valuation, development and management of land, real estate, construction and infrastructure. Our name promises the consistent delivery of standards – bringing confidence to markets and effecting positive change in the built and natural environments.

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