Drivers and Challenges Associated with the Implementation of Big Data within UK Facilities Management Sector: An Exploratory Factor Analysis Approach

MANAGERIAL RELEVANCE

The results of the study provide substantive contribution to understanding the motivation and barriers organizations face when transforming from 'traditional FM model' to an integrated 'data-driven' model. This research clarifies the various dimensions of sustainability linked with the FM operations and highlights how the integration of such targets into a company's business model and strategy may be a source of competitive advantage in the long-run. The additional and secondary risks for adopting BDA are also made clear, including the necessary organizational readiness, critical role of data quality, cost implications, the required cultural shift, the scarcity of suitably qualified human resources and the cyber security issues which unavoidably emerge. Given that the industry is at the very early stages of BD adoption using limited data sources, focus needs to be diverted to develop expertise in judgment of data quality and security, data governance policies and information management programs to accommodate additional sources and scale up the maturity levels.

ABSTRACT

The recent advances in Internet of Things (IoT), computational analytics, processing power and assimilation Big Data (BD) are playing an important role in revolutionizing maintenance and operations regimes within the wider Facilities Management (FM) sector. BD offers the potential for FM to obtain valuable insights from a large amount of heterogeneous data collected through various sources and, IoT allows for the integration of sensors. The aim of this research was to extend the exploratory studies conducted on Big Data Analytics (BDA) implementation and empirically test and categorize the associated drivers and challenges. Using Exploratory Factor

Analysis (EFA), the researchers aimed to bridge the current knowledge gap and highlight the principal factors affecting BDA implementation. Questionnaires detailing 26 variables were sent to FM organization in the UK who were in the process or had already implemented BDA initiatives within their FM operations. Fifty-two valid responses were analyzed by conducting EFA. The findings suggest that driven by market competition and ambitious sustainability goals, the industry is moving to holistically integrate analytics into its decision-making. However, data quality, technological barriers, inadequate preparedness, data management and governance issues and skill gaps are posing to be significant barriers to the fulfillment of expected opportunities. The findings of this study have important implications for FM businesses that are evaluating the potential of BDA and IoT applications for their operations. Most importantly, it addresses the role of BD maturity in FM organizations and its implications for perception of drivers.

Keywords: *Big Data, Analytics, Facilities Management, Technology Implementation*

1 INTRODUCTION

Facilities management (FM) is defined by ISO 41012:201 as an *"organizational 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"*. As such, it is an extensive field encompassing various independent disciplines whose aim is to ensure functionality of the built environment by integrating people, places, processes and technology. It covers a broad spectrum of services from building/asset maintenance, financial systems, productivity, resource management, health and safety compliance, space management, hospitality, contract management, real estate management, sustainability and domestic services [1][2][3][4]. Since FM takes a holistic overview of the businesses it supports, it is well placed to position itself as a key strategic partner significantly contributing to enhance business performance and value. The current trends around digitization have massively increased the quantity of management information available, the resolution and frequency at which it is captured, and the speed at which it can be processed. Therefore, data on building's operating value [5], productivity and processes can all be captured and recalled in more comprehensive detail than ever before [6]. In the process, organizations are generating tremendous amount of data i.e. 'Big Data' [7]. The term 'Big Data' (BD) represents a revolutionary step forward from traditional data analysis and is used to describe vast amounts of data whose size is beyond the ability of typical database software tools to capture, store, manage, and analyze and has the potential to be collected, stored, retrieved, integrated, selected, pre-processed, transformed, analyzed, and interpreted for discovering new or extracting useful knowledge [8]. To enable evidence-based decision-making, organizations need efficient processes to turn high volumes of fast-moving and diverse data into meaningful insights. Extracting insights from BD involves two sub-processes of data management and data analytics [9]. Data management is associated with data generation, storage, mining and preparation for analysis whereas, analytics refers to the techniques to analyze, acquire and extract information to provide insights of significant value to business [10].

While the business and information technology press is picturing companies that transformed their businesses or even entire industries through the use of Big Data Analytics (BDA), scientific evidence for the business value of BDA is scarce [11] as the research into the economic benefits of BD remains in an embryonic state [12]. The FM sector is no exception; although *'Digital efficiency'* is emerging to be a critical differentiator enabling FM to reduce cost, create value for customers, grow profit margins, enable efficient building operations, and even find new sources of revenue [13] [14] [15], only a handful of studies to date [15] [16] [17] [18] [19], have reported the use of BD/BDA in the FM sector. As noted by [15], there are very few case studies or best practice examples that can guide the discipline to implement BD in the sector. In response to this observed gap of knowledge, the current study aims to extend the research conducted by [16] and empirically categorize the drivers and challenges associated with BDA implementation and provide guidance on how to implement such initiatives by incorporating best practices. Specifically, the paper explores how FM organizations in UK are currently capitalizing on BDA to drive innovation and efficiency in their operations. The objective of this study is to answer the following questions.

- How is BDA implementation being managed in FM environment?
- What are the key drivers and challenges facing FM organizations when adopting BDA?

Given that very little is known about the implementation of BDA in the FM sector, the researchers adopted multiple case study approach to collect descriptive data through intensive examination of current practices using multiple sources of data [20] [21]. The identified variables were then put together in a questionnaire survey and Exploratory Factor Analysis (EFA) was conducted to identify principal factors. Consistent with the terminology adopted by [22], the term 'drivers' refers to the rationale that influence and encourage organizations to adopt novel technology (in this case BDA), whereas, challenges are the obstacles/barriers organizations face during implementation. The remainder of this paper is organized as follows. The next section includes a detailed literature review starting with setting the research context and analyzing the implication and conditions of BDA integration in business. Then, the drivers for BDA implementation in the FM sector are presented followed by the respective challenges. A detailed discussion on research methodology is then presented, followed by discussion of the results, their limitations and, implications.

2 LITERATURE REVIEW

2.1 BD AND BDA INTEGRATION IN BUSINESS: IMPLICATIONS AND CONDITIONS

BD refers to datasets whose size is beyond the ability of typical database software tools to capture, store, manage, and analyze. This definition is intentionally subjective and incorporates a moving definition of how big a dataset needs to be in order to be considered big data [7]. As per [23] [24] BD embodies the following dimensions; volume, variety, velocity, veracity and value. As the sheer volume of data available makes it virtually impossible for a single person to be able to analyze and process it effectively, BD insights remain unrealized without a methodology for collecting, organising, and analysing it. To address this, Big Data Analytics (BDA) i.e. computational mechanisms including data searching, sharing, transferring, querying, updating, modelling and simulation [8] have been developed in order to provide substantial insights based on patterns and trends that are not necessarily obvious [25].

An additional factor further reinforcing the use of BDA applications is the emergence of the Internet of Things (IoT), i.e. the radical evolution of internet into a network of interconnected objects with built-in sensors and computing capability enabling them to collect, exchange, and act on data, usually without human intervention. BDA is required for organizations to overcome the bottlenecks that are created by the IoT-generated amount of data and extract their actual value [26]. The successful integration of BDA and business processes creates a *"new class of economic asset"* which in turn helps top-performing organizations redefine their business and outperform their competitors [27]. According to [28] and [29], BDA not only influences competition and growth for individual companies, but also has wider productivity and innovation implications able to drive new revenue streams and gain competitive advantages over business rivals. Additionally, a positive correlation between intensity of analytics use and a firm's annual growth rates has indicatively been reported by [30], [31], [32] and [33].

[11] recently presented an econometric study which estimated that live BDA assets are associated with an average of 3–7 % productivity improvement. They also concluded that firms in information technology-intensive and highly competitive industries are clearly able to extract value from BDA assets, while no measurable productivity improvement were detected for firms outside these industry groups.

However, executives should also bear in mind that the maintenance of BDA and IoT capabilities involves significant cognitive, managerial, and operational costs [34] and is associated with substantial financial investments for firms [11]. Given that investments alone are unlikely to create superior BDA capabilities [35], prior to hasty use and buying costly BD tools, there is a need for organizations to first understand the BDA landscape [29]. Actually, BDA initiatives require a certain level of preparation, commitment and vision from organizations. [36] define organizational readiness for BDA projects as *"having the right people, focused on the right things, at the right time, with the right tools, performing the right work, with the right attitude, creating the right results*". According to [12], it is a unique blend of the firm's financial, physical, human, and organizational resources that create a capability which cannot be matched by competitors. A data-driven culture, the intensity of organizational learning and time are suggested as critical intangible resources needed towards this direction. [27] also notes that the absence of a comprehensive directional system, training and timeliness, could diminish the overall effectiveness of data to the extent that it literally becomes 'useless'. Furthermore, according to [34] high quality data, defined as a combination of completeness, accuracy, format, and currency of the information produced, represent an absolute precondition for using BDA and IoT and for guaranteeing the value of the data.

2.2 DRIVERS ASSOCIATED WITH BDA IMPLEMENTATION IN THE FM SECTOR

2.2.1 Assessing the Potential Value of BDA Adoption for the UK's FM Sector

According to [37], current themes proving to be popular include workplace design and optimization, increased interest in sustainability and energy management, as well as growing demands for data gathering, analysis, and reporting. Due to the market's high maturity, new opportunities become more limited with service providers increasingly looking at innovations to retain and develop new areas of business.

Data in the FM sector can be both structured and unstructured. Structured data are normally referred in Building Information Models (BIM) but a typical facility maintenance project also generates additional volumes of unstructured data, captured in photos, graphics, videos and scanned documents etc. [17]. Data systems usually used by FM staff could include Computer Aided Facility Management (CAFM) systems for the evaluation of an organization's operational efficiency and performance, BIM containing spatial information, as well as a variety of sensors and controllable devices (e. g. Heating, Ventilation, Air Conditioning –HVAC, security systems) integrated into the Building Management System (BMS) [38]. BMSs were first patented in 1996 and in that sense, data gathering and processing is not new in FM. However, the conventional BMS's isolated communication protocols and static rules are unable to respond to real-time building conditions [39], as the data processing technique is primarily based on SQL database or even spreadsheets statistics which is pretty primitive, inefficient, resource-demanding and costly [40] [41] and not intended for analytics [42]. The building services could be improved by developing more accurate context using recent IoT and BD technologies [43] [44]. Especially, IoT-enabled smart networks capable of integrating dynamic control strategies and new efficient and effective algorithms to deal with large influx of data, hold the promise of improved system reliability, greater energy efficiency, and lower costs for consumers [39] [40] [25].

It is evident from the above that the UK's FM sector fulfills the two necessary conditions (i.e. information technology-intensiveness and high competition) set by [11] for firms to be able to extract value from BDA assets. The following sections are devoted to various operational aspects which act as potential drivers for the implementation of BDA in FM businesses.

2.2.2 Ensuring Efficient and Streamlined Operations

FM integrates organizational processes to maintain the agreed services that support and improve the effectiveness of its primary activities. Therefore, an accurate and up-to-date monitoring of the context of the enterprise building environment and its surroundings is the cornerstone of FM [41]. As mostly FM activities such as assets management, preventive maintenance, etc. are laborious; the efficiency of such tasks can improve by incorporating suitable supporting technology [18]. Specifically, given that the BMS consist of a network of sensors and devices providing full visibility into – and control of – building environmental conditions and HVAC system performance [39], the large amount of precise, up-to-date and detailed data contained therein [38] represent an untapped opportunity to improve the operation and maintenance of buildings [42].

Additionally, given that FM are coming under pressure to keep the machines in excellent working condition whilst satisfying the stringent safety and operational requirements [45], BDA can be used for the development of various kinds of predictive and financially optimized maintenance strategies, suitable to streamline the labor intensive maintenance functions [15]. Applying BDA in maintenance provides substantial efficient management capabilities as the development prognostic models can help avoid complete failures in critical equipment such as chillers, boilers, fans, and pumps, reduce maintenance costs, and avoid disruptions in building services [42]. Consequent benefits include preventing breakdowns and avoiding costly downtime, deploying limited maintenance resources more cost-effectively, proactively identifying emerging problems, lowering maintenance and operations costs, and extending asset life.

2.2.3 Gaining Competitive Advantage through Sustainability

The sustainability agenda receives considerable attention nowadays with very ambitious environmental targets at both governmental and corporate level. According to [46], firms pursuing high sustainability targets generate significantly higher stock returns, suggesting that indeed the integration of such issues into a company's business model and strategy may be a source of competitive advantage for a company in the long-run. The following sections detail how the FM sector is best placed to reap the benefits of incorporating BDA led sustainability insights into the core of business operations and ensures thus an element of future proofing and competitive advantage for the organization.

2.2.3.1 Energy Efficiency

The field of energy management is increasingly becoming an area of interest for the UK FM sector with multi-million energy consulting acquisitions by traditional FM providers like MITIE and Carillion [47]. Besides, the HVAC systems alone consume about 50% of energy in buildings and 20% of the total energy [48]. Furthermore, given that utility companies worldwide are investing billions to build the smart grid infrastructure by installing smart meters and various sensors on the network [49], the potential of BDA applications in the energy field is vast. This sustainability-led initiative has resulted in a massive increase in generated data which, if managed efficiently with BDA algorithms, can result in energy cost savings through load shifting and peak load reduction strategies [42] [50] [51]. The usefulness of the above BDA enabled insights for the FM sector are confirmed by PwC [47] who highlight that the winners of the not only generate timely performance data to clients, but help providers to identify efficiency opportunities, price contracts competitively and achieve attractive returns.

2.2.3.2 Users of Buildings' wellbeing and productivity

Further to the environmental aspects previously detailed, the social dimension of sustainability, which encapsulates wellbeing and productivity, is equally important. For instance, Deloitte's Amsterdam office building uses smart lighting systems which increase convenience for the staff by enabling them to customize the brightness of surrounding lights through their mobile devices. In addition, sensors embedded in the lights track air quality, temperature, and humidity to help maintain a healthier atmosphere [14]. According to a white paper by [52], sensor data can also be valuable in shaping cleaning regimes, replenishing washroom equipment and emptying bins when full. In addition, data about the movement of individuals through open spaces can help employers boost employees' productivity by designing tasks and breaks, facilitating collaboration and socializing. Finally, IoT-enabled buildings can alleviate security concerns for both owners and tenants. Real-time monitoring can bolster internal security, and specialized weather sensors can provide advance warnings of adverse weather events [14].

2.3 CHALLENGES ASSOCIATED WITH BDA IMPLEMENTATION IN THE FM SECTOR

Though BDA initiatives are launched with the goal of obtaining actionable insights from data to handle complex business requirements and boost performance, there are still many challenges that need to be addressed before coming up with data-centric applications. [53] distinguishes three general groups of challenges, according to their relevance to data, processes and management aspects. The data-related challenges result from the dimensions of the data itself i.e. the 'Vs', the process challenges are those that can be encountered in the execution of the data processing steps, i.e. from data acquisition to modelling and interpretation, while the third group encompasses all the issues resulting from privacy and security risks, data governance and sharing practices, and the increased expenditure required. Other researchers focus on specific challenges including e.g. interoperability, security and reusability [54], data tagging, fragmentation of data sources and stakeholders' confidence [42], cost implications and lack of relevant professional skills [18]. Given that the relevant literature is very extensive, the following sections focus on the technical and management challenges viewed through the prism of FM sector operations.

2.3.1 Technical Challenges

In the context of the FM industry, there are many different potential sources of information coming from the BMS, sensors and mobile networks, field data capture (drones, laser scans, photogrammetry), Communication systems and, financial systems to name a few. The sheer volume, velocity and variety of heterogeneous data from diverse sources of varying reliability mean that errors, uncertainty and missing values will be endemic [55]. In other words, the first three dimensions of BD (i.e. volume, velocity and variety) collectively have a knock on effect on veracity [56] as the increasingly complex data structure results in imprecision and inconsistency jeopardizing its suitability for analysis [29]. This is emerging as a key hurdle preventing the widespread adoption of BDA [57]. The situation gets exacerbated by the fact that these data source systems created by different vendors do not speak the same language. Therefore, the FM industry has long been troubled with interoperability issues between its diverse systems [58], each with its distinct communication protocol creating large quantities of data posing integration challenges [43]. Another major obstacle for the widespread use of data analytics in buildings is that the data tags in existing BMSs are nonstandard and unintuitive descriptors for the sensors and actuators; they are often arbitrarily determined by each controls technician or company and thus, their format can vary drastically from one building to another [42]. In this context, organizations are forced to make significant investments in terms of time and money to manually sieve through large datasets, integrate and connect the dots [16]. In consequence, the FM industry is struggling at the very first step of ingesting data from diverse systems in a fast and predictable manner.

2.3.2 Management Challenges

2.3.2.1 Human and Financial Resources

To sort through data, so that valuable information can be constructed, human analysis is often required. While the computing technologies used to facilitate these data are keeping pace, the human expertise and talents business leaders require to leverage BD are lagging behind [59] [29]. In particular, for the FM industry, there is a mismatch between traditional engineering education and the skills required to develop analytics-driven building O&M strategies [42]. Multiple new roles are required to mediate between statisticians, business managers and IT specialists [17]. According to [42] these roles require domain knowledge in building systems and services, indoor environmental quality and occupant comfort. Moreover, the role holders are expected to demonstrate skills in applied statistics and probability, data mining and machine learning, computer programming, data visualization, sensors and communication protocols among others. Unsurprisingly, their research findings confirm that the industry experiences difficulties in finding research personnel with even a small subset of these skills. Furthermore, [60] and [35] note that beyond the observed skills gap, an additional challenge for senior management is a cultural shift required to develop the essential processes for data scientists to operate effectively, given the fact that the relevant roles have not yet been integrated in organizations.

Further to the human resources issues, a critical problem is the availability of the financial resources to cover the BD initiatives. For example, the three-year total cost of ownership for popular BDA solutions lie in the area of $40-50 million [61]. Given that the construction sector is considered amongst the low-profit-margin businesses, the necessary investment for BDA infrastructure, equipment and skilled personnel can easily be seen as costly add-ons which are more likely to be opposed and difficult to be defended [18].

2.3.2.2 Cyber security and Data Privacy

BD Security is a major issue with its own distinctive challenges. Inability to properly control data generation and access has huge implications in terms of compliance issues, unintentional data loss, exposure of data to non-legitimate users and accumulation of poor quality data [54]. These challenges are especially difficult to overcome because cyber security is not among the driving trends of the digital age [62]. In the context of the FM sector, buildings can be considered easy targets for organized criminals who wish to research an organization as part of a targeted attack. As [63] note, the risks can broadly be categorized as: Override security controls e.g. steal intellectual property; Nuisance e.g. drive up energy bills and break building systems; Disruption e.g. turning off building systems; Ransom e.g. take control of building systems; Life safety/panic e.g. threaten duty of care to staff and visitors; Staff information e.g. steal personal information, research members of staff. According to [64], despite the fact that the awareness of cyber-threats to building operations among FM professionals is high, there is no adequate standardization of the role specific responsibilities with regards to the mitigation of concerns. [65] present the use of machine learning based applications for the detection of cyber-attacks, noting that the manipulation of such tools is a major growing concern.

There is no doubt that it is high time that the industry as a whole develops a strategic roadmap and specifies standards to support BDA initiatives [57]. The US National Institute of Standards and Technology has also released the Buildings Cyber-Security Framework which provides general guidance to building owners and operators to identify and implement a cyber-security risk management strategy to secure critical buildings Information Technology and Operational Technology [62]. Respectively in the UK, the government plans to invest a total of £1.9 billion over the next five years to transform significantly the country's cyber security and launch two new cyber innovation centres to drive the development of cutting-edge cyber products and dynamic new cyber security companies [66].

Further to the abovementioned challenges in cyber security, the archiving of data from the FM systems (e.g. lighting, HVAC, access, security, HR) also introduces privacy concerns as they are mostly related with occupant personal details, behavior, comfort and productivity [42]. Therefore, it is clear that BDA implementation in the FM industry involves a unique mix of challenges relevant to data acquisition and quality, interoperability, security, privacy, cost, lack of skills, appropriate culture and role integration in the FM business.

3 RESEARCH METHODOLOGY

This paper particularly aimed to explore the under researched topic of how FM organizations in UK are currently capitalising on BDA to drive innovation and efficiency in their operations. As such, the methodological doctrine of empiricism was employed to investigate the research problem and collect verifiable empirical data. Empiricism relies on collating available facts, evidence, and sources through observation and data to induce generalizations and build theory. The researchers combined both the interpretivist (qualitative) and positivist (quantitative) methods, for example literature review and case studies were collectively used to identify forward-looking FM organizations' practices to embrace digital innovation, whereas questionnaire survey was conducted to gather quantitative data. Case study approach was deemed appropriate to collect qualitative data through intensive examination of current practices of FM organizations using multiple sources of data [20], [21]. Here three UK based organizations implementing BDA were reviewed and semi-structured interviews were conducted with nine domain experts (three in each organization) to obtain data, based on their experience and expertise, which were then analyzed using cognitive mapping. The RICS report by 16 provides a detailed overview of Qualitative Case-study analysis and the findings.

The emergent findings from Case studies were analyzed and discussed among all the co-investigators and were used as a foundation to support the development of the questionnaire. The extensive questionnaire covered Drivers, Challenges, Strategies, Outcomes and Future initiatives related to BDA implementation (Refer to [16], Appendix B). However, due to the very elaborate nature of the study, a decision was taken by the authors to restrict the scope of the current study and, present a detailed empirical quantitative analysis focusing only on the Drivers and Challenges associated with BDA implementation. As such, 25 items listed in Table 1 (Variables Column) were the measurement scales (eleven drivers and fourteen challenges) included in this study.

The questionnaire commenced with an introductory note to the respondent introducing the project, research team and the respective institutions. The note briefly discussed the rationale for the study, eligibility criteria, issues associated with confidentiality and contact details of the researchers involved. The research instrument was divided into four sections; Section A and B were designed to gather demographic information and BDA implementation status, whereas Section C the main body of the questionnaire consisted of variables to measure the abovementioned concepts. For each item, a 1 to 5 point Likert scale was developed seeking agreement/disagreement on the item where; 1- Strongly Disagree, 2- Disagree, 3 – Neither Agree nor Disagree, 4 – Agree, and 5 – Strongly Agree.

Table 1: Variables included in the Study

Code	Drivers	Code	Challenges
DR1	Reduce client's operating costs	CH1	Poor quality data
DR2	Reduce client's energy consumption	CH2	Concerns over security of the data being transmitted over the network
DR3	Efficiently manage water usage and consumption	CH3	Lack of clarity on how assets should be grouped in hierarchical structure (i.e. parent-child relationship)
DR4	Improve building performance and occupant comfort	CH4	Inconsistent connectivity (both wired and wireless) to handle bandwidth-intensive real-time applications
DR5	Improve the quality of air and environment inside buildings	CH5	Legal issues associated with aggregating massive amounts of data
DR6	Proactively address potential asset/facility performance issues to minimize risks and maximize utilisation	CH6	Ethical issues associated with data storage
DR7	Reduce the risk of failure of critical asset systems	CH7	Ambiguity associated with ownership of 'Big Data'
DR8	Provide an informed basis to successfully monitor Key Performance Indicators (KPIs) and support organizational goals	CH8	Restricted rights to remotely access and control Building Management Systems (BMS)
DR9	Deliver FM contracts more efficiently	CH9	Closed protocols from product manufactures
DR10	Maximize profitability in an increasingly complex market	CH10	Issues with legacy systems integration
DR11	Unleash new avenues to stay ahead of the competition	CH11	Lack of clear business case for funding
		CH12	Lack of Budget to roll out BDA and IoT initiatives on a larger scale
		CH13	Lack of skilled talent with good understanding of data analytics and what it means to specific FM functions/ operations
		CH14	Stakeholders resistance to change

The final section of the questionnaire aimed to gather additional comments from the respondents. The researchers particularly focused on the wording of the questions to achieve a high degree of content validity and reduce the risk of Common Method Bias (CMB). The instrument was pre-tested by a team of experienced academics to assess its comprehensiveness and relevance and where necessary questions were re-worded. It was then distributed via email to carefully selected FM professionals with rich experience of being involved with BDA implementation of their organization (this includes all the interview participants). This also dictates the response rate for the survey that depends on the respondent's knowledge about the subject area [67]. Of the 150 email requests sent; fifty-two complete questionnaires were returned, yielding an effective response rate of around 35%. 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 organizations) provided a deeper understanding of how participants viewed the statistics.

The Statistical Package for Social Sciences (SPSS) 25.0 was used to conduct various statistical analysis including EFA, Cronbach's Alpha, Non-parametric tests Kruskall-Wallis and post hoc Dunn-Bonferroni test. EFA a multivariate statistical method was used to consolidate the newly developed scales (in this case Drivers and Challenges) and detect clusters of related variables and reduce the number of variables [68]. As highlighted by [69], EFA facilitates restructuring of data by reducing the number of variables that can be used to represent linear relationships between groups of perceived indicators. In this instance, EFA was separately performed on the two groups of drivers and challenges. Here, two basic assumptions associated with factor analysis were tested i.e. multivariate analysis and sampling adequacy. Bartlett's Test of Sphericity was used to measure the multivariate normality of the variables by testing the null hypothesis that the correlation matrix is an identity matrix (chi-square output that must be significant i.e. $p<0.001$) whereas, Kaiser-Meyer-Olkin (KMO) test for sampling adequacy requires variables to have a minimum factor loading of 0.50. The anti-image correlation matrix additionally supports this; where the values (should be greater 0.5) on diagonal axis of the matrix provide a measure of sampling adequacy for each variable. Additionally, Kruskal-Wallis test (nonparametric) test was conducted to establish if there were significant differences between the ranking of the variables depending upon big data maturity level i.e. nascent, pre-adoption, early adoption, mature and visionary. This nonparametric test is used to compare three or more groups. It is apt for the current study since the sample sizes of the groups are not equal. KW test takes the median value of responses into consideration. In the current paper the researchers opted for 95% confidence interval ($P \leq 0.05$) that the differences between the perceptions of the groups are statistically different. The non-parametric test is very important because the BD maturity levels of the organizations have significant impact on the perception of Drivers and Challenges, hence it is anticipated that the agreement on these variables may vary based on these groupings. Follow-up Dunn-Bonferroni post hoc test was carried out on the significant variables to identify which of the maturity level groups were significantly different from each other.

4 ANALYZES AND RESULTS

4.1 DESCRIPTIVE ANALYSIS OF SECTION A (Participants' Details)

Descriptive analyzes were performed on the Section A and B of the questionnaire to analyze the respondents' background and generate confidence in the credibility of data collected. Overwhelming majority of the sample were Directors (40%) with considerable number of years of industry experience followed by Project and Technical Managers and, others. As such, the responses could therefore be considered as accurate reflections of the current state of affairs within the FM sector and its engagement with BDA. Consistent with findings of [70] BDA uptake emerged to be greater within larger organizations (5000+ employees) at 66% compared to small businesses (<50 employees) that were restricted to 7.5%. Nearly half the respondents had no professional memberships, while approximately a 29% of them held the British Institute of Facilities Management (BIFM) membership.

4.2 DESCRIPTIVE ANALYSIS OF SECTION B (BDA IMPLEMENTATION)

Section B of the questionnaire, designed to capture the BD Implementation, revealed that 72% of the participants reported to be at the beginning stages i.e. pre-adoption 37% and early adoption

35% at the time of survey. Suggesting that respondents and their respective organizations have only just started their BDA journey. Over half (56%) of the companies have spent between 1 to 4 years BDA initiatives and 38% of the respondents and companies having spent less than 1 year. Interestingly, 17% percentage of individuals' report having spent over 5 years on these initiatives. To support the BDA initiatives and keep pace with technological advancements, FM organizations are recruiting experienced Managers (with Data Science/ Computing/ Analytical background) to manage the FM information in all its vastness, which explains the reason why respondents have more BDA experience compared to their companies. Data Analytics skills are currently in high demand for scaling-up and commercialising the existing initiatives and launching new services.

4.2.1 SOURCES OF BIG DATA

Respondents of this study selected operational systems like, CAFM, BMS, Energy Management System (EMS) and BIM to be key sources of BDA. Other sources, such as Enterprise Resource Planning (ERP), Space Planning, Security, Waste management, Air Quality, Refrigeration, Light Detection and Ranging (LiDAR) and videos were also reported. 81% of the respondents reported using more than two systems. The challenge currently facing FM industry is consolidating and integrating data from diverse legacy systems to seamlessly operate as one.

4.3 EXPLORATORY FACTOR ANALYSIS (EFA)

Following the descriptive analysis, the EFA was individually performed on the Drivers and Challenges categories listed in Table 1 to identify the items that can be grouped into correlated factors. The data sets were assessed for sampling adequacy and consecutive iterations were performed to derive a dataset suitable for analysis. Only one item (CH14- Stakeholders resistance to change) with a factor loading < 0.5 was omitted on examining the anti-image correlation matrix, since it showed multi-collinearity. In both the instances KMO was above 0.5 and Bartlett's test sphericity was statistically significant @ 0.000 level < 0.05. Following confirmation of the suitability of data for EFA as per the aforementioned tests, Components or Factors were extracted by Principal Component Analysis with Varimax rotation and in compliance with the general rule of Eigenvalue >1. Then, the salient variables in each factor were identified and used as indicators for the factor interpretation. Principal Components Analysis (PCA) was used to identify factors with Eigen values over one and orthogonal Varimax rotation was performed to obtain interpretable factor loadings.

Table 2: Results of EFA

Group	Sub-group	Variable Code	Factor Loading	Cronbach's Alpha	Variance explained
Drivers	FM Market and Practice led Drivers	DR9	.840	0.911	44.46%
		DR11	.829		
		DR10	.826		
		DR6	.793		
		DR7	.766		
		DR4	.739		
		DR8	.714		
		DR1	.540		
	Sustainability led drivers	DR3	.943	0.802	22.28%
		DR2	.820		
		DR5	.646		
Challenges	Technological Barriers	CH9	.835	0.798	20.40%
		CH2	.729		
		CH8	.699		
		CH10	.657		
		CH4	.607		
	Issues with data governance and management	CH5	.904	0.844	19.06%
		CH6	.854		
		CH7	.771		
	Inadequate preparedness for BDA initiatives	CH12	.746	0.634	15.22%
		CH3	.714		
		CH11	.687		
	Data Quality and skill gap	CH1	.860	0.737	13.17%
		CH13	.698		

As shown in Table 2, the salient variables identified for each extracted factor are higher than 0.5, reflecting a substantial degree of contribution of each variable to its extracted factor. An appropriate collective label was given to each extracted factor so as to reflect the correlation of all the variables within.

A detailed discussion of the Groupings obtained through EFA is provided in the Discussion Section. The Drivers scale yielded two factors, *"FM Market and Practice led Drivers"* and *"Sustainability led drivers"* (Table 2). These factors explained 66.74% of total variance. Similarly, four Challenges factors were obtained that include, *"Technological Barriers", "Issues with Data Governance and Management", "Inadequate preparedness for BDA initiatives"* and *"Data quality and skill gap"*. The four factors explained 67.85% of total variance (Table 2).

Cronbach's Alpha was conducted to test the scale reliability and internal consistency of the components. The general rule of thumb is that 0.6-0.7 values indicate an acceptable level of reliability, and 0.8 or higher is considered excellent. Cronbach's Alpha values ranged from 0.634 to 0.911, all meeting the criterion level of 0.60, indicating that the newly developed scales have good reliability and internal consistency.

4.4 KRUSKAL-WALLIS TEST

Kruskal-Wallis test performed on all the variables revealed that only four variables from the Driver's cluster (*DR1*, *DR7*, *DR8*, *DR10*) emerged to be statistically significant because they had a p-value below the significant test value of 0.05 (Table 3). On the other hand, the remaining twenty variables have their p-values ranging from 0.056 to 0.895, which are greater than 0.05 hence they were not statistically significant. It implies that only the four-abovementioned variables did receive significantly different views on their rankings based on BD maturity levels.

Table 3: Results of Kruskal Wallis Test

Variables	**Chi-Square**	**df**	**Asymp. Sig.**
Reduce client's operating costs *(DR1)*	9.667	4	0.046
Reduce the risk of failure of critical asset systems *(DR 7)*	11.716	4	0.020
Provide an informed basis to successfully monitor Key Performance Indicators (KPIs) and support organizational goals *(DR 8)*	9.725	4	0.045
Maximize profitability in an increasingly complex market *(DR 10)*	11.526	4	0.021

A follow up Dunn- Bonnferroni pair wise comparisons conducted for each variable revealed that only the p-value comparing DR7 for Nascent-Early Adoption and Nascent-Corporate Adoption; and DR10 for Nascent-Pre Adoption groups were significant ($p < 0.001$). As can be observed from Figure 1 significant differences are highlighted using an orange line to join the two different groups. The Adj. Sig column makes the adjustments for multiple testing using the Bonferroni error correction (Table 4). These results imply that significant differences were distributed as follows:

Table 4: Results of Dunn-Bonferroni Post hoc Tests

Variables	Sample 1-Sample2	Test Statistic	Std. Error	Std test Statistic	Sig	Adj Sig
Reduce the risk of failure of critical asset systems *(DR 7)*	Nascent-Early Adoption	-18.167	6.070	-2.993	.003	0.028
	Nascent-Corporate Adoption	-21.071	7.284	-2.893	.004	0.038
Maximize profitability in an increasingly complex market *(DR 10)*	Nascent-Pre Adoption	-18.962	6.089	-3.114	.002	0.018

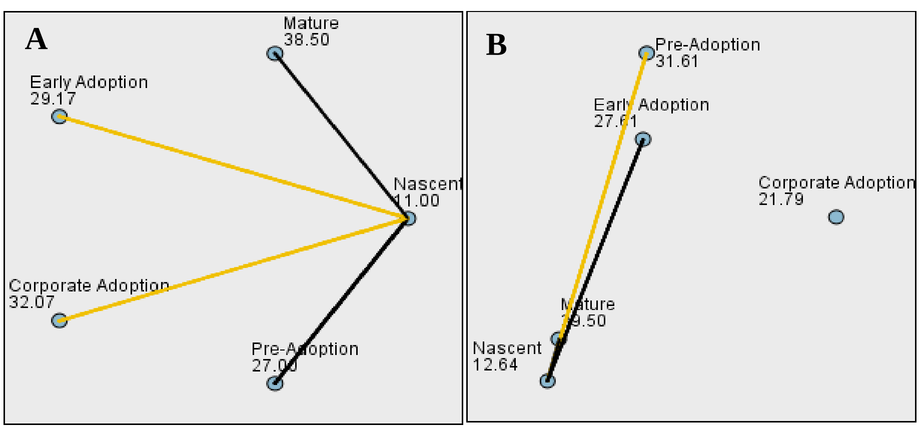

Figure 1: Pairwise Comparison of groups

A- *Reduce the risk of failure of critical asset systems (DR7),*

B- Maximize profitability in an increasingly complex market (DR10)

For the variable DR7 the ranking of the Nascent group was significantly different from Early and Corporate Adoption groups. Suggesting that Corporate Adoption and Early Adoption groups (mean values of 32.07 and 29.17 respectively) were more in agreement that they implemented BDA and IoT in their operations with the aim to reduce the risk of failure of critical asset systems than the Nascent group (mean value of 11.0). This can be explained by the fact that organizations at Nascent stage tend to have a low awareness of BD or its value and, are only exploring the concept of analytics [71]. Whereas during the Early adoption stages, the organizations have developed Proof of Concepts (PoCs) which usually starts with operating critical assets at maximum efficiency. It's even more evident in Corporate adoption stage where the Clients/ end-users get involved, gain insights and transform the way they conduct business.

Similarly, for the variable DR10 the Pre-Adoption (mean value of 31.61) group was more in agreement that BDA implementation was driven by maximizing profitability margins than Nascent group (mean value of 12.64). At Pre-adoption stage organizations tend to thoroughly research into the concept of BDA and invested in new technology [71]. Suggesting that these firms aim to take advantage of insight-driven BDA initiatives to maximize profitability.

5 DISCUSSION

The following section discusses the six extracted factors according to the descending order of variance explained by each factor.

5.1 DRIVERS FOR ADOPTION OF BIG DATA IN FM SECTOR

The following two themes emerged under the category of Drivers that include;

5.1.1 FM Market and Practice led Drivers

This factor accounts for the largest amount of total variance (44.46%). It encompasses eight variables i.e. DR9, DR11, DR10, DR6, DR7, DR4, DR8 and DR1. In the highly competitive, diverse and labour intensive service industry, organizations are increasingly looking to modernize service delivery, maximize system performance and reduce operating costs. The pressure on pricing is coming from both client and market competition [72]. As such, FM organizations are under enormous pressure to be technologically-innovative and develop new delivery models to tackle margin pressure [73] and drive efficiency at the same time. Specifically, IoT and BDA are believed to be key to achieving efficiency savings, sustainable growth and Key Performance

Indicators (KPIs) such as, end-user comfort, benchmarking engineering compliance, energy consumption etc.

Secondly, FM organizations increasingly see the need to reduce risk and enhance the resilience of critical mission assets. Critical assets could be systems/processes/facilities that are essential for smooth running of operations [74], and whose performance on the 'front-line' has high consequence of failure. Predictive analytics in this instance can help to identify any potential issues before failure occurs thereby maximising asset utilization. The early warning notifications typical of predictive maintenance regime help to prioritize and allow more lead-in time to strategically plan job activities. Thus, eliminating any overheads associated with unplanned asset maintenance and streamlining contract pricing mechanisms. Availability of robust historical data means that pricing for contracts could be based on actual modelled costs as opposed the industry standard which tends to be an estimate (on the higher side) [16]. Thus, there is price certainty and commercial advantage to be reaped based on the power of BD.

5.1.2 Sustainability led Drivers

Sustainability led drivers account for 22.38% of total variance. The cluster comprises of three variables that include; DR3, DR2 and DR5. As highlighted by [75], the operational phase of the building by far has the greatest impact on the environment, wellbeing of the end-users and the economy. It is during this phase that majority of the costs associated with any building during its total lifecycle are accrued [76]. Therefore, FM organizations have a significant role to play in minimizing the environmental impact, non-value-adding activities and the whole-life costs of facilities. In this regards, FM organizations are not only expected to offer a seamless package of sustainability related services but comprehensive reporting and propositions to improve their overall environmental performance [77]. As noted by [78] creating a comfortable indoor environment is emerging to be a demanding task. In a bid to support these sustainability objectives, a growing number of FM organizations are investing in BDA and IoT technology to remotely monitor and collect sensor data to better understand the performance of the buildings. These insights derived from real time information gathered around equipment performance, facility usage and operations are greatly contributing towards enhancing resource efficiency, cost optimization and end-user productivity. Specifically, the remote monitoring services provide real-time granular performance data on critical equipment, including insights around energy profiling, equipment operating conditions and health, space management, thermal comfort etc.

5.2 CHALLENGES ASSOCIATED WITH ADOPTION OF BIG DATA IN FM SECTOR

Four themes emerged under the category of challenges, that include; Technological barriers, Issues with Data Governance and Management, Inadequate preparedness for BDA initiatives, and Data quality and skill gap. Variables/ items for each theme are provided in Table 2.

5.2.1 Technological Barriers

The cluster Technological Barriers accounts for 20.40% of the total variance. It comprises five items that include: CH9, CH2, CH8, CH10 and CH4. Though IoT holds the potential to transform asset management, there are several technological challenges that are preventing integration of operational systems (OS) for business growth. The key problem lies in the fact that Information Technology (IT) systems were designed to connect applications and share data whereas, OS (closed) and proprietary were conceived to be standalone entities not designed to be connected or even accessed remotely [79]. Unifying OS and IT infrastructures requires significant intervention to align the systems' architecture and communications protocols [79]. A further level of complexity is introduced with regards to the 'security' of the information that is transmitted over the network, which is highlighted to be one of the biggest challenges in deploying BD technologies [80]. Stipulations around physical locations of servers, reliance on cloud based computing, and security have sharply increased concerns and are impeding progress of new technology adoption. Specifically, concerns are being raised around the remote monitoring of the BMS, which lack security in control systems and as such are very susceptible for attacks and thefts [81], [82]. Significant research is required in the area of cyber security to firstly understand potential types of risks and thereafter implement safeguards and mitigation measures [82]. The technological aspect is further compounded by inconsistent connectivity in hard to access locations (basements/ plant rooms) where the bandwidth required to transmit information might not be available at that time. Due to these technological barriers FM organizations are unable to take full advantage of available data sets and fully automate the building maintenance activities.

5.2.2 Issues with Data Governance and Management

This cluster for 'Issues with Data Governance and Management' accounts for 19.06% variance. It consists of three variables that include; CH5, CH6 and CH7. This move of the FM organizations towards predictive maintenance strategy building on the data harvested from a number of systems and sharing it with other parties is exposing them to unprecedented levels of risks. Given the very high consequences of data breach (loss of clients, legal penalties, loss of intellectual property etc.), it becomes critically important that BDA initiatives are not only supported by the management but have clearly established guidance and procedures for data governance [83]. The key challenge here is an understanding between Client-FM on the "ownership" i.e. who has sustainable control over data so as to safeguard it from potential threats. Since most FM companies are in early stages of data capture there is very little understanding of policies and procedures associated with governance, data ownership, aggregation and ethical issues. Studies by [84] and [18] reiterate similar issues whereas, [85] raised concerns specific to energy BD and privacy information which are particularly vulnerable to cyber-attacks. Inability to address these issues would mean that the companies may not be legally entitled to use such data and moreover, would be jeopardising their reputation and finances [83].

5.2.3 Inadequate Preparedness for BDA Initiatives

This sub group consisting of following three variables; CH12, CH3 and CH11 accounts for 15.22% variance. BD initiatives more than anything require organizations to adopt a strategic and disciplined approach to prepare and equip themselves to extract greater benefits [47]. Organizational readiness in this context assesses whether it is prepared for the change, and that its people are ready to join and work within the new environment [86]. This multi-level construct is influenced by a number of dimensions from IT infrastructure, to data management and governance, to maturity assessment etc. [71]. The respondents of this study in particular picked management support and technical capability as key challenges. It is a well-known fact that BD projects require substantial investments in terms of infrastructure (upgrade from the traditional Online Transaction Processing- OLTP and SQL tools to scalable database with unique query tools) and personnel training and hire [87], [88]. According to [89], on average organizations are spending 18% of their overall IT budget on BD projects. Therefore, it is not surprising that *"only large organizations with deep pockets"* are better equipped to implement these resource intensive projects [90].

An additional hurdle with these projects is the difficulty in building the business case. Securing funding from senior leadership requires a clear view of business goals i.e. understanding what exactly needs to be accomplished and how this addresses their company's problem. Since very little is known about the potential FM applications of BDA and there is a relatively small pool of completed projects, FM companies are struggling to clearly establish the scope of proof-of–concept (PoC) which is a realistic attainable goal with a clear time parameter [16].

On the technical front, the very first step towards smart asset management involves appropriately grouping assets into systems, subsystems, components, etc. [36]. Establishing parent-child relationships and equipment hierarchy is critical since it facilitates asset identification, data analysis, reporting for metrics, and failure threads (e.g., mean time between failures) [91]. Currently, for FM organizations accustomed to working with informal hierarchical structures, classifying assets into primary, secondary and tertiary tiers is proving to be a time consuming exercise. Additionally, lack of clarity on asset hierarchy, means that data collected is not fit for purpose and the organizations are either unable to achieve the intended outcome or they lack relevant information for informed decision-making [92]. Conclusively, these results indicate that the organizations need to holistically prepare themselves to BDA related practices and applications to realize the full potential and innovation opportunities.

5.2.4 Data Quality and Skill Gap

This sub-group consisting of variables CH1 and CH3 accounted for 13.22% variance. One of the biggest challenges facing businesses as data volumes and sources continue to grow is the lack of capabilities to collect correct, reliable, consistent and timely data for decision-making [36]. As highlighted by [93], what happens in reality is that organizations tend to collect far more data than they possibly can use; but end up with not having the data that they really need. The review of literature suggests a general lack of consensus among the researchers on the definition and dimensions of data quality. As such, it becomes very difficult to measure the quality of data [94]. Additionally, since FM BD is obtained from various heterogeneous sources, quality or 'fitness' of data (unstructured or semi-structured) is posing to be a significant challenge. This mainly stems from manual data handling, incomplete reports, data duplication, inaccurate work orders, missing data sets, lack of real-time data, lack of context richness, inaccuracy etc. The sheer scale and speed at which complicated data is ingested by BD technologies is creating several challenges like, difficulty in integrating data with complex structures and types, processing data in reasonable timeframe, processing technology's incapability to capture 'timeliness' of data, and lack of standards for data quality [94]. A study by [18] also confirms that the prevalence of poor quality data in the building industry is significantly affecting the production of high value analytics.

With data quality being the fundamental building block for analytics, organizations need to divert substantial efforts to remove risk caused by bad data. Inferences drawn from such inconsistent datasets are increasingly forwarding faulty analytical results to downstream technicians, leading to scepticism about organizational capability [16]. This process of creating clean and reliable data is very time consuming in that it involves numerous data pre-processing techniques to eliminate inconsistencies and noise [95]. [96] recommend that future studies should focus on *"encrypting large datasets, reducing the computation power of encryption algorithms, and applying different encryption algorithms to heterogeneous data"* to address data quality issues.

Furthermore, as businesses strive to offer innovative services to make them competitive, they are finding it increasingly difficult to find the right people to support the company's adoption of novel technology. Current market conditions demand multi-disciplinarity i.e. combination of business and analytics skills to produce actionable insights [97]. A survey conducted by [14] revealed that specifically UK companies are facing significant hurdles in recruiting appropriately skilled staff and this is only going to get worse post UK's exit from the European Union. [72] confirm that the BD talent gap is something that organizations are increasingly coming face-to-face with. [74] argue that specialized courses and programs in management, data and computer science should be developed to train talents for roles like, Chief Data Officer, Digital Officer, Analytics Officer etc.

6 CONCLUSION

The FM industry's core business heavily relies on collating and analyzing large and diverse volumes of data that are continually being produced by critical mission assets, BMS, ERP, CAFM systems etc. As such the industry has always been collecting large amounts of information from transactions, purchase requests, warranties and data generated by FM operations. However, the recent advancements and improvements in analytics and high-performance computing, mean that companies are not only able to access new sources and types of under-leveraged data but are better placed to extract valuable insights from vast amount of complex and heterogeneous data that would otherwise remain hidden [98].

This paper aimed to present an overview of some drivers and challenges that accompany the rise of BDA in the UK FM sector. Aimed to develop a better understanding of these issues, the researchers built on their previous study where they interviewed three case-study FM companies, followed by an industry-wide questionnaire survey from 52 respondents heavily involved with BDA implementation.

The results of the descriptive statistics imply that currently the FM BD market is at pre/early adoption stage but it is only expected to mature as more and more progressive firms seek to enhance organizational effectiveness and efficiency. The researchers were also able to subtly tease out how the perception for certain drivers varied with BD maturity levels. Unsurprisingly, due to the complexity and challenges associated with BDA, larger FM businesses well equipped with resources and established structures emerged to be front-runners in terms of adoption.

The results of the EFA helped to further categorize the drivers and challenges into subgroups. In terms of drivers, the heightened competition within the market and FM industry's growing sustainability commitments emerged to be key drivers compelling companies to come up with differentiation strategies to stay ahead of the competition and expand the range of services offered to the client. Technological development in the area of automated predictive maintenance is seen to be a precious source of competitive advantage. However, introducing complex technology in live working FM environment comes with considerable challenges like, technological barriers, issues with data governance and management, inadequate preparedness and, data quality and skill gap. A review of these identified sub-groups suggests that along with technological issues, process and organizational preparedness are just as important. In that successful implementation of technology warrants support and commitment from senior management in terms of long-term investments, resource allocation and address the ever-important data governance, security and ethical challenges. Additionally, optimal implementation of BDA demands new skill-sets and job roles to adapt to the changing technological landscape.

6.1 IMPLICATIONS FOR THEORY AND PRACTICE

The results of this study have several important implications for both literature and the FM industry. Since UK leads the sector in terms of sophistication and maturity, it is timely and essential to understand the new business avenues that forward-looking companies are exploring, following broadened client expectations, slower revenue growth and uncertainty around UK's decision to leave the European Union [37]. Firstly, this study builds on the conclusions of recent econometric analysis documenting the fact that the UK's FM sector fulfils the two necessary conditions (i.e. information technology-intensiveness and high competition) to be able to extract value from BDA assets. Secondly, to this date, there is no research that empirically identifies and categorizes critical drivers and challenges associated with BDA implementation in the UK, which is the largest outsourced FM market in Europe. The importance of investing and developing digital capabilities suggests that the academia and industry have to come together to identify the diverse skill-sets needed to effectively and appropriately deal with this transformational change and develop talent management strategy for industry 4.0. As highlighted by [99], cross-program education courses will be key to churning professionals with broad skills covering both technical and business aspects. The bottom line for BD adoption research is of course further investigation to understand the implementation strategies and value outcomes, which the researchers aim to empirically address in upcoming publications.

6.2 LIMITATIONS

This study has several limitations that must be taken into consideration when interpreting the results and their implications. Since the study was conducted in UK, there may be certain limitations in generalizing the findings to other developing economies. Future studies need to extend the investigation and survey a larger sample size. It would be interesting to incorporate case studies from developing countries and SME's to gain a wider understanding.

Acknowledgement

The authors would like to acknowledge the financial support received from RICS Research Trust Fund (Project No. 492) for the successful completion of this research.

REFERENCES

[1] B. Atkin, and A. Brooks, *Total Facilities Management.* Oxford, Blackwell Science, 2000.

[2] D. Amaratunga, D. Baldry, and M. Sarshar, "Assessment of facilities management performance what next?," *Facilities,* vol. *18,* no. *1/2,* pp. *66-75,* Jan. 2000.

[3] H. B. Kok, M. P. Mobach, and O. S. Omta,"The added value of facility management in the educational environment," *J Facil Manag,* vol. *9,* no. *4,* pp. *249-265,* Sept. 2011.

[4] B. Nutt, and P. McLennan, *Facility management: risks & opportunities*. Oxford, Blackwell, 2000.

[5] C. Engelbrecht, and J. Willis, "Business Outcomes for data-driven facilities: A new look at Building Value," Siemens, 2015. [Online]. Available: https://www.downloads.siemens.com/download-center/Download.aspx?pos=download&fct=getasset&id1=A6V10702457

[6] C. Yiu, "The Big Data Opportunity Making government faster, smarter and more personal," Policy Exchange, 2012. [Online]. Available: https://policyexchange.org.uk/wp-content/uploads/2016/09/budget-2011-policy-exchanges-response.pdf

[7] J. Manyika, M. Chui, B. Brown, J. Bughin, R. Dobbs, C. Roxburgh, and A. Hung Byers, Big data: The next frontier for innovation, competition, and productivity, McKinsey Global

Institute, 2011 [Online]. Available: https://www.mckinsey.com/~/media/McKinsey/Business%20Functions/McKinsey%20Digital/Our%20Insights/Big%20data%20The%20next%20frontier%20for%20innovation/MGI_big_data_exec_summary.ashx

[8] S.E. Bibri, "The IoT for smart sustainable cities of the future: An analytical framework for sensor-based big data applications for environmental sustainability," *Sustain Cit Soc,* vol. *38*, pp. *230-253,* Apr. 2018.

[9] A. Labrinidis, and H. Jagadish, "Challenges and opportunities with big data," *Proc. VLDB Endowment,* vol. 5, no 12, pp. *2032–2033,* Aug. 2012.

[10] A. Gandomi, and M. Haider, "Beyond the Hype: Big data concepts, methods, and analytics," *Int J Inform Manag*, vol. 35, no. *2*, pp.*137–144*, Apr. 2015.

[11] O. Müller, M. Fay, and J. vom Brocke, "The Effect of Big Data and Analytics on Firm Performance: An Econometric Analysis Considering Industry Characteristics," *J Manag Inform Syst*, vol. *35*, no. *2*, pp. *488-509*, May 2018.

[12] M. Gupta, and J.F. George, "Toward the development of a big data analytics capability," *Inform Manag*, vol. 53, no. *8*, pp. *1049-1064*, Dec 2016.

[13] D. Frodl, B. Owens, L. Wayman, J. Skoldeberg, T. Brady, A. Ladha, E. Hitzke, M. Kennedy, J. Christiansen, and A. L. Richards, "Digital Efficiency," Intel and General Electric, 2017.

[14] S. Kejriwal, and S. Mahajan, "Smart buildings: How IoT technology aims to add value for real estate companies," Deloitte, 2016. [Online]. Available: https://www2.deloitte.com/content/dam/Deloitte/nl/Documents/real-estate/deloitte-nl-fsi-real-estate-smart-buildings-how-iot-technology-aims-to-add-value-for-real-estate-companies.pdf

15] V. Ahmed, A. Tezel, Z. Aziz, and M. Sibley, "The future of Big Data in facilities management: opportunities and challenges", *Facilities*, vol. *35*, no.*13/14*, pp.*725-745*, Aug. 2017.

[16] A. Konanahalli, L.O. Oyedele, M. Marinelli, and G. Selim, "Big Data: A new revolution in UK Facilities Management Sector," RICS, 2018. [Online]. Available: https://www.rics.org/globalassets/rics-website/media/knowledge/research/research-reports/big-data-a-new-revolution-in-the-uk-fm-sector-rics.pdf

[17] M. Mawed, and A. Al-Hajj, "Using big data to improve the performance management: a case study from the UAE FM industry," *Facilities*, vol. 35, no. *13/14*, pp.*746-765*, Oct. 2017.

[18] M. Bilal, O. Oyedele, J. Qadir, S. Ajayi, O. Akinade, H. Owolabi, H. Alaka, and M. Pasha, "Big Data in the construction industry: A review of present status, opportunities and future trends," *Adv Eng Informat*, vol. *30*, no. *3*, pp. *500-521*, Aug. 2016.

[19] JLL, "*Reinventing Facilities Management for the Digital World*," Jones Lang Lasalle, Inc, 2016. [Online]. Available: http://www.corenetglobal.org/applications/KCO/Document.aspx?itemNumber=37044&download=1.

[20] R. K. Yin, *Case study research: Design and methods*. 4th Ed. Sage, Thousand Oaks, CA, 2009.

[21] P. D. Leedy, and J. E. Ormrod, *Practical Research: Planning and Design*. 8th ed. Pearson Merrill Prentice Hall, Upper Saddle River, NJ, 2005

[22] I. Mignon, "Inducing large-scale diffusion of innovation: An integrated actor- and system-level approach," Doctoral Thesis, Linköping Univ., Linköping, Sweden, 2016.

[23] Y. Demchenko, C. D. Laat, and P. Membrey, "Defining Architecture Components of the Big Data Ecosystem," *in Procs of* Int Conf Collab Tech Syst, Minneapolis, 2014, pp. 104-112.

[24] IBM, "Harness the value of big data to build smarter infrastructures," IBM, 2017. [Online]. Available: https://www-01.ibm.com/common/ssi/cgi-bin/ssialias?htmlfid=TIW14160USEN.
[25] B.-A. Schuelke-Leech, B. Barry, M. Muratoric, and B.J. Yurkovich, "Big Data issues and opportunities for electric utilities," *Renew Sustain Energ Rev*, vol. 52, pp. *937-947*, Dec. 2015.
[26] D. Mourtzis, E. Vlachou, and N. Milas "Industrial Big Data as a result of IoT adoption in Manufacturing," *in Proc. 5th Global Web Conf Res Innov for Fut Prod*, 2016, vol. *55*, pp. 290 – 295.
[27] D. Bumblauskas, H. Nold, P. Bumblauskas, and A. Igou, "Big data analytics: transforming data to action," *Bus Process Manag J*, vol. *23*, no.*3*, pp. *703-720*, June 2017.
[28] D. Mishra, Z. Luo, S. Jiang, T. Papadopoulos, and R. Dubey, "A bibliographic study on big data: concepts, trends and challenges," *Bus Process Manag J*, vol. *23*, no. *3*, pp. *555-573*, June 2017.
[29] U. Sivarajah, M. M. Kamal, Z. Irani, and V. Weerakkody, "Critical analysis of Big Data challenges and analytical methods," *J Bus Res*, vol. *70*, pp. *263-286*, Jan 2017.
[30] T.H. Davenport, and J.G. Harris, C*ompeting on Analytics: The New Science of Winning*. Boston: Harvard Business Press, 2007.
[31] S. LaValle, E. Lesser, R. Shockley, M.S. Hopkins, and N. Kruschwitz, "Big data analytics and the path from insights to value," *MIT Sloan Management Review*, vol. *52*, no. *2*, pp. *21–31*, Dec. 2011.
[32] R. Wegener, and V. Sinha, "The value of big data: How analytics differentiates winners," Bain & Company, 2013. [Online]. Available: www.bain.com/Images/BAIN%20_BRIEF_The_value_of_Big_Data.pdf
[33] D. Simchi-Levi, J. Gadewadikar, B. McCarthy, and L. LaFiandra, "Winning with analytics," Accenture, 2016. [Online]. Available: https://www.accenture.com/_acnmedia/Accenture/next-gen/hp-analytics/pdf/Accenture-Linking-Analytics-to-High-Performance-Executive-Summary.pdf
[34] N. Côrte-Real, P. Ruivo, and T. Oliveira, "Leveraging internet of things and big data analytics initiatives in European and American firms: Is data quality a way to extract business value?," *Inform Manag*, in press, available: https://www.sciencedirect.com/science/article/abs/pii/S0378720617308662
[35] W. Ross, C.M. Beath, and A. Quaadgras, "You may not need Big Data after all," *Harv Bus Rev*, vol. *91*, no. *12*, pp. *90*-98, Dec. 2013.
[36] A. Koronios, S. Lin, and J. Gao, "A data quality model for asset management in engineering organizations," in *Proc.of Int Conf Inf Qual*., 2006, MIT, MA, USA, November 10-12th.
[37] Global FM, "Global Facilities Management Market Report", Global FM, 2018. [Online]. Available: https://www.iwfm.org.uk/sites/default/files/2019-01/24315%20Global%20FM%20Market%20Report%202017_0.pdf
[38] A. Kucera, and T. Pitner, "Semantic BMS: Allowing usage of building automation data in facility benchmarking," *Adv Eng Informat*, vol. 35, pp.*69-84*, Jan. 2018.
[39] B. Ramprasad, J. McArthur, M. Fokaefs, C. Barna, M. Damm, and M. Litoiu, "Leveraging existing sensor networks as IoT devices for smart buildings," in *Procs. IEEE 4th World Forum on IoT*, 2018, pp. *452-457*.
[40] C. Tu, X. He, Z. Shuai, and F. Jiang, "Big data issues in smart grid – A review," *Renew Sustain Energ Rev*, vol. *79*, pp. *1099-1107*, Nov. 2017.

[41] A. Malatras, A. Asgari, and T. Beauge, “Web Enabled Wireless Sensor Networks for Facilities Management,” *IEEE Syst J*, vol. *2*, no. *4*, pp. *500 – 512*, Dec. 2018.
[42] H.B., Gunay, W. Shen, and G. Newsham, “Data analytics to improve building performance: A critical review,” *Autom Construct*, vol. *97*, pp. *96-109*, Jan. 2019.
[43] M. Victoria Moreno, L. Dufour, A. F. Skarmeta, A. J. Jara, D. Genoud, B. Ladevie, and J.-J. Bezian, “Big Data: The Key to Energy Efficiency in Smart Buildings,” *Soft Comput*, vol. *20*, no. *5*, pp. *1749-1762*, Apr. 2016.
[44] M. Bakhouya, Y. NaitMalek, A. Elmouatamid, F. Lachhab, A. Berouine, S. Boulmrharj, R. Ouladsine, V. Felix, K. Zinedine, M. Khaidar, and N. Elkamoune, “Towards a Data-Driven Platform using IoT and Big Data Technologies for Energy Efficient Buildings,” *3rd Int Conf Cloud Comp Tech App (CloudTech)*, 2017, pp. 1-5.
[45] G. Palem “Condition-Based Maintenance using Sensor Arrays and Telematics,” *Int J Mob Net Com Tel*, vol. *3*, no. *3*, pp.*19-28*, June 2013.
[46] R. Eccles, I. Ioannou, and G. Serafeim, “The Impact of Corporate Sustainability on Organizational Processes and Performance,” *Manag Sci*, vol. *60*, no. *11*, pp. *2835-2857*, Nov. 2014.
[47] P. Bloomfield, E. Cameron, M. Grygiel, and S. Hawes, “Facilities Management: A quiet revolution,” PwC, 2014. [Online]. Available: https://www.pwc.fr/fr/assets/files/pdf/2017/12/facilities-management-quiet-revolution.pdf
[48] L. Pérez-Lombard, J. Ortiz, and C. Pout, “A review on buildings energy consumption information,” *Energ Build*, vol. *40*, no. *3*, pp. *394-398*, 2008.
[49] M.H. Rashid, “AMI Smart Meter Big Data Analytics for Time Series of Electricity Consumption,” in *Procs of IEEE Int Conf Trust, Sec Pri Comp Comm/ 12th IEEE Int Conf Big Data Sci Eng.*, 2018, pp. *1771-1776*.
[50] A.A. Munshi, and Y.A.-R. I. Mohamed, “Electric Power Systems Research, Big data framework for analytics in smart grids,” *Elec Power Syst Res*, vol. *151*, pp. *369-380*, Oct. 2017.
[51] F. Ascione, N. Bianco, C. De Stasio, G. Mauro, and G. Vanoli, “Simulation-based model predictive control by the multi-objective optimization of building energy performance and thermal comfort,” *Energ Build*, Vol. *111*, pp. *131-144*, Jan. 2016.
[52] Active, “Building a new world: Getting workplace technology working for you,” Active Workplace Management, 2019. [Online]. Available: https://www.fmj.co.uk/pdf/Active_whitepaper.pdf
[53] R.V. Zicari (2014), “Big Data: Challenges and Opportunities,” in *Big Data In Computing*, Florida: CRC Press Taylor & Francis Group, 2014, pp.*103-130*.
[54] S. Dhar, and S. Mazumdar, “Challenges and best practices for enterprise adoption of big data technologies,” in *Procs of Tech Man Conf*, 2014, pp. 1-4.
[55] H.V. Jagadish, J. Gehrke, A. Labrinidis, Y. Papakonstantinou, and C. Shahabi, “Big data and its technical challenges,” *Communication of the ACM*. vol. *57*, no. *7*, pp. *86-94*, July 2014.
[56] B. Saha, and D. Srivastava, “Data quality: The other face of Big Data,” in *procs of IEEE 30th Int Conf Data Eng*, 2014, Chicago, IL, pp. 1294-1297.
[57] J. Moyne, and J. Iskandar, “Big Data Analytics for Smart Manufacturing: Case Studies in Semiconductor Manufacturing,” *Processes*, vol. *5*, no. *3*, Sept. 2017.
[58] J. Ploennigs, B. Hensel, H. Dibowski, and K. Kabitzsch, “BA Sont – A modular, adaptive Building Automation System Ontology,” in *procs of IECON 2012 - 38th Annual Conf IEEE Ind Electr Soc*, pp. 4827–4833.

[59] P. Russom, "Best Practices Report -Big Data Analytics," TDWI, 2011. [Online]. Available: www.sas.com/content/dam/SAS/en_us/doc/research2/big-data-analytics-105425.pdf
[60] R. Drake, "BI Whitepaper - Management Challenges in the Big Data Era: Building on business intelligence: the data led revolution and its impact on British industry", Connect, 2015. [Online]. Available: https://www.savortex.com/wp-content/uploads/2015/10/Draft-White-Paper.pdf
[61] A. Asthana, and S. Chari, "Cost-Benefit Analysis: Comparing the IBM PureData System with Hadoop Implementations for Structured Analytics," IBM, 2015. [Online]. Available: http://www.cabotpartners.com/Downloads/TCO-Study-Pure-Data-versus-Hadoop-May-2015.pdf
[62] M. Mylrea, S.N. Gupta Gourisetti, and A.Nicholls, "An Introduction to Buildings Cybersecurity Framework," in *2017 IEEE Symp Series Comp Int (SSCI)*, 2017, Honolulu, HI, pp. 1-7.
[63] C. Grundy, "Cybersecurity in the built environment: Can your building be hacked?," *Corp R Estate J*, vol. *7*, no. *1*, pp. *39-50*, Aut/Fall 2017.
[64] G. Mayo, and D. Snider, "BAS and cybersecurity: A Multiple Discipline Perspective," in *procs of Amer Soc Eng Man Int Ann Conf*, 2016, Concorde, NC, pp 310-319.
[65] A. Handa, A. Sharma, and S.K. Shukla, "Machine learning in cybersecurity: A review," *WIREs Data Mining Knowl Discov.*, vol. *9*, no. *4*, e1306.https://doi.org/10.1002/widm. 1306, July/Aug 2019.
[66] HM Government, "National Cybersecurity Strategy 2016-2021," HM Government, 2016. [Online]. Available: https://www.enisa.europa.eu/topics/national-cyber-security-strategies/ncss-map/national_cyber_security_strategy_2016.pdf.
[67] S. J. Yates, *Doing Social Research*. Sage, London,2004.
[68] M. J. Norusis, *SPSS 10.0 guide to data analysis.* Prentice Hall, Englewood Cliffs, N.J, 2000.
[69] M.M. Marzouk, and E.F. Gaid, "Assessing Egyptian construction projects performance using principal component analysis", *Int J Prod Perform Manag*, vol. 67, pp. 1727-1744, Nov 2018.
[70] T. H. Davenport, and J. Dyché, "Big Data in big companies". International Institute for Analytics 2013 [Online]. Available: http://docs.media.bitpipe.com/io_10x/io_102267/item_725049/Big-Data-in-Big-Companies.pdf.
[71] F. Halper, & K. Krishnan, *TDWI Big Data Maturity Model Guide*, 2014.
[72] A. Tan, "*Smart steps, new opportunities –Business services outlook".* Deloitte, 2018 [Online]. Available: https://www2.deloitte.com/content/dam/Deloitte/uk/Documents/bps/deloitte-uk-business-services-outlook-2018.pdf.
[73] Ernst and Young, "*Facilities Management-Time to shift change"*. Report 2017 [Online]. Available: https://www.ey.com/Publication/vwLUAssets/ey-fy18-facilities-management-time-for-a-shift-change/$FILE/ey-fy18-facilities-management-time-for-a-shift-change.pdf.
[74] C. Liu, C-K. Tan, Y-S. Fang, T-S. Lok, "The Security Risk Assessment Methodology". "*Procedia Eng*, vol. 43, pp. 600-609, 2012.
[75] A. Aaltonen, E. Määttänen, R. Kyrö, and A. Sarasoja, "Facilities management driving green building certification: A case from Finland". *Facilities*, vol. 31, no. 7/8, pp.328– 342, May 2013.

[76] D. A. Jordani, "BIM and FM: The Portal to Lifecycle Facility Management". *Journal of Building Information Modeling*. pp.13–16. Spring 2010.
[77] M. Nousiainen, and S. Junnila, "End-user requirements for green facility management". *J Facil Manag*. vol. 6, no. 4, pp. 266-278, Sept 2008.
[78] CIBSE, *Managing Your Building Services*. London, Chartered Institute of Building Services and Engineers, CIBSE Knowledge Series KS02, 2005.
[79] Redhat, *Bridging the gap between operational technology and information technology*. White paper, 2016.
[80] W. Bell, *The Big Data Cure*, Report 2014 [Online]. Available at: http://www.meritalk.com/bigdatacure.
[81] CPNI, *Adopting a security-minded approach to Building Management Systems*. Centre for Protection of National Infrastructure Report, 2017.
[82] M. Peacock, and M.N. Johnstone, *"An analysis of security issues in building automation systems". Proc. 12th Aus Info Sec Man Conf., 2014, pp. 100 – 104.*
[83] Ernest and Young, *Big data- Changing the way businesses compete and operate*. Report, 2014 [Online]. Available at: https://www.ey.com/Publication/vwLUAssets/EY_-_Big_data:_changing_the_way_businesses_operate/$FILE/EY-Insights-on-GRC-Big-data.pdf
[84] M. Colas, R. Nambiar, I. Finck, R.R. Singh, and J. Bauvat, *Cracking the Data Conundrum: How successful companies make big data operational*. Capgemini Consulting Report 2014 [Online]. Available at: https://www.capgemini.com/consulting/wpcontent/uploads/sites/30/2017/07/big_data_pov_03-02-15.pdf.
[85] K. Zhou, C. Fu and S. Yang "Big data driven smart energy management: From big data to big insights". *Renew Sustain Energ Rev*, vol. 56, pp. 215-225, April 2016.
[86] P. Chanyagorn, and B. Kungwannarongkun, "ICT Readiness Assessment Model for Public and Private Organizations in Developing Country". *Int. J. Inf. Educ. Technol.*. Vol.1 no.2, pp. 99-106, June 2011.
[87] M. B. Kalema, and M. Mokgadi, "Developing countries organizations' readiness for Big Data analytics". *Probl Perspect Manag.* vol. 15, no.1, pp. 260-270, May 2017.
[88] Juniper Networks, *Introduction to Big Data: Infrastructure and Networking Considerations Leveraging Hadoop-Based Big Data Architectures for a Scalable, High-Performance Analytics Platform*. White paper [online] 2012. Available at: http://www.juniper.net/us/en/local/pdf/whitepapers/2000488-en.pdf.
[89] VansonBourne *The State of Big Data Infrastructure: Benchmarking global Big Data users to drive future performance*. Report 2015.
[90] C. A Ardagna, P. Ceravolo, and E. Damiani, (2016) "Big data analytics as-a-service: Issues and challenges". *IEEE Int Conf Big Data 2016*, pp. 3638-3644.
[91] D. Bertolini, *Maximo Asset Management made simple.* Netexpress USA Inc, 2016.
[92] IPWEA, *International Infrastructure Management Manual*. Australia/New Zealand Edition. Merrill Prentice Hall, Upper Saddle River, NJ, 2002.
[93] A. V. Levitan, and T. C. Redman, "Data as a resource: properties, implications and prescriptions". *"Sloan Management Review",* vol.40, no. 1, pp. 89-101. 1998.
[94] L. Cai, and Y. Zhu, "The Challenges of data quality and data quality assessment in the big data era". *Data Sci J*, vol. 14, no.2, pp. 1-10, May 2015.

[95] J. Han, M. Kamber, and J. Pei, *Data Mining: Concepts and Techniques*. Morgan Kaufmann, 2006.
[96] N. Khan, I. Yaqoob, I. Hashem, Z. Inayat, M.A. Waleed, M. Alam, M. Shiraz, A. Gani, "Big Data: Survey, Technologies, Opportunities, and Challenges". *"The Scientific World Journal",* pp.1-18, July 2014.
[97] Accenture, *Big data analytics in supply chain: Hype or here to stay?* Accenture Global Operation Mega-trend Study, 2014.
[98] H. Simo, *Big Data: Opportunities and Privacy Challenges*. Fraunhofer-Institut für Sichere Informationstechnologie, Darmstadt, Germany, 2015.
[99] K. Brooks, *Career success starts with a "T"*. Psychology Today, 2012 [Online]. Available at: https://www.psychologytoday.com/gb/blog/career-transitions/201204/career-success-starts-t.

Author's Biography

Dr Ashwini Konanahalli is the Programme Leader for MSc Construction Management with Digital Engineering. She was previously a practicing Architect and has worked on several architectural projects in India and Northern Ireland. She has significant experience of securing Knowledge Transfer Partnerships (KTP) in the area of Digitized Built Environment. She was also the PI of RICS Grant on Big Data Analytics for Facilities Management. This report captured 2 years work on how BDA is currently utilized and the opportunities it offers for FM organizations.

Dr Marina Marinelli is a Lecturer in Engineering Management at the University of Leicester, UK. She holds a civil engineering degree and a PhD in Construction management from the National Technical University of Athens (NTUA). Besides Big Data applications in facilities management, her research interests include cost management of construction projects and equipment, Civil infrastructure cost prediction with data mining techniques and Value driven appraisal of projects.

Prof. Lukumon Oyedele is the Assistant Vice-Chancellor for Digital Innovation and Enterprise at the University of the West of England (UWE). Prof. Oyedele has about £19.2 million in research funding from various funding bodies. He has authored 139 papers for peer-reviewed international journals (87) and conferences (52). He has successfully supervised 9 PhD students and 75 Masters Theses. He has served on several academic advisory panels and committees of governments and private organizations in the UK and overseas.