FACILITIES MANAGEMENT DOMAIN REVIEW: POTENTIAL CONTRIBUTIONS TOWARDS DIGITALISATION

Conor Shaw[1,3], Flávia de Andrade Pereira[1,4], Ciaran McNally[2] and James O'Donnell[1,3]
[1]School of Mechanical and Materials Engineering, University College Dublin, Ireland
[2]School of Civil Engineering, University College Dublin, Ireland
[3]UCD Energy Institute, University College Dublin, Ireland
[4]CARTIF Technology Centre, Energy Division, Valladolid, Spain

ABSTRACT

Digitalisation within the facilities management (FM) sector has great potential to positively impact the environmental performance of the architecture, engineering, construction and operations (AECO) industry. Currently, the domain suffers from poor data integration with other disciplines and earlier life-cycle phases. Though solutions which address the interoperability issue are replete in the literature, there remains no comprehensive alignment. This domain review paper synthesises the key literature around digitalisation within FM. In doing so, it outlines a broader working definition of FM, identifies key subtopics and gaps in knowledge and recommends a direction for future research contributions.

INTRODUCTION

According to the International Energy Agency's Global Status Report (2017), buildings and construction together account for around 40% of anthropogenic carbon dioxide (CO_2) emissions. These *greenhouse gases* are having a warming effect and causing the Earth's climate to change to the detriment of society (Intergovernmental Panel on Climate Change 2018).

In recent years it has become broadly understood that in order to more accurately account for financial and environmental impacts of a building project, a whole life view should be taken, referred to as the life-cycle cost (Kale et al. 2016). Until recently the focus has been on reducing these costs primarily during design and construction (Krstić & Marenjak 2012), however, given that around 70% of the costs are incurred during the operation and maintenance (O&M) phase of a buildings life-cycle (Geekiyanage & Ramachandra 2018), the focus is broadly shifting. An example of this thinking can be seen in the structure of public-private partnerships (PPP) whereby the contract for O&M of the asset incentivises consideration of this whole life cost perspective during design (Atkin & Brooks 2015). Geekiyanage & Ramachandra (2018) discuss the significant factors influencing O&M costs, concluding that the greatest influence can be had in the design stage. This was demonstrated by Kohler & Moffatt (2003) who first mapped the stages of a construction project against the familiar graph of diminishing influence on cost over time (Figure 1) from project management theory.

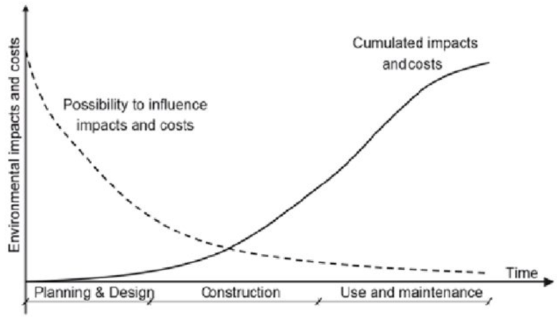

Figure 1: Phases of a building project and the diminishing influence on cost over time (Kohler & Moffatt 2003)

With the increasing complexity of systems within buildings and infrastructure, as well as a trend towards the outsourcing of non-core business activities by organisations, facilities management (FM), only emerging as a formal profession since around the 1960s, is rapidly gaining significance (Sari 2018). In the words of the International Facilities Management Association (2021), FM is a profession which "encompasses multiple disciplines to ensure functionality, comfort, safety and efficiency of the built environment by integrating people, place, process and technology". Despite this ambitious mandate, a regularly cited report by the *National Institute of Standards and Technology* of productivity within the facilities management profession found that two-thirds of waste in the sector could be associated with various degrees of manually retrieving information from poorly managed sources (Gallaher et al. 2004).

It is widely recognised that the construction industry and built environment in general are undergoing a digital transformation from physical document based workflows to digital information based, data driven decision making. Investigating digital disruption within the AECO industry, Lavikka et al. (2018) explain that digitalisation "enables collaborative value creation through new forms of interaction, improved information sharing and transparency among stakeholders". Of particular significance has been the development of building information modelling (BIM) technology and processes which enable the digital, object-oriented modelling of construction activities and products (Sacks et al. 2018). These digital prototypes may be analysed in various ways to more effectively communicate design intent and resolve interdisciplinary conflicts; the process of clash detection, for example, having been shown to reduce errors during construction (Wong et al. 2018, Love et al. 2011). However, Edirisinghe et al. (2017) explain that although BIM is now widely adopted during the design and construction phases, uptake has been limited among professionals involved in operating and maintaining (O&M) built assets, with, according to Gnanarednam & Jayasena (2013), computer aided facilities management (CAFM) processes still based largely on conventional information technology (IT) methods such as tabulated data and 2D drawings.

Given the importance of a whole-life focus, as discussed above, it appears that considerable value may be gained by improving and expanding digitalisation efforts during this later life-cycle phase. Indeed much attention can be seen in this direction over the past decade, both academia and industry showing increasing interest, as reflected in the work of Matarneh et al. (2019) which reports significant growth in the number of publications featuring both the keywords “BIM” and “FM” in their abstract (Figure 2).

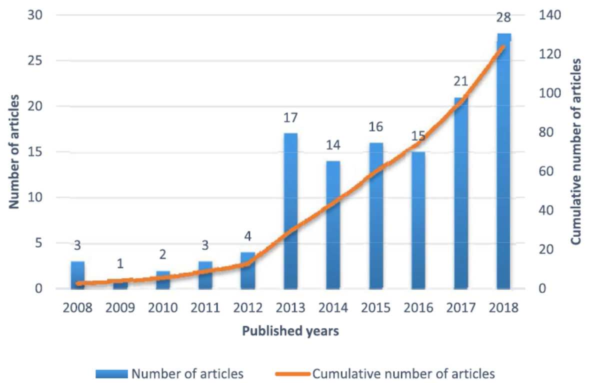

Figure 2: BIM for FM articles published over the last decade (Matarneh et al. 2019)

Unsurprisingly, given the global focus on environmental sustainability in recent years, the greatest concentration of BIM for FM research focuses on *energy management*, while *information exchange* is seen as the greatest challenge to the sector (Gao & Pishdad-Bozorgi 2019). This is because FM services rely largely on information inherited from other disciplines further back along the project life-cycle as well as operational data collected during use.

Many bespoke, standalone and proprietary solutions have been proposed and developed which partially solve these information gaps, however, due in large part to the fragmented nature of the industry as well as the loose definition of the FM domain, there remains a lack of consensus among academics and practitioners concerning the best approach for successful and practical information exchange between BIM and FM systems (Matarneh et al. 2019).

So far we have identified digitalisation as being a key enabler of efficiency within the FM domain, while BIM may provide a centralised repository of multidisciplinary data for use by project stakeholders. Despite this, and according to the authors discussed, data interoperability remains a significant challenge in the effective digitalisation of FM services.

Within this context, this paper aims to firstly outline a working definition and scope for the facilities management domain within which we may orientate the work and identify key related topics and literature. The paper will then synthesise this body of literature, identifying gaps in knowledge as well as promising developments which address domain challenges. Finally, potential contributions will be proposed in the context of a future research project where, ultimately, we wish to facilitate greater environmental efficiency, and to do so for as wide a group as possible within the broad spectrum of those operating and maintaining built assets.

DOMAIN DEFINITION AND SCOPE

The emergence of FM as a formal profession

According to Atkin & Brooks (2015) the origins of FM can be traced to the American railroad companies sometime in the 1800s, where the evolving utility began to be thought of rather as a *facility* than as its comprised buildings and tracks, though it is not until the middle of the last century we see the term actually used. Broadly it can be seen as a development of the role of building maintenance management, though importantly has evolved to encompass the “*softer* side of an organization’s support services” (Atkin & Brooks 2015). Today, the industry is growing rapidly with an increasing trend towards outsourcing of non-core activities (McKinsey & Company 2019), particularly with the aforementioned life-cycle view taking precedence and a redoubling of focus on energy efficiency, reflecting perhaps growing acceptance of climate science (Pew Research Center 2019).

This formalisation has led to the establishments of professional institutions around the world as well as international standards for the FM domain including ISO 41001:2018 (Facility Management - Management systems) and the ISO 19650 series (the recent *Part 3: Operational phase of the asset* geared specifically towards FM practitioners). Among other benefits, international standardisation reduces the need for customisation between projects and societies by serving as a common language which defines standardised requirements and can streamline data exchange (Gao & Pishdad-Bozorgi 2019). However, despite the establishment of certain conventions by ISO and others, the definition of effective exchange requirements remains incomplete, as will be discussed throughout.

Defining a working definition of FM

Reflecting the broad scope and case specificity of the evolving domain, varying definitions are provided in the literature, the subject itself having become the focus of multiple academic studies including the work of Tay & Ooi (2001) and Nor & Azman (2014). The International Organization for Standardization (*41011:2017 FM - Vocabulary*) defines facilities management 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". The International Facilities Management Association (2021) provide a similar definition adding that such organisations, by nature, are composed of multiple disciplines. In the words of Nor & Azman (2014) "it remains a contentious issue and definitions depend on the local culture, organization's interest and people's personal interest".

With this in mind, and with general consensus at least in principle, the definition which best encompasses the objectives of this review is provided by Barrett & Baldry (2003) who define FM as "an integrated approach to operating, maintaining, improving and adapting the buildings and infrastructure of an organization in order to create an environment that strongly supports the primary objectives of that organization". The reason for selecting this definition being that it abstracts away from the majority of interpretations which put a focus on FM services supporting the core-*business* of organisations, allowing us to take a broader view to include non-commercial or informal O&M activities.

The diversity of FM services

As we've seen in the divergence of opinions in defining the domain, the diversity of activities which may be encompassed by an FM service is extensive. The following non-exhaustive list, adapted from Gao & Pishdad-Bozorgi (2019), provides a general picture of the range of activities for which FM may be responsible within an organisation.

- maintenance, repair and renovation
- energy management / energy planning
- security
- health and safety / fire safety
- cleaning and waste management
- IT management
- catering
- outsourcing / supply chain management

Ultimately it is case specific and, as stated above, will include activities which support the objectives of that organisation; but this diversity of competences offers an indication of the reason standardisation poses such a challenge particularly within this domain.

Data requirements for managing a built asset

FM data may include anything from building plans, to time-series sensor data, or from archival energy metre readings to occupancy information for fire safety. As in the case of possible FM activities, the list is theoretically endless. Something that can be comprehensively agreed by academics and practitioners is that effective O&M is reliant on well organised, good quality and validated data. Furthermore, as discussed previously, a significant proportion of this information is inherited from other disciplines, from earlier phases of the project life-cycle, and often with little or no consultation on the part of the end user.

From an industry practitioners' perspective 85% of FM teams surveyed in a study by Liu & Issa (2013) considered the information they had received from earlier phases to be inadequate for effective O&M. A number of strategies have emerged which address this issue of providing useful FM data. The Construction Operations Building information exchange (COBie) standard, developed in recent years, has been widely lauded as the solution. It organises asset information data, collected throughout design and construction, into standardised tabular form to be conveyed to CAFM systems. Yet according to Pärn et al. (2017) "whilst some academics expound the virtues of COBie, anecdotal evidence suggests that this *one shoe fits all* approach is not well received by practitioners – indeed, the general consensus appears to suggest that there is little value in collecting data for the sake of such". Rogage & Greenwood (2020) suggest an alternative to bypass COBie, however maintaining consistency with the data, though technical in nature, is found to be significantly undermined by variation in practitioner approach, as well as human error.

Another challenge during O&M is the integration of disparate data types from mechanical, electrical and plumbing systems, again, the FM team often familiarising with the situation post occupancy. The development of building automation system (BAS) protocols which integrate smart devices, establishing an internet of things (IoT) with BIM as a data repository, is another area receiving much attention in the literature as reflected in the domain review by Tang et al. (2019).

RESEARCH OUTLOOK

This section examines firstly the landscape of the state of the art in digitalisation within the FM domain. It focuses particularly on domain reviews, summarising areas which are receiving much academic attention and identifying others which are covered less thoroughly. It then focuses on particular challenges faced by current researchers and describes promising developments within these areas in the interest of identifying gaps in knowledge and opportunities for future contributions.

Current research landscape

In their analysis of AECO publications based on a parametric search of the keywords "BIM" and "FM", Yalcinkaya & Singh (2014) identify the generic term "information exchange" as the single greatest common topic of interest. This assertion is more recently confirmed by Matarneh et al. (2019) using a similar *keyword clustering* approach, resulting in the synonymous "information management" which in their study included "information exchange" in the grouping process. More specifically, Gao & Pishdad-Bozorgi (2019) identify the *nature* of said "information" which is of greatest interest among researchers as that relating to "energy management".

This finding aligns with recent proliferation in use of the term "Digital Twin", a topic which has become perhaps the most significant buzzword in academic and popular literature since "BIM" itself around a decade ago (and leading to similar contention as debate continues over an absolute definition). Regularly misappropriated as being synonymous with "3D building models" (Sacks et al. 2020), a key characteristic agreed by authorities on the subject is that a Digital Twin must incorporate a live stream of data between the physical and digital representation of the asset (Rosen et al. 2015).

A domain review by Fuller et al. (2020) attests to the upsurge in interest from academia and industry alike in recent years. Receiving attention from almost all sectors of the built environment, the topic has become an important area of focus, particularly for the FM domain, the utilisation of the technology being restricted to the O&M phase (Khajavi et al. 2019). With this primary focus on information and data flow there is a growing trend towards the exploration and application of traditionally computer science related topics as the domain strives to bridge the digital divide between itself and the cyber and physical worlds of other actors.

The authors are in agreement on the prevalence of "maintenance and repair" generally as a topic within the FM literature, however cited sources diverge significantly in reporting on research around "health and safety management", Gao & Pishdad-Bozorgi (2019) reporting growing interest while Matarneh et al. (2019) communicate stagnation on the topic. The following is a non-exhaustive list of other areas of note within the FM research, for which interest remains limited. These include:

- standardisation and domain definition;
- engagement of FM in early design;
- security and emergency management;
- education and training of FM professionals; and
- renovation and retrofit.

Having previously identified the growing focus on energy efficiency, and given that our existing building stock performs so poorly in this regard leading to widespread policy moves towards extensive deep retrofit (UN Environment and International Energy Agency 2017) it would seem counter-intuitive that the topic of renovation should receive such limited attention, however it is not wholly unexpected. A similar phenomenon may be observed throughout the AECO literature more broadly, Volk et al. (2014) illustrating the rationale for research to focus on "recently completed buildings with a BIM at hand rather than on existing buildings without a BIM".

There are however, two areas within the literature where retrofit features as a subtopic. Firstly, and almost in direct response to the trend described above, with regard to *data capture*. Research in this direction tends to focus on investigating the benefits and limitations of using different techniques to develop as-built geometrical models (Matarneh et al. 2019) as opposed to expounding fundamentally on the renovation topic itself. Secondly, in connection with work around *energy performance and simulation*, often in comparing retrofit alternatives. Given the above, it would appear there is a growing need for research in this area, particularly with regard to the role of FM, who are tasked with operating buildings in an energy efficient manner. However, there exists a clear disincentive to embark on the complex topic as a researcher, that is the inherent absence of available models describing the existing situation.

Challenge in defining and standardising the domain

As discussed previously, the industry has yet to arrive at an agreed definition of the FM domain. We have also seen the diversity in activities and resulting information requirement which may fall within the FM remit. And though various international and industry standards have been established to guide aspects of the domain, Pärn et al. (2017) providing a useful timeline of BIM-FM standardisation (predates the ISO 19650 series), the organisation specificity and diversity within the field makes an all-encompassing, yet not over-general, standard challenging (Gao & Pishdad-Bozorgi 2019). Yalcinkaya & Singh (2014) suggest that a more appropriate focus may be to develop an understanding of the unique dynamics of organisations. They suggest an *Agile* approach to technology adoption on an *as-required* basis, rather than fitting organisational FM processes to an ever changing technology landscape which would result in a "continuous effort of adaptation".

What *has* been well defined recently in international standards is guidance on the contractual organisation of project teams, including FM teams, in the ISO 19650 series. The set of documents establishes roles to be used in procurement contracts such as: "appointing party" (meaning the employer), "appointed parties" (meaning contractors) as well as defining terms such as "project information model" (PIM) and "asset information model" (AIM) and specifying at which stage of a project each is to be used. Consensus on such definitions is helpful in areas such as: establishing claims to intellectual property, enabling access to *common data environments* and clarifying legal obligations and organisational hierarchies (UK BIM Alliance 2020).

Furthermore, the ISO 19650 series establishes a requirement for delivering project information in the open data format Industry Foundation Class (IFC). This standard (as defined in ISO 16739), developed by BuildingSMART International along with a wide consortium of industry, academic and intergovernmental stakeholders, aims to ensure the sustainability and transparency of built environment information by ensuring delivery in a non-proprietary, commercially neutral format (buildingSMART 2020). Although this does much for facilitating equity in participation and simplifying contract deliverables, steady bidirectional exchange is not consistent between software packages. According to Huahui & Deng (2018) this derives from "differences in domain knowledge" and is because "software tools have diverse methods to represent the same geometry, properties and relations", the cause due to erroneous semantic interpretations. This is a challenge which is increasingly being approached using computer science based methodologies.

Challenge in data acquisition and interoperability

Sacks et al. (2018) explain that construction projects require intense collaboration between large groups of independent stakeholders, each generating information about the product and the process, typically using different digital tools with multiple data formats which are generally incompatible. Both the industry and academic literature are replete with solutions which address this interoperability challenge from various angles, but as Dimyadi et al. (2016) explain, "none has yet evolved into a practical solution". One reason that endeavours up to now have been unsuccessful, they suggest, is that "they have all been isolated attempts which lack any form of industry-wide standardisation", leading the authors to focus on the use of the open format IFC, as discussed above. Their proposed solution, however, follows a relatively recent trend in this area of development towards computer science based methodologies, namely cloud enabled Semantic Web technologies. These are identified by Santos et al. (2017) in their extensive BIM domain review, as both an emerging topic and as having significant potential, due to their suitability to decentralised contexts.

Niknam & Karshenas (2017) explain that "the Semantic Web is designed to solve the information integration problem by creating a web of structured and connected data that can be processed by machines. It allows for combining information from different sources with different underlying schemas distributed over the Internet". In other words, information is stored *once* only, where it is generated, and access is provided via a unique web address, or *uniform resource identifiers* (URI). In addressing the interoperability challenge Pauwels et al. (2017) illustrate that "with the Semantic Web and Linked Data efforts [...] the building domain has the opportunity to address these needs using established technologies", highlighting a crucial aspect of any general approach, making use of available technology to enable the widest possible adoption.

However, as authorities on the subject with their seminal review *Semantic Web Technologies in AEC industry: A Literature Overview*, Pauwels, Zhang & Lee (2017) also recognise that there is yet to be a single solution proposed which fully solves the challenge, recommending that the *Information Delivery Manual* (IDM) and *Model View Definition* (MVD) methodologies of BuildingSMART are, at present, most fit for purpose. However, the authors conclude that Semantic Web technologies could be effectively employed for defining and sharing IDM and MVD exchange requirements between stakeholders, an approach demonstrated by Lee et al. (2016). According to key authors in this field, the main barriers impeding wider utilisation of Semantic Web technologies include: the need for optimisation of data formats (given the inherent and unwieldy amounts of data involved in construction projects) as well as maintaining URI links over time (Pauwels, Krijnen, Terkaj & Beetz 2017, Pauwels, Zhang & Lee 2017, Krijnen & Beetz 2020).

We have seen that web-based strategies are being explored as a promising approach to connect disparate data, a significant feature of digital FM whereby the trajectory is towards a live link of physical information to a digital data pool, or *Digital Twin*, utilising advances in IoT technology. However, while technical solutions are being scrutinised in the literature, there exist fundamental and systemic issues within the industry which pose a challenge of perhaps equal significance for digitalisation within the FM domain. That challenge is the point in time at which FM teams become involved in the construction process.

Challenge to enable early FM involvement in projects

According to McAuley & Lefebvre (2019) in their work on *early contractor involvement* in construction projects, given that Integrated Project Delivery (IPD) and other collaborative forms of contractual arrangement are most conducive to bringing about the benefits of the BIM methodology, stakeholders are unlikely to realise the true advantages by holding to traditional methods of lowest bid procurement strategies. But still, despite ample precedence in the US, the UK, Finland and Australia, in most parts of the world such collaborative contract types are not the cultural or contractual norm. In a related work, McAuley (2016) demonstrates the potential benefits of early FM involvement in public works projects. The author prescribes the use of such aforementioned collaborative contract types and determines the development of conditions which enable early FM involvement, as being fundamental to ensuring efficiently operating public sector buildings in the future. Liu & R.A. Issa (2014) found, in their study from the FM perspective, that during the design phase, participants in a BIM project tended to focus predominantly on clash detection and ignore future maintenance issues. Pärn et al. (2017) agree, urging that considerations of actual operational issues should not be limited to the post occupancy phase. They propose a holistic "knowledge based feedback loop" and involvement of FM teams during the early stages of design, throughout construction and to commissioning.

It appears to be a widely held view among authors in the domain that a significant barrier to effective digital O&M is the delayed inclusion of FM professionals within the design and construction process. Furthermore, utilising emerging collaborative contract types such as IPD may facilitate this new paradigm, precedence for which is currently available in a number of countries. According to the authors, such arrangements provide optimal conditions to realise the benefits of the BIM methodology and so it would appear that, though the technical challenges are considerable, contractual and social obstacles play perhaps an equally important role.

DISCUSSION OF CONTRIBUTION

It is clear that agreement on an absolute and all-encompassing definition of the FM discipline poses a perhaps unattainable (or even misguided) challenge. Nevertheless, further work in decomposing the domain will facilitate the development of more clearly defined data exchange requirements, assisting in the advance towards seamless interoperabilty which is the key obstacle to progressing digitalisation. In the absence of viable top-down technocratic standardisation, the emergence of which until now has been gradual, promising developments in interoperability are currently emerging from the discipline of computer science, namely Semantic Web technologies.

Though authors in this field acknowledge that the solution is incomplete, they recommend that research in this direction will be worth the effort as it promises a common, practical approach using existing technology (Pauwels et al. 2017). Farghaly et al. (2018) provide a detailed approach for developing a taxonomy of O&M exchange requirements while Lee et al. (2016) offer a similar ontological approach to a related problem. By adapting these methodologies, significant benefits for further understanding the FM domain are likely, Pauwels, Zhang & Lee (2017) explaining that "the main contribution of building an ontology is an improved understanding of the actual domain of discourse". The potential for Semantic Web methodologies to address the interdisciplinary data exchange issue is considerable whereby we consider an ability to link and *comprehend* heterogeneous information garnered from various perspectives. This may result in new knowledge or understanding by means of logical reasoning, drawing from domain-specific data types which may be otherwise incompatible.

A particular definition of the FM domain was selected at the outset of this paper for the purpose of encapsulating a broad scope of stakeholders. Rather than limiting the scope of facilities management activities solely to a commercial context, it is the intention that future contributions towards a digitised semantic knowledge for the domain enable a wider societal participation. Whether formally or informally carrying out FM related activities, those who reduce the negative impacts of operating and maintaining buildings, do so to the benefit of the wider built and natural environment, and thus, should have the means to avail of, or contribute to, this proposed collection of knowledge.

CONCLUSIONS

Through the synthesis of domain reviews, various under-researched FM activities have been identified, including *renovation*. Due to increasing environmental concerns globally, improving the thermal performance of our aging building stock through energy retrofit poses great potential for carbon emissions reduction and FMs, as the operators of buildings, can play a significant role here. Early FM involvement in construction projects, enabled by already existing collaborative contract forms such as IPD, is identified in the literature as being essential to realising the benefits of the BIM methodology, as it is during this earliest stage when the greatest influence may be had on the later operation of the asset. Such conditions require addressing both the contractual as well as technical challenges.

Despite growing digital capabilities among practitioners, interoperability across disciplinary software remains the greatest technical barrier to exploiting the proven efficiency resulting from digitalisation. Semantic Web technologies are an emerging approach to address this issue. Currently no one solution is agreed, but as top-down technocratic standardisation remains gradual, the approach is gaining interest among researchers in the field as one that is practical and makes use of currently available technology. Developing a semantic taxonomy, based on a specific use case within FM as a consensus process, is a direction for future work towards a common FM ontology.

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