BRIDGING BUILDING OPERATION AND MAINTENANCE REQUIREMENTS IN ARCHITECTURAL DESIGN PRACTICE THROUGH BUILDING INFORMATION MODELLING

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ABSTRACT

While considering Facilities Management (FM) at the early design stage could potentially reduce the efforts for maintenance during the operational phase of buildings, few efforts in the construction industry have integrated FM into the design phase. Thus, this study assesses the readiness of Architects to adopt BIM towards providing FM information for enhancing operation and maintenance of buildings. A case study of the COBie extension of Revit Architecture 2015 was used to extract some information subsequently used to design a structured questionnaire. Data was fetched from 54 Architecture firms in Kaduna. The readiness of Architectural firms' to providing FM information for BIM towards facilitating effective operation and maintenance based on the extracted features or components (in Revit architecture) was assessed. The readiness assessments result shows that all information required extracted from COBie extension are significant (with Relative Index; RI of all factors studied > 0.44) towards facilitating effective operation and maintenance in FM. Furthermore, while the potential benefits of providing FM information using BIM from early design stage has high significance in facilitating effective FM operations, the barriers of providing FM information using BIM from early design stage also has significance in facilitating effective FM operations. However, although results show that both benefits and barriers have significance, the significance of the benefits outweigh that of the barriers (RI for all factors > 0.75). The study concludes that, a holistic integration of players in building project delivery at an early stage of the design process may enhance the fragmented nature of collaboration and enhance effective FM during operations and maintenance of buildings.

Keywords: Architectural design, Building Information Modelling, Facilities Management and Operation and maintenance.

INTRODUCTION

In order to achieve accurate operation and maintenance of buildings, timely and accurate information is needed to sustain decision-making. Obtaining accurate information however demands pertinent questions to be asked. What needs to be done to effectively operate and maintain a building and/or facility? How should it be done? Achieving the right answers to these questions (among others questions) is dependent on information generated during the planning, design, and construction stages of the building or facility. A source of information aiding effective FM according to Goedart and Meadati (2008) are the as-built drawings documents usually provided when construction is completed in the form of printed or scanned documents. These documents having the final versions of the building design reflecting the current state of the facility include: as-built drawings; operation & maintenance (O&M) manuals; specifications of the installed equipment with serial numbers, make, model among other documents.

Keeping any facility operating at its best efficiency warrants an effective Facilities Management practice which is sometimes enormous. Facilities Management (FM) has been defined as 'a process that encompasses multiple disciplines to ensure functionality of the built environment by integrating people, place, process and technology' (IFMA, 2006). Operation and maintenance, while being one among several core competency areas of FM as outlined by International Facility Management Association (IFMA) is undoubtedly often the longest and most expensive phase in a facility lifecycle. It accounts for approximately three times the cost of construction (Fuller 2010; Pavic, 2010; Abbas, 2013). A tool used for achieving effective FM is Building Information Modelling (BIM) which is a management approach to the collection and exploitation of information across a project. Central to BIM is a 3D computer model that contains graphical and non-graphical information about design, construction and operation of an asset. The digital toolset enables projects to be designed and built several times virtually, rehearsing and optimising an assets lifecycle and eliminating errors, waste and inefficiency (Philip, 2012). The major difference with older building design and operation tools and BIM is that BIM assists designers to develop a computer-interpretable digital model of a facility that contains stored/retrievable data about the facility; which is termed as the 'information model' (Nederveen, Beheshetiand Gielingh. 2010).

Few efforts in the construction industry have been made to involve FM in the design stage of using BIM. Architectural firms have a vital responsibility towards improving efficiency in the FM industry by developing accurate designs that will bring about quality, efficient and sustainable buildings while using BIM tools as a platform (Cottset al. 2010). Mohammed and Hassanain (2010) argue that, direct involvement of Facilities Managers in the design stage has the potential to reduce maintainability problems during the operation phase of the facility. Moreover, the involvement of Facilities Managers in the integrated design process will contribute to reduction of design errors leading to major repairs, and alterations of facility during operations. While there exist large applications of BIM in design, Eastman et al, (2011) and also Kubba (2012) stress that few practitioners infuse information enabling the effective operation and maintenance of buildings at the early design stage. The study attempts to identify and assess the requisite information required for effective FM in the operation and maintenance stage of buildings in Architectural design practice through the concept of BIM. It is hoped that, results would improve synergy surrounding the linkages between the FM practice and Architectural design in sustainable BIM practice.

LITERATURE

The advent and increased awareness of using BIM in the building industry has triggered so many researches on relevance of information related to its use and implementation. There are numerous case studies that provide unabridged evidence to support the idea that the use of BIM makes the building process more efficient and effective (Eastman, Teicholz, Sacks and Liston, 2011). It was reported that the BIM benefits of providing FM information with the most value to a project included; Life cycle cost reduction, easy integration with operation and management systems, customer satisfaction and optimized management and operation of facilities. Additional benefits include: improved sharing, exchange and communication of information, increased collaboration in design, construction and operation of buildings, more accurate analysis such as sustainability, energy modelling, and air-flow, amongst others. However, the benefits of BIM can only be realised upon proper implementation by an organisation (Bew and Underwood, 2010; Eastman et al. 2011; Khosrowshashi and Arayici, 2012).

While FM in its early days primarily covered cleaning, upkeep and repairs, FM has evolved to address variety of functions within an organisation. This latter scope of FM is confirmed from its definition by British Institute of Facilities Management (2000) defines FM as the integration of multi-disciplinary activities within the built environment and the management of their impact upon people and the workplace. Similarly, FM is defined 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 theprimary objectives of that organization" (Atkin and Brooks, 2009).

Access to information is a key elementrequired by a Facilities Manager to aid informed decisions in FM. Similarly, a Facilities Manager ought to posess the skill to read the building and how it is performing over time and benchmark the performance of buildings to other buildings. FacilitiesManagersneed to be able to understand what type of building is being managing, what systems are in place, what components and where they are in the facility manuals and warranties. It is equally important that a Facilities Manager understands the information not needed and is able to exclude information that has no valuein operating and managing the facilities (Gudmundur, 2014). Therefore, a clear definition and a detailed analysis of what information should be captured in the design-build phase needs to be comprehended by a Facilities Manager.

For each project, there is a common data set that will apply for all buildings. Table 1 shows the basic information needed for facilities, from what phase and from what discipline it comes from. This information are documented in the as-built drawing and other relevant reports.

Table 1: Design information required from different Professions

Design Phase	Information	Profession
Pre-design	Information on buildings energy performance, quantities, sizes, and spatial information. Information can be used for LCC analysis and design comparison.	Architect
Design	Rooms: Spatial information, floor, wall and ceiling information. Component requirement and so on, Zoningfor examples fire, access and so on. Construction codes	Architect
	Spaces: Energy analysis, requirements of MEP components.	Services Engineers
	Zones: Different HVAC zones registered	
	Structural requirements	Structural Engineer
Construction	As-built information, materials, manufacturers, installation dates, warranties, production information, spare part list, suppliers and manufacturer's instructions.	Contractor
	Components placement, as-built design.	Architect
	As-built MEP system placement.	Services Engineers

Source: Gudmundur (2014)

The as-built drawing and other supporting documents reports all checks and inspections made after the installation of the systems, reports of starting-up and shutting-down the systems of the facility, and warranties & guarantees of the systems installed in the facility.Gathering, organizing and entering this information into the facilities FM computer maintenance system for a typical building can be labour intensive and, to some extent an error-prone process with no additional value for the management of the facility (Gallaher, 2004).

According to De Silva (2011), Facilities Managers can contribute significantly in the delivery of effective decisions based on their practical experience on maintainability problems that they face during the operation phase. For this reason, it is vital to integrate FM information in the early design phase to bring attention to future maintainability issues in design. The 2D as-built drawings for example, are proved to be inefficient during operations phase. Bringing the operation stage in design can definitely bridge the existing gap of BIM application beyond design and construction.

The Royal Institute of British Architects (RIBA) defines BIM as a "digital representation of physical and functional characteristics of a facility creating a shared knowledge resource for information, forming a reliable basis for decisions during its lifecycle, from earliest conception to demolition" (RIBA, 2013).

Essentially, it reveals that BIM supports the retrieval of data from a single database. The data about a building project in a BIM model includes information that can be used to provide assistance in the analysis of design alternatives, construction, management and operation of the facility, such as; quantities and material properties can be easily extracted and used to perform several building analysis, high quality construction documents, fabrication details, construction planning and visualisation sequence, schedules, rapid development of cost estimates, energy performance and building maintenance amongst others (Cetiner, 2010).
Moreover, BIM provides the prospects for a virtual information model to be transferred from the design team (architects, engineers, consultants and others), to contractor and subcontractors (Builder and his craftsmen) and finally to the owner and Facilities Managers with each stakeholder contributing their own additional discipline specific information and tracking of changes to the single model (Bew and Underwood, 2008; Cetiner, 2010; RIBA, 2013).

Construction Operations Building Information Exchange (COBie) approach was developed as an organizational solution to address the lack of standardizationand organization of the several documents that are handed over to the owner at the end of theconstruction stage. The COBie approach is to enter the data in a pre-specified format as it is created during design, construction, and commissioning (East, 2007). The COBie deals with operations and maintenance (O&M), as well as more general FM information. It collects data from designers, as they guidedesign, and contractors build. It categorizes and structures the information in a practical and easyto implement manner (East, 2007). COBie is asubset of theIndustry Foundation Classes (IFC), andit can beproduced from an IFCmodel thatcontainsthe information needed to create the COBie model, alternatively the COBie model can be populated by manual methods using the spreadsheet representation of the model (Malleson, Stefan and Stephan, 2012).

METHODOLOGY

This research uses two techniques of data collection. The first technique involves a case study whereby a 3D model of a residential duplex is generated using COBie extension of Revit Architecture 2015 to extract information needed to aid effective FM of buildings during the operations and maintenance stage. This technique of information extraction is based on the three (3) stages described below:

Stage 1; Revit Architecture was used to extract the requisite information of major building elements needed during the Architectural design. The COBieschedule was also used in adjusting the schedules to meet the basic requirements of additional parameters. The attributes section of the extension is as shown in Plate I

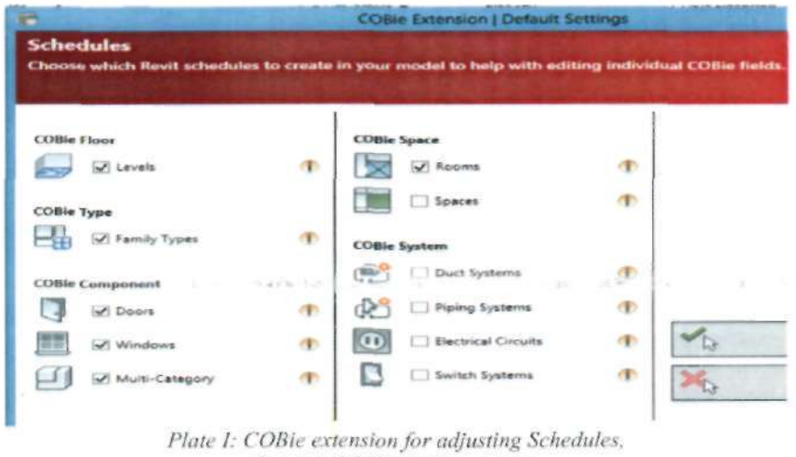


Plate I: COBie extension for adjusting Schedules.
Source: COBie Revit extension

Stage 2; These parameters are intended to carry information about individual objects within the projectused by architects for designing and managing information about occupied areas within the building. Architectural objects within the model are linked to the rooms like windows, doors and furniture. While the zone manager was used in creating different zones within the buildingwhichallowscreating multiple zones depending on their function e.g. fire compacts and access routes as shown in Plate II.

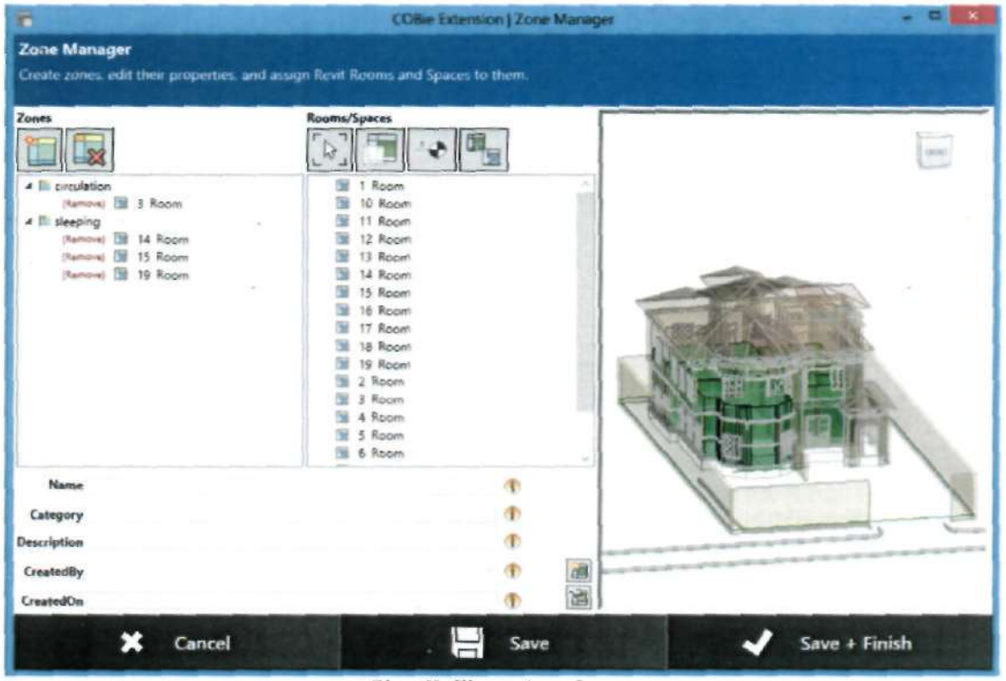


Plate II: Illustration of zone manager.
Source: COBie Revit extension

Stage 3: This involves extraction of major building elements and/or component information produced at the end of the BIM design stage necessary for effective FM in the operation and maintenance of buildings. The major building element's parameters information necessary were extracted (refer to Table A1 in Appendix). Afterwards, this extracted information were refined (refer to Table A2 in Appendix) and subsequently used in the design of the questionnaire. Plate III is a pictorial representation. Thus, the general information extracted using the COBie from the case study is presented in Table A1 and theselected information from the COBie for this studyis also presented in Table A2(all in the Appendix) together with thevisual representation of the residential duplex building used as a case study in Plate A1 (also in the Appendix).

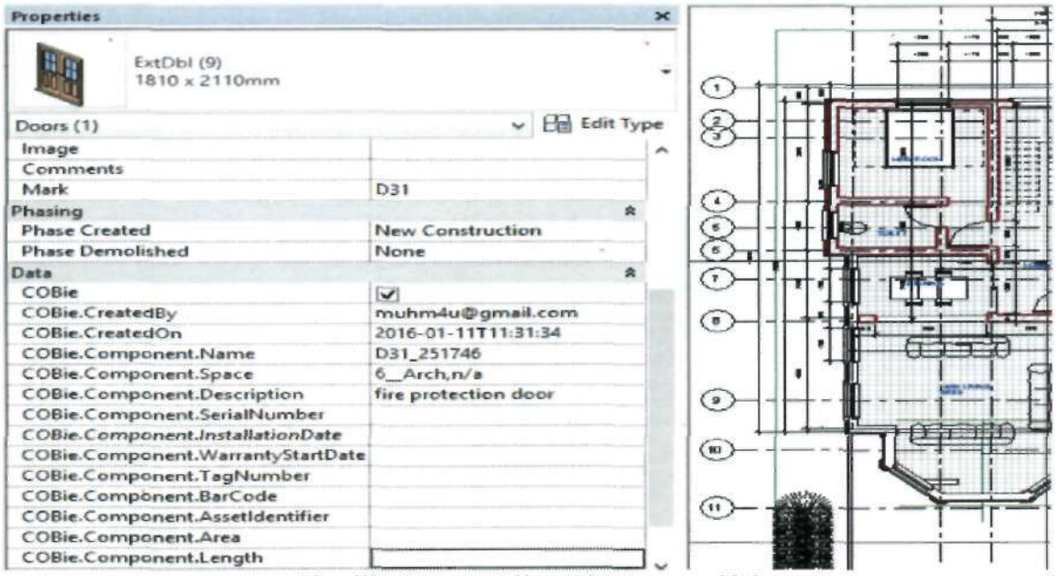


Plate III: Illustration of how information is added
Source: COBie Revit extension

The second technique is a survey using a structured questionnaire designed using data obtained in the case study. The questionnaire seeks for valued opinions of Architects onrequisite information that will enable effective FM in operations and maintenance of buildings yet, enhance BIM. The study area covered in the survey is Kaduna-Nigeria. In the view of the fact that all the Architectural firms cannot be studied, the sample size is limited to Architectural firms registered with the Nigerian Institute of Architects (NIA) located within Kaduna State.Making use of Yamane (1967)'s formula for calculating sample size as given in equation 1 a sample size was computed.

$$n = \frac{N}{1+N(e)^2} = 54 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where;
n = required sample size
N = the population size (62)
e = level of precision (0.050)

A total of 54 questionnaires were distributed to Nigerian Institute of Architects (NIA) registered Architectural firms operating within Kaduna state using judgemental sampling. Furthermore, opinions sought were that of Architects.The readiness of Architectural firms' to providing FM information for BIM towards facilitating effective operation and maintenance based on the extracted features or components (in Revit architecture) was assessed. The choice of such non-probability sampling is informed by the claim of Fellows & Liu (2008) where they recommend its use when a researcher intends to use some informed judgement to determine the population and or sample of a study. Similarly, Saunders, Lewis, & Thornhill (2009) recommend judgemental sampling when a researcher wish to select respondents that are particularly informative in fulfilling the research objectives. Furthermore, Kumar (2011) recommend the use of judgemental sampling if a research seeks to use experts in a field of inquiry. A five point Likert scale is used to assess the readiness of Architects to provide the requisite information that will enable effective FM in the operations and maintenance of buildings. Other assessments are on

the benefits and barriers to providing FM information as using BIM towards effective operations and maintenance in FM.

Relative Index (RI) was used to analyse the data obtained as given in equation 2. Specific to construction management researchers however, Aigbavboa, Liphadzi & Thwala (2014) and also (Sodangi et al. 2014) not only encouraged the use of RI in construction management researches, but also hold the opinion that the use of RI is suitable for analysing data consisting of Likert items (as used in this research).

The RI is computed using the equation by Holt (2014) and also Muhwezi, Acai, & Otim (2014) as shown in equation 2.

$$\text{Relative Index (RI)} = \frac{\sum fx}{\sum f} \times \frac{1}{k} \qquad \text{----------(2)}$$

Where:

$\sum fx$ = is the total weight given to each attributes by the respondents
$\sum f$ = frequency of the respondents choice on each point on the scale
K = maximum point on the Likert scale (in this case k=5)

While ranking of the items under consideration was based on their RI values, The Interpretation of the Relative Index (RI) values is as follows:

RI $\leq$0.44, assessed to have no significance
0.45 $\leq$ RI $\leq$0.66, assessed to have fair significance.
0.67 $\leq$ RI $\leq$0.75, assessed to be have significance.
RI $\geq$ 0.75 assessed to have high significance.

RESULTS AND DISCUSSION

Although a total of 54 questionnaires were distributed, only 39 were retrieved and used for analysis. Results are as presented in Table 2 to Table 5 based on different categories. The results in Table 2 depict the Architectural firm's readiness to provide floor related information that will enable effective FM at operations and maintenance stage of the building.

Table 2: Readiness to provide Floors related information

SN	Information Required	Frequency					Σf	Σfx	RI	Rank
		1	2	3	4	5				
1	Floor finish material	5	6	14	15	9	39	164	0.84	1st
2	Spatial description	6	12	8	4	9	39	136	0.70	2nd
3	Structural element	5	7	8	8	11	39	130	0.66	3rd
4	Manufacturer	11	10	6	5	7	39	104	0.54	4th
5	Roughness	11	13	7	6	2	39	86	0.44	5th

1= Never, 2= rarely,3= occasionally, 4= frequently, 5= very frequently

Results in Table 2 shows that the readiness of Architects to provide 'floor finished material' information has high significance (for RI $\geq$0.75) towards facilitating effective operation and maintenance in FM. Also, the readiness of Architects to provide 'spatial description' information for floors have significance (0.67 $\leq$ RI <0.75) towards facilitating effective operation and maintenance in FM. Furthermore, the readiness of Architects in consideringfloor as a structural element and also considerations of the manufacturers of floor (finishes) have fair significance (0.45 $\leq$ RI $\leq$0.66) towards facilitating effective operation and maintenance in FM. Finally, the readiness of Architects in considering roughness has no significance (RI $\leq$ 0.44) towards facilitating effective operation and maintenance in FM.

Table 3: Readiness to provide walls/ partitions related information

SN	Information Required	Frequency					Σf	Σfx	RI	Rank
		1	2	3	4	5				
1	Spatial description	3	6	4	15	12	39	147	0.76	1st
2	Finish material	4	6	7	13	9	39	134	0.68	2nd
3	Structural element	8	9	5	11	6	39	115	0.58	3rd
4	Manufacturer	7	10	9	8	5	39	111	0.56	4th

1= Never, 2= rarely, 3= occasionally, 4= frequently, 5= very frequently

Results in Table 3 shows that the readiness of Architects to provide information on the spatial description of wall/partition has high significance (for RI ≥0.75) towards facilitating effective operation and maintenance in FM. Also, the readiness of Architects to provide 'finish materials' information for wall/partition have significance (0.67 ≤ RI <0.75) towards facilitating effective operation and maintenance in FM. Furthermore, the readiness of Architects in considering wall/partition as a structural element and also considerations of the manufacturers of wall/partition (finishes) have fair significance (0.45 ≤ RI ≤0.66) towards facilitating effective operation and maintenance in FM.

Table 4: Readiness to provide Doors, Windows and curtain panels related information

SN	Information Required	Frequency					Σf	Σfx	RI	Rank
		1	2	3	4	5				
1	Spatial description	9	13	2	3	12	39	113	0.58	1st
2	Frame/panel/architrave material	12	10	9	4	6	39	105	0.54	2nd
3	Finish material	8	15	5	4	7	39	104	0.52	3rd
4	Ironmongery and other accessories	11	13	5	6	4	39	96	0.50	4th
5	Manufacturer	15	11	4	7	2	39	91	0.46	5th

1= Never, 2= rarely,3= occasionally, 4= frequently, 5= very frequently

Results in Table 4 shows that the readiness of Architects to provide information in all five information required studied have fair significance (0.45 ≤ RI ≤0.66) towards facilitating effective operation and maintenance in FM.

Table 5: Readiness to provide ceiling and roof system information

SN	Information Required	Frequency					Σf	Σfx	RI	Rank
		1	2	3	4	5				
1	Finish material and accessories	11	12	4	3	9	39	104	0.54	1st
2	Spatial description	10	14	2	5	8	39	100	0.52	2nd
3	Manufacturer	12	9	5	8	5	39	102	0.52	2nd
4	Roof trusses	9	13	5	5	7	39	100	0.52	2nd

1= Never, 2= rarely, 3= occasionally, 4= frequently, 5= very frequently

Results in Table 5 shows that the readiness of Architects to provide information in all four information required studied have fair significance ($0.45 \leq RI \leq 0.66$) towards facilitating effective operation and maintenance in FM.
Table 6 depicts results of Architects response on potential benefits of providing information using BIM that will facilitate effective operation and maintenance in FM.

Table 6: Potential benefits of providing FM information using BIM

S/N	Benefits	Frequency					Σf	Σfx	RI	Rank
		1	2	3	4	5				
1	Life cycle cost reduction	0	0	3	17	19	39	172	0.88	1st
2	Optimized operation of facilities	0	0	6	15	18	39	168	0.86	2nd
3	Customer/client satisfaction	0	0	5	22	12	39	163	0.84	3rd
4	Easy integration of operation systems	0	2	5	21	11	39	158	0.82	4th
5	Increased building performance	0	6	9	12	12	39	147	0.76	5th

1= Never, 2= rarely, 3= occasionally, 4= frequently, 5= very frequently

All five potential benefits to providing FM information using BIM studied have high significance (for $RI \geq 0.75$) towards facilitating effective operation and maintenance in FM.

Table 7: Barriers to providing FM information using BIM

S/N	Barriers	Frequency					Σf	Σfx	RI	Rank
		1	2	3	4	5				
1	Lack of collaboration of FMs and Architects	0	0	17	13	9	39	148	0.76	1st
2	Inadequate data required for FM operations	0	4	20	11	4	39	132	0.68	2nd
3	Lack of information exchange capabilities	2	8	11	12	6	39	129	0.66	3rd
4	No best practice/guidelines	3	13	8	7	8	39	121	0.62	4th
5	Lack of understanding buildings operation	15	7	9	3	5	39	93	0.48	5th

1=Strongly disagree, 2=Disagree, 3=Undecided, 4=Agree, 5=Strongly Disagree

Table 7 depicts results on the barriers to providing FM information using BIM. Results show thatlack of collaboration of Facilities Managers and Architects have high significance (for $RI \geq 0.75$) towards facilitating effective operation and maintenance in FM. Also, Inadequate data required for FM operations and also Lack of information exchange capabilities both have significance ($0.67 \leq RI \leq 0.75$) towards facilitating effective operation and maintenance in FM. Furthermore, No best practice/guidelines and Lack of understanding buildings operation both have fair significance ($0.45 \leq RI \leq 0.66$) towards facilitating effective operation and maintenance in FM.

Table 8 depicts the Barriers affecting collaboration between design and FM teams.

Table 8: Barriers affecting collaboration between design and FM teams

S/N	Barriers	Frequency					Σf	Σfx	RI	Rank
		1	2	3	4	5				
1	Lack of FMs in early design stage	0	4	16	7	12	39	144	0.74	1st
2	Language/communication gap	1	7	13	8	10	39	136	0.70	2nd
3	Responsibilities not clearly defined	0	12	16	11	0	39	116	0.60	3rd
4	FM role not understood by design team	5	14	7	9	4	39	110	0.56	4th
5	FMs do not understand design	6	8	16	9	0	39	106	0.54	5th

1=Strongly disagree, 2=Disagree, 3=Undecided, 4=Agree, 5=Strongly Disagree)

Results show that Lack of FMs in early design stage, Language/communication gap and also Responsibilities not clearly defined all have significance ($0.67 \leq RI \leq 0.75$) towards facilitating effective operation and maintenance in FM. Furthermore, FM role not understood by design team and also facilities managers do not understand design both have fair significance ($0.45 \leq RI \leq 0.66$) towards facilitating effective operation and maintenance in FM.

CONCLUSION

Necessary Architectural information to support FM operations from the design stage has been extracted through a case study of COBie extension of Revit Architecture conducted in the light of FM support areas. The readiness assessments result shows that all information required extracted from COBie extension are significant towards facilitating effective operation and maintenance in FM. This implies that the Architectural firms studied are ready to provide FM information that will enable effective operations and maintenance of buildings. Results on the variation of the relative indices of the extracted information however indicate that variability in aspects needing attention to achieve readiness.

Also, while potential benefits of providing FM information using BIM from early design stage has high significance in facilitating effective FM operations, the barriers of providing FM information using BIM from early design stage also has significance in facilitating effective FM operations. However, although results show that both benefits and barriers have significance, the significance of the benefits outweigh that of the barriers (RI for all factors ≥ 0.75). The significance obtained in these results comply with works of Eastman *et al,* (2011) and Kubba (2012) where they claim that exporting significant as-built information makes the lifecycle of the building effective and optimize management and operation of facilities.

Furthermore, while literature has identified the prevailing knowledge gap on BIM application by Architects from early design stage to facilitate efficient FM operations is mainly due to lack of collaboration within the AEC/FM industry, the manifestations of the barriers affecting collaboration between design and FM teams all have significance towards facilitating effective operation and maintenance in FM. Hence, alternatives to mitigating these barriers through synergy and teamwork will aid effective FM delivery in the operations and maintenance of buildings. Furthermore, integration of FM information as well as Facilities Managers in the early design stage may reduce the fragmented nature of the AEC/FM industry in the building development processes.

Further research should be conducted to establish the readiness levels of all other sectors of the Nigerian construction industry on the use of BIM at the design stage of FM operations. This is because the use cannot just be achieved by one segment of the industry since building project delivery is a collaboration

between several players in the industry such as engineers, builders, quantity surveyor, contractors, clients/facility managers, suppliers, manufacturers because possessing some fair level of readiness of players in the industry will improve the use of BIM for FM operations.

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