Modelling Construction Management Processes in a Digital Built Environment

Wilfred M. Matipa[1], Raj Shah[1], Sam-Odusina Temitope[1], Dianne Marsh[1]

[1]Liverpool John Moores University, FET, SBE, Byrom Street, Liverpool, UK.

w.m.matipa@ljmu.ac.uk

Abstract

Since the United Kingdom (UK) government introduced Building Information Modelling (BIM) Level 2 in 2016, the construction industry has made strides in mapping construction business processes to a BIM enabled work environment. While the modelling of building products has been made possible through the use of various architectural software systems, the industry faces challenges with regards to the modelling of construction processes pertinent to construction management in a digital built environment. It can be argued that for construction management to realise the potential from using BIM, there is a need to create a modelling tool that instantiate a myriad of undocumented tasks, events and decisions related to logistics, health and safety and the impact on delivery schedules; the supply chain, and the milestones. Such data as well as commercial data on construction tends to be abstract in nature, and cannot easily be represented in a BIM Level 2 model. This research was designed with an interpretivism philosophical standpoint; whereby it questioned the perception industry practitioners on how the industry undertakes the modelling of construction processes. It used a questionnaire survey to gather opinion on how practitioners are modelling abstract data types pertinent to construction management processes. Results from the research show that the industry adopts strategic protocols for implementing BIM. However, such a strategy has an insignificant impact on modelling construction process data, save for scheduling (construction programming). This paper proposes a framework for modelling construction processes using international standards on data models. The aim of the framework is to steer the focus to resolving some of the many challenges of modelling construction process. Such challenges can no longer be ignored if the industry is to move to Level 3 BIM. If implemented, the framework could promote the creation of customised systems for construction managers to capture data embedded in construction processes; and improve data manipulation and analysis. Such systems are critical to the attainment of the Level 3 BIM under COBie code of practice.

Key words: Building information modelling, Construction Knowledge, Construction Management Processes, Industry Foundation Classes, Interoperability,

1. Introduction

The worldwide realisation of the potential benefits associated with the deployment of building information modelling (BIM) [1] has created, inter-alia, a destructive force of unrealistic framing and hype [2] attributable to stifling process modelling of construction activities. On one hand scholars claim that BIM has proven, and outstanding results in construction processes by enhancing knowledge sharing with regard to a building or facility throughout its life cycle from the conceptual design to facility management [1, 3-5]. On the other hand, scholars believe that as innovative as BIM strategies could be [6] the construction industry still requires a massive effort with regards to modelling information related to processes pertinent to delivery of projects [2, 7-8]. Currently the construction industry uses pervasive data modelling tools such as digital cameras, tablet computers and other handheld gadgets, drones, and the like [9], to capture data on building product and processes. This implies that the industry uses varied digital gadgets to capture and generate data of varied sort at any stage in the construction process, hence, the industry remains largely fragmented in the way it handles construction data [10]. While the technology to capture building product data is fully developed, there is a challenge related to modelling tacit knowledge from a section of experienced construction management workforce. The introduction of the BIM strategy of construction delivery, as is the case with Level 2 BIM initiative of the UK government of 2016 [10], essentially takes away the most familiar and user friendly means of modelling knowledge and ideas (paper, pen, and the like) on construction processes. The unintended consequences of using BIM has been the massive loss of knowledge because current technological systems are ill-prepared to capture data from highly experienced workers who are disinterest in a gadgetry driven work environment.

This paper proposes a framework for construction process modelling that is centred on the use of international standards on data models. It uses results from a survey to demonstrate that the discourse on BIM has largely been ignoring modelling abstract data types pertinent to the successful operationalisation of construction management processes.

2. Challenges of Modelling Contextual and Social Competencies necessary for managing construction processes

"If it isn't broke, don't fix it" – construction industry mantra

As the worldwide construction industry undergoes a paradigm shift driven by the adoption of BIM [11] some owners and operators are yet to discover the added value of BIM in their respective areas of interest, especially the information management within their organisations [8]. Anecdotal evidence shows that experienced construction management workforce have a rule of thumb that prefers proven construction processes to new ones because the former have served the industry over the years need not be changed for the sake of change than the later. Meaning that before introducing change, there should be evidence showing that new approaches could outperform current ones. It could, therefore, be argued that modelling process information using BIM requires robust scrutiny and evidence based data that could sway industry decision makers to adopt it.

According to Kassem et al., [12] BIM is the process of generating, storing, managing, exchanging and sharing building information in an interoperable and reusable way. The critical issue has been to operationalise the interoperable know-how that underpins decision making on construction processes so as to ease the justification and estimation of the resource consumable at a given time-period of the project. Even though there a perception that BIM uptake would continue increasing in the short term, enforced Level 2 BIM [13] coupled with client demand have been the cardinal drivers of BIM thus far [11]. However, the increase in the uptake of BIM in its current form does not address the challenges of modelling processes that are critical to smooth operationalisation of construction projects. Construction processes, by nature, encompass technical, contextual and behavioural (or social) competencies that are necessary to achieve project excellence [14]. It implies that one should manage people, processes, resources, results as well as project purpose. However, for construction process specialists to model the necessary data from the desired level of competencies they would have to utilise and go beyond current BIM standards and guidelines [13, 16 -18]. Such an achievement is desired, but highly unrealistic as at 2018 because the industry largely hovers on Level 2 BIM under the COBie code of practice [11, 13, 15]. Therefore, the challenge for modelling construction process information lies with the top-down BIM initiative strategy because it focus more on strategy and less on data process modelling.

Frailty of Top-Down BIM Initiatives

The full benefits of BIM for construction management could only be realised when the industry moves to a fully interoperable model (Level 3 BIM of COBie code of practice) – by file sharing system or by database system, with the capability to model technical and commercial data for the whole project [15]. Such an aspiration could be realised if construction management research could redirect the energy on process data modelling using international standards [13, 17 – 18]. Currently, construction processes have unlimited approaches through which they could be modelled mainly because of the varied nature of data types [17]. For instance, construction process model would not only depict schedule data, but also contract documentation to model legal information necessary to operationalise the project [1]; contracts to model risks and responsibilities of project stakeholders [19]; and the expert knowledge to model best practice from construction managers [3,20]. Khosrowshahi and Arayici [3] opined that BIM implementation is a major change management task, involving diversity of risk areas. The identification of the challenges and barriers is therefore an imperative precondition of this change process. While generic preconditions have been explored over the past decade, there is a gap in addressing fundamentals of process modelling with regards to construction processes and the competencies of managing projects. The major factor has been the "abstract" nature of the data types needed to model processes.

Despite the realisation of the need to revisit the modelling of construction processes, BIM implementation strategies tend to focus on organisational, cultural and management related action points. For instance, Khosrowshahi and Arayici [3] proposed three structured patterns to systematically tackle technology, process and people issues in BIM implementation. These are organisational culture, education and training, and information management [3]. Similarly, Aranda-Mena et al., [4] identified mechanisms of informing project management practice on the business benefits of building information modelling (BIM) adoption. They found that there was a need for "shared understanding on business drivers to adopt BIM for managing the design and construction process of building projects ranging from small commercial to high-rise" [4]. Motawa and Almarshad [7] opined that the "next generation of BIM should seek to establish the concept of Building Knowledge Modelling (BKM). They argued that BIM applications in construction, including those for asset management, had mainly been used to ensure consistent information exchange among the stakeholders [7]. Yet BKM needed to utilise knowledge management (KM) techniques into building models to advance the use of these systems [7]. Motawa and Almarshad [7] proposed a "BIM module to capture relevant information and case-based reasoning (CBR) module to capture the operational knowledge of maintenance activities. The structure of the CBR module was based on analysis of a number of interviews and case studies conducted with professionals working in public BM departments [7]. The suggestion departs from the international initiative articulated in [18]; the critical issue is to address the challenge at data model level using Express modelling language. Even though the current BIM strategies promote data sharing, knowledge is kept by those who possess it; mainly because their decisions are not easily modelled due to lack of mechanisms to do that. Project management practices in construction refers to, inter alia, process based modelling in order to plan and control the delivery of projects as efficiently as possible, and within health and safe working environment. The ISO standard for IFC, using STEP modelling language has established the route way to neutral modelling of building information of all sort, including both explicit and tacit knowledge. However, the challenge has been the creation of user friendly interfaces that could model tacit knowledge, within a dynamic construction management environment.

3. Research Design and Results

The research was designed with interpretivism philosophy [21, 22] whereby the questions to be asked if respondents were perceived to require detailed explanation and justification [23]. Hence, the research was implemented using a questionnaire survey.

Questionnaire Survey

A United Kingdom (UK) wide questionnaire survey was undertaken. The estimated population (N) of the survey exceeding 53k employed construction specialists in commercial management in the UK [24], it was inevitable to target as many respondents (n) as possible. The sample was naturally stratified by the profession classification i.e. construction related practitioners such as quantity surveyors and construction managers. Rose et al., [25] opined that if the population cannot easily be estimated, a proportion thereof (n) could be estimated using the following formula as shown in equation 1.

$$n_r = \frac{4pq}{d^2} \tag{1}$$

Where: n_r is the required sample size; p is the proportion of the population, $q = 1 - p$ and d is the margin of error. Since the proportion of construction professionals, using BIM could not be established, p was presumed to be 2 % plus or minus; the minimum n_r calculated was 385. A key factor to consider was the natural stratification of the population; hence, it was presumed that there was an element of homogeneity in the population (N); hence, the margin of error was increased to 10% (39). In such case, the minimum sample size was reduced to 96 (39). Sounderpandian [26] opined that if a sample (n) was based on the central limit theorem, the minimum elements therein should be 30. The target sample (n) for the research, therefore, was 385, with a minimum of number of elements set at 30. A web-link was created for the survey, resulting in 184 valid responses, resulting in a 47.79% rate of response.

Research question: to what extent do BIM implementation strategies address modelling of construction management processes?

To answer the research question, six themes were incorporated in the questionnaire survey, and the include: (i) perception of innovation in modelling construction process data; (ii) value addition of data models to construction processes; (iii) perception of ultimate benefits of data models; (iv) modelling systems information; (v) modelling sustainable construction processes, and (vi) models based on International Standards.

Perception of Innovation in Modelling Construction Process Data

The initial theme was to assess the perception of innovation in modelling construction process data. By innovation, it was envisaged that BIM could be perceived as a vehicle for modelling technical as well as commercial data [6]. The results indicated that there is a strong perception that BIM was addressing strategic competencies (64%) at the expense of technical and operational processes. Discourse on modelling construction processes was only perceived to imply "Gantt charts" and schedule related data (67%). In reality, there are a myriad of key competencies for construction process which would have been modelled, but the means to model them is limited at best.

Value Addition of Data Models to Construction Processes

According to Bosch et al., [8] owners and operators are presumably yet to discover the added value of BIM for maintenance and information management within their organisations. Construction processes were more complex than building maintenance; hence, it was critical to explore "sources of inefficiency and ineffectiveness" of BIM. Bosch et al., [8] found that current added value of BIM in the operations stage was marginal; mainly because challenges of alignment between the supply of and demand for information and the context-dependent role of information [8]. Therefore, the second question related to the perception that data models could add value to construction processes. The rationale for this question was to assess how BIM was assessed with relation to existing construction processes. The result from the survey indicated that 72% of the respondents felt that value addition was represented through 4D simulation of schedule and resource planning. The same reason was cited by Li et al., [27]. The industry struggles to capture data models with information from the wider supply chain on construction objects. This weakness is compounded by the scanty nature of construction and commercial data because the nature of this type data is mainly abstract and dynamic.

Perception of Ultimate Benefits of Data Models

Lindkvist [5] opined that "BIM offers a holistic approach to building projects across a number of practices. However, projects have a relatively short-term benefit of using BIM with 80 per cent of the cost of an asset spent in operations. The ultimate benefit of BIM is when the information which the end user inherits from building projects creates value that occurs over a long period of time [5]. Therefore, the questions regarding the perception of ultimate benefit of data model was aimed at assessing if respondents had a long term view of BIM. The response shows that 83% felt that construction management processes are critical in assuring the asset owner throughout the life cycle of the product. However, there was an overemphasis on the schedule, resource management and commercial management.

Modelling systems information

Respondents were asked how the deal with data models for various building systems necessary to operate a facility. Love et al., [28] argued that BIM models emphasised the integration of software packages for architectural, structural, heating ventilation and air conditioning and hydraulics; mainly because such elements have scale, geometry and can be visualised. They argued that there were many systems with no scale or geometry;

and that they could not be visualised [28]; yet they are equally vital to the development of facilities. Therefore, respondents were asked how they allowed for the modelling of building systems. 84% of the respondents argued that they buy off-the shelf data models for systems information. The response shows that just like respondents found it hard to model systems information the same goes for construction management processes. It is prudent to learn from systems information models (SIM); and use a system of isolating classes that have not been instantiated.

Modelling Sustainable Construction Processes

For BIM to make a positive impact on sustainable construction it would have to facilitate the modelling to Level 3 [13, 15, 29] In such a situation the role of modelling standards such as COBie cannot be underestimated [29]. Therefore, respondents were asked if they were modelling construction processes that enhanced sustainability in the industry. 74% of the respondents felt that they had not reached the stage where they could model all elements and processes to promote sustainable construction. This shows that there is a realisation that process of instantiating particular classes within existing data schema such as COBie has been challenging; meaning that models that claim to be contain robust building data have less information than they purport to possess.

Models Based on International Standards

Respondents were asked about the role of international modelling standards for capturing construction process models. Alwan and Gledson [29] assessed the use of COBie data schema for building asset modelling. Hence, the question on the role of standards was critical to this research. The response shows that over 90% of respondents had a strategic awareness of the role that international standards on data models played in the construction industry. However, the perception of standards was attributed to regulating how the industry and its stakeholders conducted themselves in the BIM working environment. The response indicates that there has been a gap as to how industry could contribute to the use of data models such as ISO 10303-1 [17] and ISO 16739[18]; which focus on building product and process representation.

4. Framework for Isolating un-instantiated Classes from the Model

Using the answers from the six themes in section 3, it was possible to generate a basic flow-chart in Fig. 1; depicting the framework for isolating various classes from the industry foundation classes (IFC) schema. The IFC data schema [18] was selected for this research because it offers high level neutrality needed for developing research prototypes.

Step 1

Reading the flow chart (Fig. 1) from left to right, the framework starts with finding an instantiated IFC data model for any building product, especially with geometry and other data objects. The starting point for the framework herein Figure 1 indicates that there is a need for geometric data model. This is usually created using computer aided design (CAD) software – usually presented in 2 Dimension (2D) or the 3-Dimension (3D). This is the normal practice in any construction process because geometric models need to be interpreted with regards to the construction process that is required for the modelled building to be fully built into a tangible facility for the end user.

Step 2

The second step in the framework proposed herein should be to validate the type of data model created using a CAD software tool in step 1. The validation process requires verification of the file type; i.e., if the file is saved as proprietary format or a neutral file format. This process is critical to the process of modelling construction processes because a neutral file is critical for construction managers to share the data, else, they would need to use proprietary software similar to the one used by the CAD modelling software. A standard data schema dictates the type of file generated by the CAD model. If the data schema used is not neutral, it means that the research would be dealing with strategic issues about BIM, and would not be continued. However, if the data schema has IFC, COBie schema or Express data, then the research could continue.

Therefore the validation step in Fig. 1 shows the two routes for the research. If the question on the data schema was a “No”, the research would have ended; else the research was to continue with five (5) more activities (see Fig. 1). The four activities include: (i) checking for the industry foundation classes (IFC) schema or COBie schema or any Express Data modelling system that could have been used; (ii) isolating any instances classes in the schema which would not have been instantiated by the CAD software tool; (iii) developing a tool that can be used to instantiate the classes that were not instantiated. This stage is but a prototype for the research; and (iv) Test the prototype on Abstract Data Type (ABT) classes within the schema. (v) Once these four steps had been met, there could be a needed to test the prototype on construction process as well as commercial data such as the ones used in the industry. After these five steps detailed recommendations would be made from the research.

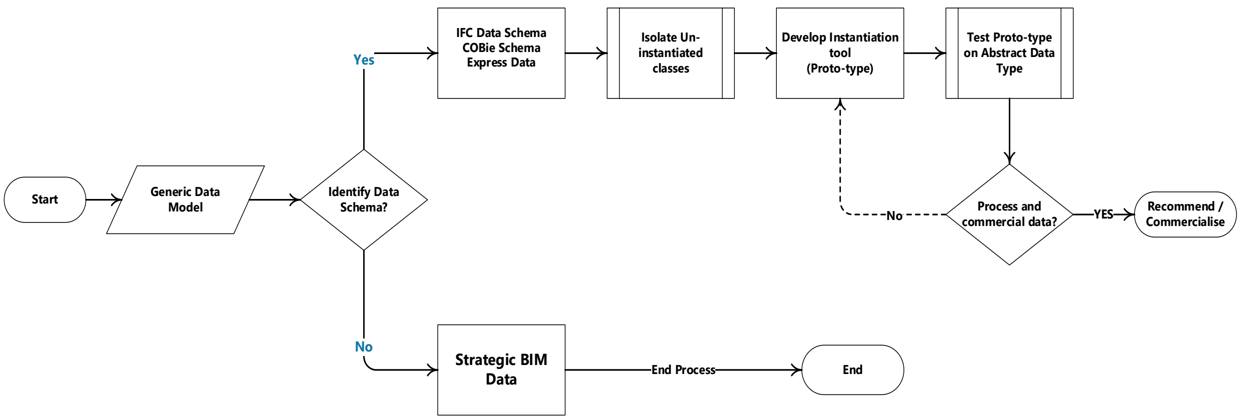

Fig. 1: Framework for isolating un-instantiated IFC Classes from the Schema

Step 3

Third step involved the implementation process of step 2 using a computer programming language of the research team's choice. This meant that after validating the type of data schema, the research would then move to isolating un-instantiated classes in the schema. The process of isolating the un-instantiated schema could be undertaken in any programming environment such as Python, C++, Java, C# and the like. The final phase of the framework is to develop a prototype that would act as a tool for instantiating classes in the IFC schema. By so doing it could be possible to instantiate abstract data types of the IFC schema. In the process it would give an opportunity to model construction process "algorithms" gained through experience and tacit knowledge. Such aim is to allow for the capture and storing of process data repositories for the benefit of new entrants to the industry and future generations. These could relate to: sequencing of tasks; temporary work designs; resource allocation; health and safety indicators; risk assessment protocols, and the like

5. Proposed GUI for Instantiating Abstract Data For construction Processes

Based on the research framework shown in Fig. 1, section 4, it was possible to commence the implementation of the research results by taking three key steps herein summarised in Fig. 2.

(i) Firstly, it was possible to obtain a generic data model with enough building information in the model. A proprietary software called Autodesk Revit 2018 was used to create a CAD model. The file was saved using a neutral IFC schema.

(ii) Secondly, the integrity of the model was verified and it was modelled in IFC schema using Autodesk Revit modelling tool- 2018. The verification process involved the ability to safe the model using a neutral file schema supported by Autodesk. However, not all classes were instantiated; especially the abstract data type classes (ADT) that are pertinent to the process of modelling construction processes. Fig. 2 shows a dotted rectangular coloured shape to highlight sections of the framework that have been implemented thus far.

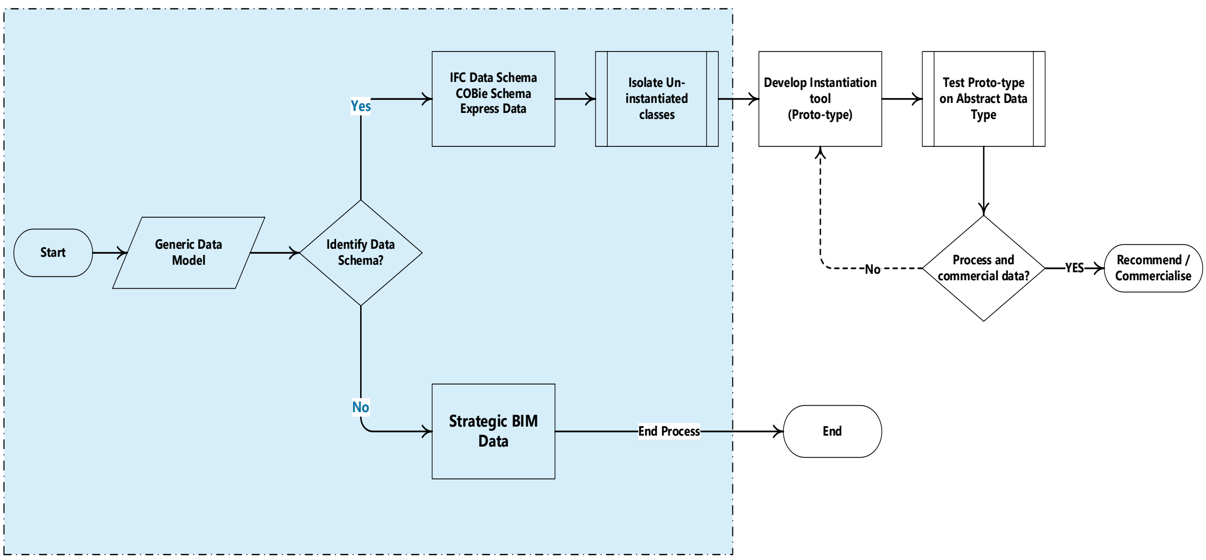

Fig. 2: Implementation of the Framework for instantiating IFC classes

(iii) Thirdly, it was found that using computer programming environment, the team was able to identify IFC classes from the Revit model, an example shown herein Fig. 3. Using the programming environment, it was possible to isolate classes that were not instantiated by the Revit modelling tool.

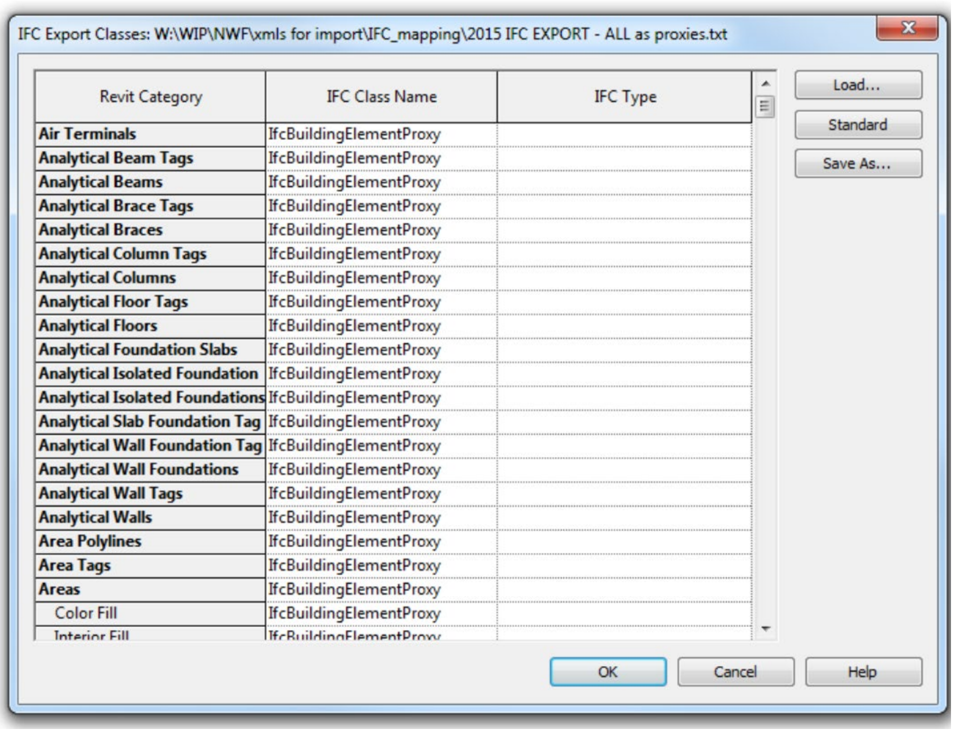

Fig. 3: Example of the Programming Environment Isolating Un-instantiated IFC classes under Python Programming Language

(iv) Having identified the IFC classes with no instances, the research moves onto the development of the proto-type that could be useful for the independent instantiation of classes within the IFC schema. This stage is under review by the research team.

Testing and Evaluating the Framework

As the construction industry continue to claim benefits for adopting BIM, construction management processes largely remain outside data models because of the abstract nature of the data that represents the said processes. For example legal information of a construction project cannot be modelled as an “object”, yet it is critical to the construction process. Legal information is of abstract data type, critical to the management of stakeholder responsibilities, but has challenges to model within the BIM environment [30]. Kähkönen and Rannisto [20] argued that construction project management is heavily built around document control and relating events such as change orders, submittals, transmittals and requests for information; hence, there is a reliance on electronic data/document management systems (EDMS). However, it could be argued that EDMS as a short to medium term solution to the modelling of construction processes; and mitigates the interoperability challenge to a limited extent.

EDMS do suffer from the lack of software interoperability; because it only speeds up the manual way of working; does not fundamentally address interoperability as per international BIM standards. Davies et al., [31] opined that the potential for BIM to improve processes is documented, but few projects realise that potential. This is because construction processes are laden with a myriad of undocumented tasks, events and decisions related to logistics, health and safety [32], and the impact on delivery schedules; and the supply chain, and the milestones. Such challenges cannot be ignored any longer for the industry to move to Level 3 BIM [15] (SEC, 2014) else the BIM working environment would continue being insignificant in the operational life of facilities [33]. It can be argued that adopting strategic protocols for implementing BIM has an insignificant drive on the process of data modelling [34]. Making BIM mandatory does not address the challenges of modelling construction processes; this should be a focus of researchers within that field [35]. Therefore, the goal for researching in modelling construction process need to focus on metal analysis of the pertinent data in Level 3 BIM [36]; else the status quo is likely to have a negative impact on future construction workers because knowledge is being lost through a natural process such as retirement of the most experience people [37]; whose knowledge cannot be captured and shared with new entrants to construction management

6. Conclusion

As the construction industry continues to claim benefits for adopting BIM, the modelling of construction management processes and their embedded knowledge remains stagnant. This is mainly because of the abstract nature of the data that typify construction processes. As a result, construction processes are laden with a myriad of undocumented tasks, events and decisions related to logistics, health and safety and the impact on delivery schedules; and the supply chain, and the milestones. Such challenges cannot be ignored any longer for the industry to move to Level 3 BIM else the BIM working environment would continue being insignificant in the operational life of facilities. This paper argues that strategic protocols for implementing BIM have an insignificant drive on the process of data modelling. Making BIM mandatory does not address the challenges of modelling construction processes; this should be a focus of researchers within that field. Therefore, the research proposes a framework for construction process modelling that is centred on the use of international standards on data models. It uses results from a survey to demonstrate that the discourse on BIM has largely been ignoring modelling abstract data types pertinent to the successful operationalisation of construction management processes. If implemented, the framework could create a customised system that could promote forward looking and backward compatibility with IFC data manipulation. Such a mechanism would contribute immensely to the attainment of the Level 3 BIM under COBie code of practice because the mechanism could capture algorithms used by construction process specialists in various scenarios; and then the data captured could be the basis for develop a data repository that could be useful now and for the future.

7. References

[1] Jamil, A.A.H., and Fathi, M.S., (2018) "Contractual challenges for BIM-based construction projects: a systematic review", Built Environment Project and Asset Management, https://doi.org/10.1108/BEPAM-12-2017-0131

[2] Fox, S., (2014) "Getting real about BIM: Critical realist descriptions as an alternative to the naïve framing and multiple fallacies of hype", International Journal of Managing Projects in Business, Vol. 7 Issue: 3, pp.405-422

[3] Khosrowshahi, F., and Arayici, Y., (2012) "Roadmap for implementation of BIM in the UK construction industry", Engineering, Construction and Architectural Management, Vol. 19 Issue: 6, pp.610-635

[4] Aranda-Mena, G., Crawford, J., Chevez, A., and Froese, T., (2009) "Building information modelling demystified: does it make business sense to adopt BIM?", International Journal of Managing Projects in Business, Vol. 2 Issue: 3, pp.419-434

[5] Lindkvist, C., (2015) "Contextualizing learning approaches which shape BIM for maintenance", Built Environment Project and Asset Management, Vol. 5 Issue: 3, pp.318-330

[6] Murphy, M.E., (2014) "Implementing innovation: a stakeholder competency-based approach for BIM", Construction Innovation, Vol. 14 Issue: 4, pp.433-452

[7] Motawa, I., and Almarshad, A., (2015) "Case-based reasoning and BIM systems for asset management", Built Environment Project and Asset Management, Vol. 5 Issue: 3, pp.233-247

[8] Bosch, A., Volker, L., and Koutamanis, A., (2015) "BIM in the operations stage: bottlenecks and implications for owners", Built Environment Project and Asset Management, Vol. 5, Issue: 3, pp.331-343

[9] Aziz, Z., Zainab Riaz, Z., and Arslan, M., (2017) "Leveraging BIM and Big Data to deliver well maintained highways", Facilities, Vol. 35 Issue: 13/14, pp.818-832

[10] The Infrastructure and Projects Authority (2016) “Government Construction Strategy 2016-20”, The infrastructure and Projects Authority (IPA) March 2016, HM Treasury and Cabinet Office, London.

[11] Eadie, R., Browne, M., Odeyinka, M., McKeown, C., and McNiff, S., (2015) "A survey of current status of and perceived changes required for BIM adoption in the UK", Built Environment Project and Asset Management, Vol. 5 Issue: 1, pp.4-21

[12] Kassem, M., Kelly, G., Dawood, N., Serginson, M., and Lockley, S., (2015) "BIM in facilities management applications: a case study of a large university complex", Built Environment Project and Asset Management, Vol. 5 Issue: 3, pp.261-277

[13] BS 1192-4 (2014) “Collaborative production of information Part 4: Fulfilling employer’s information exchange requirements using COBie –Code of practice”, The British Standards Institution, London

[14] International Project Management Association (IPMA) (2018) “IPMA standards – Project Excellence Baseline (PEB)” IPMA, Amsterdam https://www.ipma.world/projects/standard/ <Accessed: 18/08/2018>

[15] Specialist Engineering Contractors’ (SEC) (2014) “First Steps to BIM Competence A Guide for Specialist Contractors”, Published by the Specialist Engineering Contractors’ (SEC) Group in collaboration with the BIM Academy at the University of Northumbria, https://www.thefis.org/wp-content/uploads/2016/09/BIM-Guide-2014-1.pdf <Accessed: 18/08/2018>

[16] BS 1192:2007+A2 (2016) “Collaborative production of architectural, engineering and construction information –Code of practice”, The British Standards Institution, London

[17] ISO 10303-1 (1994) “Industrial automation systems and integration -- Product data representation and exchange -- Part 1: Overview and fundamental principles” Technical Committee: ISO/TC 184/SC 4 Industrial data, ISO, Geneva

[18] ISO 16739 (2013) “Industry Foundation Classes (IFC) for data sharing in the construction and facility management industries”, Technical Committee: ISO/TC 184/SC 4 Industrial data, ISO, Geneva

[19] Construction Industry Council (CIC) (2018) “Building information modelling (BIM) protocol second edition: Standard Protocol for use in projects using Building Information Models”, CIC, London

[20] Kähkönen, K., and Rannisto, J., (2015) "Understanding fundamental and practical ingredients of construction project data management", Construction Innovation, Vol. 15 Issue: 1, pp.7-23

[21] Saunders, M., Lewis, P., and Thornhill, A., (2009) “Research Methods for Business Students, 5th edition”, Pearson Education Limited, Harlow

[22] May, T., (2011) “Social Research: Issues, Methods and Process 4th Edition, McGraw Hill – Open University Press, Maidenhead

[23] Rosenthal, M., (2016) “Methodology Matters: Qualitative research methods: Why, when, and how to conduct interviews and focus groups in pharmacy research”, In Currents in Pharmacy Teaching and Learning July-August 2016, Vol. 8(4), pp509-516

[24] Strata.com (2017) “Total number of quantity surveyors in the United Kingdom (UK) from 2011 to 2016 (in 1,000)”, https://www.statista.com/statistics/319241/number-of-quantity-surveyors-in-the-uk/ <Accessed: 12/01/2017)

[25] Rose, S., Nigel Spinks, N., and Canhoto, A.I., (2015) “Management Research: Applying the Principles”, Routledge – Taylor Francis, London

[26] Sounderpandian, A., (2008) “Complete business statistics 7th Edition”, McGraw-Hill/Irwin

[27] Li, H., Chan, G., Skitmore, M., and Huang, T., (2015) "A 4D automatic simulation tool for construction resource planning: a case study", Engineering, Construction and Architectural Management, Vol. 22 Issue: 5, pp.536-550

[28] Love, P.E.D., Zhou, J., Matthews, J., Sing, C-P., and Carey, B.,(2015) "A systems information model for managing electrical, control, and instrumentation assets", Built Environment Project and Asset Management, Vol. 5 Issue: 3, pp.278-289

[29] Alwan, Z., and Gledson, B.J., (2015) "Towards green building performance evaluation using asset information modelling", Built Environment Project and Asset Management, Vol. 5 Issue: 3, pp.290-303

[30] Olatunji, O.A., and Akanmu, A., (2015) "BIM-FM and consequential loss: how consequential can design models be?” Built Environment Project and Asset Management, Vol. 5 Issue: 3, pp.304-317,

[31] Davies, K., McMeel, D.J., and Wilkinson, S., (2017) "Making friends with Frankenstein: hybrid practice in BIM", Engineering, Construction and Architectural Management, Vol. 24 Issue: 1, pp.78-93

[32] Riaz, Z., Parn, E.A., Edwards, D.J., Arslan, M., Shen, C., and Pena-Mora, F., (2017) "BIM and sensor-based data management system for construction safety monitoring", Journal of Engineering, Design and Technology, Vol. 15 Issue: 6, pp.738-753

[33] Edirisinghe, R., London, K.A., Kalutara, P., and Aranda-Mena, G., (2017) "Building information modelling for facility management: are we there yet?", Engineering, Construction and Architectural Management, Vol. 24 Issue: 6, pp.1119-1154

[34] Mei, T., Wang, Q., Xiao, Y., and Yang, M., (2017) "Rent-seeking behavior of BIM- and IPD based construction project in China", Engineering, Construction and Architectural Management, Vol. 24 Issue: 3, pp.514-536

[35] Day, M., (2011) “BIM Is Likely to Become Mandatory for Public Projects”, Architects' Journal; January 13 2011, Vol. 233 Issue 1, p24-25, 2p

[36] Noor, B.A., and Yi, S., (2018) "Review of BIM literature in construction industry and transportation: meta-analysis", Construction Innovation, https://doi.org/10.1108/CI-05-2017-0040

[37] Sfakianaki, E., (2015) "Resource-efficient construction: rethinking construction towards sustainability", World Journal of Science, Technology and Sustainable Development, Vol. 12 Issue: 3, pp.233-242,