A Preliminary Approach towards Integrating Knowledge Management with Building Information Modeling (KBIM) for the Construction Industry

Vinita P Bhatija, Nithin Thomas, and Nashwan Dawood

***Abstract*—Construction industry is becoming highly volatile and competitive due to increasing progression in information and communication technologies. These are often considered to be company's superior assets in providing profitability and competitive edge in the market. However, the most valuable resource is "knowledge", which is a refined form of information. The conservative, fragmented and adversarial conventional aspects of the industry are seen in the negative light for making implementation of these technologies difficult in the beginning due to various factors discussed in this paper. This paper presents a literature review of, standalone approaches, Building Information Modeling (BIM) and Knowledge Management (KM) to understand its role in increasing project efficiency in terms of time, cost and quality. Finding of a questionnaire survey conducted suggests that only 70% of the focus group were aware of KM approach in the construction Industry. However, a positive trend towards knowledge sharing is perceived as over 90% of the respondents felt that there is a need for sharing of knowledge among project participants. The paper concludes with a theoretical model over lay of KM & BIM features over RIBA plan of works to demonstrate potential contribution of the two approaches via integration. The paper also provides recommendations for future research direction by integrating to shift the paradigm from information exchange to knowledge sharing, in other words, knowledge based BIM – Building Knowledge Management (KBIM).**

***Index Terms*—BIM, KBIM, KM, Integration.**

I. Introduction

Construction Industry has been one of the main factors in immensely contributing to the economic growth of a county; fiscal policies are often favorable to this sector, acknowledging its influence in directing the economy of developing countries [1]. An ongoing research that started as a graduate dissertation in 1974 by [1] looks at all aspects of construction industry such as strategic management, technology adoption, productivity, and transparency with special reference to developing countries. Reference [2] comprehended that lack of data on the industry resulted in poor identification of its strength and weaknesses which hindered the development of more explicit improvement plans. Keeping Singapore as a reference, owing to its success post information-age, [1] stated that technology adoption and transfer is crucial to enhance the progress of construction industry.

Reference [3] discussed two main reasons for resisting technology change, human intention and internal facilitating conditions. Technology can help standardize mundane tasks and utilize resources more effectively [4] however, change is often considered to be disruptive to employees, hence management push is considered crucial. To help management increase adoption process, parameters identified in Unified Theory of Acceptance and Use of Technology (UTAUT) are scrutinized in [3]. The general parameter is the performance expectancy which is defined as 'the degree to which an individual believes that using a particular technology will help him or her to attain success in job performance' [5]. If this thinking is perpetuated on an organization level and beyond it becomes an industry mindset. On a larger scale, alternative procurement routes that are designed depending on various evaluation practices and on risk allocation dynamics amongst various stakeholders are considered being another factor in resisting change. As gaining a collective agreement on discontinuing conventional practices, in the fragmented environment of construction is difficult [6].

This paper begins with an introduction to the construction industry and its attitude towards adopting new technologies. A critical analysis of recent studies carried out in BIM and KM are discussed. Recommendation to integrate KM with BIM to make the technology for effective is spoken about in detail towards the end. A survey was conducted to gather preliminary data on industry awareness of BIM, KM and its applications. Outcomes, limitations and recommendations are discussed within this research paper. The focus group for the survey consisted mainly of consultants or BIM specialists (60%), contractors (27%), clients (10%) and Academia (3%) with experience of working in Asia (65%), Middle East (30%) and rest in Europe, America and Australia.

II. Building Information Modelling – An Overview

BIM has been in existence for as over as 30 years, however, it only gained popularity in 2002 when Autodesk released it to its users. In the recent times, local governments have been taking initiatives to encourage industry professionals to implement BIM in their construction process. For example, after successful completion of projects like the London Olympic 2012, Heathrow Final Stage Terminal 5 and the famous 48 floor Leaden Hall Building "The Cheesegrater", UK government required all contracts to comply with level 02 BIM implementation [7].

Recent survey carried out by NBS [8] states that in UK 59% of the industry professionals use BIM; the numbers further

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increased post mandate in 2011 when the government regularized the implementation of BIM in projects costing 5 million pound and above. In UK, construction amounts to 10.6% of G.D.P. which is equal to 47,751 G.B.P. millions; 3,153 G.B.P. million worth greenhouse gas emission are recorded per G.D.P. from construction alone. If the Pareto principle, 80/20 rule is applied, in theory the initial cost of construction and relative whole life cycle cost of built asset would amount to 238,755 G.B.P. millions; the value can be carved by 50% with the implementation of B.I.M and by 33% for capital cost (C.A.P.E.X.) and operating cost (O.P.E.X.). Even though, shockingly, as per N.B.S. surveys, only 12% of the total 59% users in U.K apply BIM at facilities management level.

Seeing the success rate of projects by degrees, Dubai Municipality became the first authority in UAE to mandate BIM for all large scale projects i.e. 40 stories and above including all government projects, Circular 196 (2013), superseded by 207 (2015). Mandating the technology is seen as an effective way of collaboration between the industry and government to implement newer technologies and embedding them in their existing system [2]. However, these initiatives need to be highlighted for all aspects of construction such as design, cost, planning, and quality to comprehend its importance [7].

BIM as defined in [9] is a digital representation of physical and functional characteristics of a facility; through visualization it eliminates uncertainty at various stages of construction. BIM output is a fine example of interoperability and coordination as it requires the input of various softwares such as revit for design, TEKLA for structures, CADMep for MEP, DesignBuilder for sustainability, Primavera for scheduling and Candy for pricing [10]. Hence, as aptly defined in [11][12] BIM is not just software; it is a process and software.

Reference [13] defined BIM as a multidimensional framework (n.D.); the 3.D. model can be expanded to incorporate various project aspects such as 4.D. for scheduling, 5.D. for costing, 6.D. for facilities management, 7.D. for sustainability, and 8.D. for disaster management. Also, Integrated Project Delivery (I.P.D.), which is the much needed approach for collaborative and effective communication to eliminate redundancies, has been seen in conjunction with the innovation of this technology in [14]. These models are continuously being updated to incorporate latest changes to create an accurate illustration of the project before its commencement, during operation and commissioning phase until the end of its lifecycle. Speaking of I.P.D., in [15] the author believes BIM adoption is the key to facilitate coordination between special purpose vehicles and end-users in private-public partnerships, for optimizing profitability.

Reference [16] collected data from 32 major projects and the statistics show, 80% decrease in preparing cost estimates, 10% reduction in project value through clash detection. However in few cases, BIM has caused the budget to increase due to insufficient knowledge of operating the software and its limitations [17]. Apart from these, [8] revealed that 67% of BIM users and 64% of non-BIM users confirmed cost was a major barrier to BIM uptake.

A. BIM Drawbacks

Several BIM researches are in consensus of the fact that cost and time savings resulting from comparing options in BIM viewer and clash detection are quantified and substantiation is provided. However, efficiency gain through collaboration and information sharing which increases profitability, better client-customer relationship, and enhances time management in monetary terms is not recorded [12]. Reference [11] researched return of investment (R.O.I.) for 10 projects; results ranged from 140% to 39,900%. Monetary gains highlight the technology's economic potential but less emphasis is given to adopting the technology at earlier stages of construction like design. Another problem which remains untapped is the lack of regulations standardizing the use of BIM from the design stage for efficient facilities management operations. However, many researchers are in favor of this line of approach [18].

The multidimensional framework of BIM in a highly layered and in a complicated project can significantly increase discrepancies at 4.D. and 5.D. levels. Since the technology is still evolving and is in its primitive stage not all disciplines are familiar with it; different subcontractors provide their schedule and cost in non-interoperable technologies which then have to be entered into the master file of BIM. Accountability of this inaccurate data entering is not defined in contractual terms. Other issues such as Legal related to licensing and ownership of the model and Technical design liability arising from inaccurate data entering have not been covered. Hence, before the process and software is implemented, risk should be identified and allocated [7].

III. Knowledge Management (KM) – An Overview

TABLE I: Types of Knowledge [24]

Explicit/Hard Skill	Tacit/Soft Skill
Contractual issues Resource allocation	Human behavior Crisis handling
Coordination with all parties	Dealing with Clients
Effective planning and monitoring skills	Encouraging innovation and development

Peter Duckers as early as 1993 defined knowledge management as "The basic economic resource – the means of production is no longer capital, nor natural resources. It is and will be knowledge," [20]. Reference [21] claims that among a plethora of contracting companies in the region, companies surviving at the top owe their growth to a lot of interrelated factors, however, the most shared ability is that of a treasured resource of knowledge directing and sustaining that success. According to a survey conducted in [22], number of employees above the age group of 60 has doubled whereas employees under 24 years of age have reduced by 27%. This is owing to the years of knowledge and experience mature employees bring with them. Reference [23] believes that the effect of an employee leaving the company could be substantially dampened if that knowledge could be restored for future. Past experiences could compress the learning curve, increasing firm's efficiency and reducing cost. Every now and then, an individual's recollection capacity limits them from applying best solutions, resulting in ineffective decision making and rework (see Table I).

The basic components of knowledge management include acquiring, converting, storing, reuse and protection [4]. All of the focus group agreed that knowledge should be shared and over 89% agreed that knowledge should re-used. These basic components can contribute towards achieving project goals faster and safer [25]. Knowledge acquired is broadly classified as explicit/hard skills and tacit/soft skills [26]; whereas explicit knowledge is information that can be documented and made easily accessible through platforms like Groupware, office online library and Aconex, tacit knowledge refers to information an individual gains through experience. Reference [27] proposed socialization, externalization, combination, internalization SECI model that converts tacit knowledge to explicit knowledge. KM at individual and company level can be facilitated through social media platforms (facebook, twitter, LinkedIn) and through support of organizations (trainings, meetings, events) [23].

Reference [28] identified that Artificial Neural Network (ANN), an ontology based programme that requires experience could be used for forecasting cost to an accuracy of 79.3% to 82.2%. Clients could use this to develop a budget, study risks involved, analyze market to understand benefits and strategize capital recovery schemes accordingly. Number of blogs online by experts for the industry have been increasing, to name a few, The Project management hut, Hearding cats, Project Management.com, these provide insights to the best practices that are updated regularly as the industry has realized that the technology is evolving. However, the common downside to this system is that often project managers do not have the time to file and classify data for easy retrieval. Reference [24] argued that knowledge shared through blogs is textual; it should be saved in multiple formats like video, audio, text to ensure the context of the content is not misinterpreted. For example, Bechtel Corporation has corporate lessons learned programme which stores information for use at three levels; textual, PC and Online Library. Similarly, Critchfield Mechanical Inc. improves coordination to simplify design and gather industry input by conducting multiple meetings. Whereas, N.B.S. sponsored file of failure database of 1982 collects lessons from past projects that have experienced failures to ensure mistakes are not repeated [25].

However, the most argued concept of KM as defined in [29] is the fact that every project is unique i.e. no two projects face similar internal and external risks; they vary in nature, size and degrees hence no such thing as one size fits all exists. Reference [30] through Hamming weighted proximity developed a method to obtain maximum similarity between new projects and target case.

A. Existing Studies on KM – A Global Perspective

Reference [24] in their study provided valuable substantiation by surveying 500 respondents, mostly holding managerial positions in Malaysia to develop a relationship between knowledge management and organization growth performance. The quantitative approach through Smart PLS (partial least square) software shows that KM components mentioned above, especially knowledge conversion enhances the performance growth of a company. Reference [31] explored the middle-path to success, that is neither technology driven nor does it rely completely on knowledge base. Success is a result of making the right decisions at the right time, avoiding mistakes/rework, forecasting future and cutting back on wastage of resources, as construction industry accounts for 10-30% of waste generated worldwide [32].

Reference [33] studied the relationship between organization structure and implementation of KM in Chinese centric culture. The authors in their research ranked the biggest obstacle in adopting newer technology as management support followed by costs involved in training and educating staff involved with the organisations. Focus group ranked lack of skilled manpower as the least possible reason for adoption of new technology and the authors see the same as a positive trend in the industry. Study revealed that adhocracy and decentralized structures enabled knowledge conversion to upgrade business performance than traditional and bureaucratic environment of organization. Whereas [34] discussed productivity from macro-productivity at corporate level to nano-productivity at individual level. The study claims that implementation of KM at micro-level is important to reduce financial impact at companies economic levels.

Reference [35] differentiates passive knowledge which is related to an individual's way of thinking from active knowledge that bridges the gap between thinking and doing. Using events to shed light on practice knowledge as it is exposed to more threats than thinking knowledge which is structured for an ideal situation. As each project in construction is unique and is exposed to different challenges, filtering the best possible solution requires a high level of judgment of knowledge. Hence, further categorization of available knowledge for adoption of practice based approach is deemed necessary. The author also points out that decision-makers react to situations instead of investigating the best practice. Reference [36], empirically highlighted the significance of knowledge acquisition and application. They emphasize on the need to dissect knowledge, make it accessible and to further refine it to make it relevant to job in hand.

B. Knowledge Management Disadvantages

Though the technology serves as an excellent tool to avoid rework and improve decision-making process, few parameters that could be affecting negatively cannot be overlooked. Some of these have been highlighted below:

1) Limiting innovation. Firms could undermine an individual's personal knowledge by relying strongly on corporate knowledge. It further reduces human potential to think or react under pressure. Although mistakes repeated and time/cost overruns are reduced due to ineffective decision-making [35].
2) Value added from implementation of KM in projects. Very little literature is available defining the return on investment from adopting KM. KM does not have quantifiable measures to assess its value to a project or organization [37].
3) Fragmented nature. Pinning down to one best solution would be debatable due to the fragmented nature of

construction field involving various stakeholders with different views and opinions [29].

4) Legitimacy. Authenticity and accuracy of information provided is highly crucial as solutions are based on projects similarity basis, output can be misleading if the information entered is not factual. Also, location factors can be considered to be challenging as external environments can greatly affect the progress of works and subsequent completion of project [38].

IV. Application of Knowledge based BIM

With KM based BIM, information and knowledge is created from different members involved in designing, construction, commissioning, maintenance, lessons learnt and knock-on effects of failure if not recorded or captured could have serious cost and time implications due to ineffective decision-making [39].

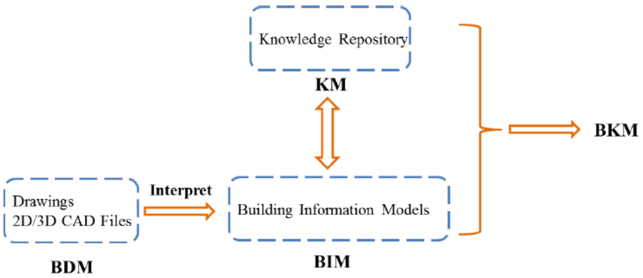

Fig. 1. Development of BDM, BIM and BKM [39].

Reference [40] in his paper presents an extensive literature review on 180 projects showing scarce BIM implementation in existing buildings due to difficulties faced in collecting and converting data into schematic BIM model. The lack of as built data resulted in ineffective project management, time and cost loss during repair works. Integrating the two approaches could positively effect and enhance different functionalities offered by the two standalone approaches.

A. Interoperability – BIM and KM

Efficient data storage for facilities management (FM) and compatibility of KM with BIM at later stages from inception of the project could make BIM implementation more effective in terms of time, cost and quality. As highlighted earlier, KM. branch ANN which is a cost forecasting tool can be used for BIM 5D. Reference [41] empirically concluded that three major reasons for loss of time on construction projects from poor quality of information are:

1) Time is wasted in searching the right quantity of information
2) incomplete and outdated information, and
3) Loss of relevant information due to delay in late recovery of data.

B. Security and Information Exchange

Reference [42] identified that information is not available at all organizational layers and information is on a need to know basis. This is overcome by having an additional layer of information exchange in BIM which could be made accessible to stakeholders, however privacy, security and information exchange protocols have to be defined to set clear boundaries to prevent misuse of data. Unfiltered information available on BIM models especially with the application of 4D and 5D, could suffer scrutiny for misuse by potential suppliers and subcontractor like prefab etc. An additional layer of K-BIM could only reflect data relevant to the information seeker. Survey results placed adversarial nature of the industry, lack of trust amongst project stake holders and fragmentation of industry as major factors affecting application of KM in the industry. Hence it is important to set out clear guidelines and information exchange protocols prior to KBIM implementation.

C. Application between BIM & KM

Reference [43] claims that decision making via case base reasoning of similar projects could make the projects more efficient and time implications on completion of project could be reduced. In Knowledge-assisted BIM-based visual analytics for failure root cause detection in facilities management reference [44] identifies patterns of root causes for failure to prepare preventive action plans. Computer maintenance and management systems carry maintenance and inspection records and CoBie delivers information on O & M manuals for handover; both of these are compatible with BIM.

D. Lean Management

Often in traditional procurement route of construction the organization structure is fragmented, exchange of information is critical whereas in procurement routes like design, build and management contracting, and PPP stakeholders are involved from the start of the project, requiring collaboration and coordination. If BIM is implemented at latter stages of the process, data flow would be episodic if not maintained, resulting in loss production and waste generation. Waste generation is at the heart of lean management which aims at performing activities which would impart value to the process and be in sync with customer requirements [45]-[46]. From a lean management perspective the author analysis the significance of content, quality of information and its consequence on FM. services process.

E. Stakeholder Interface

Stakeholder interface can use KBIM models for faster decision making and problem solving. Based on the query/problem encountered, FM. managers could retrieve data pertaining to the field which could facilitate faster decision making and data entering in BIM. [42].

F. Value Engineering (VE)

This section attempts at critically analyzing the creativity and risk management aspect of KM technology to increase the collective capability of the VE team, increasing efficiency of the VE exercise [26]. VE was first adopted in 1950, a tool to maximize product function by decreasing its cost. However, primary data suggests that 43% consider VE as a marketing scheme due to their highly expensive workshops [47]. VE is step-by-step procedure towards decision-making and includes the following stages Issue Analysis, Function Analysis, Creativity and Evaluation [48]. KM integrated with BIM could serve as a valuable database for VE Knowledge can be acquired by revisiting different options tried on similar projects in the past, lessons learnt, materials used and their cost fluctuations, etc. Reference [26] applies the Theory of Inventive Solving (TRIZ) at creativity phase, as often at these workshops the team finds solutions from the scratch; having stored valuable ideas documented and developed in previous workshops could curb redundancy. These practices could optimize the VE workshop outcomes. Reference [49] states that the solver in TRIZ gives a possible outcome however the final decision lies in the hands of the solver. However, certain methodologies may become outdated over a period of time due to rapid advancements in industry. Hence, these need to be updated regularly.

Reference [43] in their study on K-BIM concluded that cohesive knowledge-based BIM systems can deliver innovative features for construction operations. Conversely, integrating Knowledge Management ideologies in CBR systems with Information Management codes in BIM systems is a way forward for the transformation from 'Building Information Modelling' to 'Building Knowledge Modelling'. Benefits of K.BIM include documenting results to ensure if the implementation resulted in benefits to projects which could be of significant importance for convincing industry professionals and breaking conventional barriers, often faced before adopting a new technology in this conservative field of construction.

V. Conclusion

Reference [50] defined the construction industry as "*ineffective, adversarial, fragmented, and incapable of delivering to its customers*". Whereas, [51] proposed improvement plans and change divers that included integrated project process or in other words, I.P.D and the heart of Lean Management - improved management and supervisory skills to avoid redundancies. BIM and KM have been excellent tools for positively contributing towards these initiatives, but, face challenges from both aspects; implementation and practice. Most of the concerns related to usage are common and overlap such as interoperability, security, legal concerns, value engineering and management. With construction industry in the UK moving towards implementation of level 2 BIM, all of the focus group agreed that there is a requirement of adoption strategy for knowledge management and that the approach would benefit the industry. One of the bases of several instances of literature review, the authors has identified an overlay approach towards KM and BIM as represented in Fig. 2 below:

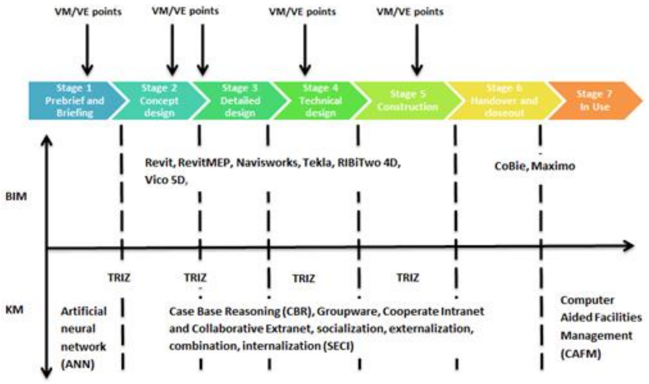

Fig. 2. A Proposed approach for BKM layered with RIBA PoW (Adapted from [10] - [26] - [28] - [52]).

All of the focus group unanimously agreed that there is a growing need to upgrade current trend of technologies that are being used to increase project efficiency, which shows the industry is looking for innovation and does believe that technology will be a contributing factor towards this drive.

Authors identified that the industry is seeking a positive trend towards knowledge sharing over 90% of all the respondents felt that there is a need for sharing of knowledge between clients, consultants, contractors and amongst project stakeholders. Interestingly over 97% of the respondents were open to the idea of a holistic collaborative approach amongst project stakeholders.

A. Limitations

Only 70% of the focus group were aware of KM approach in the construction Industry and over 40% of the focus though being specialist in the field of BIM were not aware of specific approach for KM This has to be considered as a limitation for findings and the need to reach out to wider spectrum of users with K.M knowledge.

B. Future Research

More research is needed in this area, given the benefits of combining the two approaches for increasing the efficiency of projects delivered in construction industry. KM integration can fill those obsolete gaps of information that sometimes lack in BIM Although these approaches have been encouraged in the industry, by quantifying its benefits in monetary terms could further ease the implementation process. The authors will be further working towards developing a framework towards implementation of KM along the lines of BIM and its processes.

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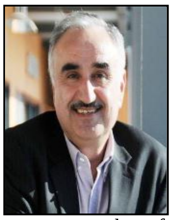

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