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Conceptual Model of Building Information Modelling Usage for Knowledge Management in Construction Projects

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Abstract. Knowledge management (KM) draws on a vital role in highly participatory and diversified working environment of construction projects. Knowledge keeps construction firms competitive and boosts performance high in future work. However, large and chaotic projects require KM achieved with technological support thorough the project life cycle. Building information modelling (BIM) has a wide range of interaction between researchers and practitioners as a new and promising area of technological research and implementation in construction. In the last decade, many researchers worked on the use of BIM in the construction industry. Collaborative interaction is one of the most important promises of BIM. Collaboration between construction professionals can be improved by firmly managed project knowledge. With BIM solutions, it can be easier to externalize, integrate, internalize and socialize knowledge. Operational knowledge and strategic knowledge can be managed through interactive BIM models. This study aims suggesting a conceptual model representing KM process through BIM. A comprehensive literature review on KM and BIM was established to construct the theoretical framework for the assignment of a conceptual model for BIM usage in KM process of construction projects. The proposed conceptual model is a road map for adapting KM process with BIM as a new KM tool. The ability of BIM to manage knowledge is determined. KM process is identified for construction projects. Existing process is reviewed and modified for the BIM usage. In future studies, empirical research will be conducted to strengthen the validation of the proposed model.

1. Introduction

Knowledge-based perspective is in the light of strategic management researchers [1]. Knowledge and its deployment are recognized as competitive advantage for the organizations [2,3]. Organization's sustainability depends heavily on collective knowledge used efficiently and on readiness to acquire and adopt new knowledge [4]. Even the traditional perspective accepts the value of knowledge and its management as a strategic factor for sustainability and competitiveness [5]. There are many approaches to KM identified in literature [1, 6, 7, 8, 9, 10]. AEC industry is highly knowledge intensive in terms of the unique nature of each project, project-based knowledge need, organizational structure of the projects, etc. [11, 12, 13, 14, 15]. The fragmentation in the construction industry consequently causes difficulties in effective communication of knowledge throughout the project stakeholders along the project life cycle. Therefore, problems occur in such a time, cost, and scope sensitive projects. This research aims to identify a new conceptual model for KM with BIM in construction projects. KM and BIM subjects are critically analyzed with using an evolutionary approach. The industrial revolutions and information and communication technologies (ICT) evolution's effect on BIM technologies are considered in conceptualizing the model. Traditional KM in construction industry and up to date BIM methodology is assessed. KM process for construction projects delivered with BIM is redefined. Future research directions of the field are suggested along with the ICT, KM, and BIM evolution analysis.

The paper continues with presenting the methodology that underpins the research. Literature review and evolutionary analysis of KM, ICT, and BIM follows the methodology section. The next section introduces the conceptual model proposed for KM process with BIM in construction projects. The final section includes conclusive remarks about the contribution of the paper and future directions in the research field.

2. Methodology

The paper analysis a wide range of published KM and BIM literature in generic field and in AEC industry. Recently, project and construction management researches are in the light of KM and BIM literature [16, 17,18, 19, 20,21). The paper addresses the main question of "How BIM methodology changes the KM process from an evolutionary perspective in AEC industry?". The research approach employed from the evolutionary perspective of industrial revolution and ICT draws the past, now, and future intentions in the field of KM in AEC industry. The assumptions of other researchers may differ according to their adopted perspective in the field. An interpretation of industrial revolution and ICT evolution effects on BIM to picture a holistic understanding of KM process in AEC industry through a research review is realized. With this perspective, KM process changes over time according to update and developments in ICT field. Therefore, BIM as a new methodology and technological tool introduced in AEC industry may lead changes in KM process in construction projects. The paper suggests the interpretation of industrial revolution and ICT developments' effect on BIM and BIM's mediated effect on KM process in AEC industry is stated with construction professionals' frame of reference.

3. Industrial Revolutions (1st to 4th Generation) and ICT Evolution (1st to 3rd Generation)

The industrial revolution from 1st to 2nd led ease of production. Increasing production rates triggered researches on how to manage the production process. The computational capabilities improved with the 3rd industrial revolution. 3rd industrial revolution period witnessed the emergence of web technologies. The rise of web technologies came true within last three decades. ICT evolution of web technologies called Web 1.0, Web 2.0, Web 3.0 respectively. Web 1.0 (integration and store of knowledge) is about the knowledge silos. Web 1.0 has inflexible and centralized environment that places a frictional role in knowledge sharing. There is not much room for communicating knowledge, interaction, and collaboration. Web 2.0 (internalization and share of knowledge) enables knowledge sharing and the use of knowledge. Kabir [3] states that the evolution of web led the transition from static web pages to interactive and user-driven environments. The web has evolved from being a knowledge store to a knowledge-sharing platform. Web 3.0 (socialization and use of knowledge) challenges the reuse of shared knowledge by a knowledge network for knowledge transformation in an improved state. The human and computer interaction in web 3.0 triggerS the emergence of dynamic generation of knowledge through better collaborative web interaction environment. The new era in the industry changed the analogue, mechanical, and electronic technology into digital technology which is called "information era" that enable improvements in ICT. 3rd industrial revolution and improvements in ICT impacts construction industry despite the fact that the industry's bulky movement towards the new information era. ICT technologies in construction industry are mainly used in realizing traditional tasks, to eliminate barriers to communication, accelerate processes, and obtain needed information. Majority of ICT used work is performed within closed networks and intranet. Current web technologies allow web-based tools, ontology-based semantic tools. However, construction industry is in relatively slow in adopting modern web-based technologies. Nowadays, industry experiencing a new transition to next level. The next level of web technologies of which, web 4.0 (institutionalization of knowledge) is about open, transparent, fast, and accurate communication of data and information and about creating reliable knowledge over big data, will enable the full integration among "things" and cyber technologies. The new revolution is called "industry 4.0". The requirements for an industry 4.0 system are namely; interoperability, information transparency, technical assistance, and decentralized decision-making.

Table 1. The reflection of industrial revolution and ICT evolution on BIM and collaboration level [BIM maturity level info is fed by reference no 22]

Year	Industrial Period / ICT Evolution / KM Generation	BIM Maturity Level / BIM Dimensions	Collaboration Level and Tools	Feature
1990s	Industry 3.0 Web 1.0 KM Gen. 2	BIM Level 0 / 2D and 3D CAD drawings, lines, shapes, arcs, texts, etc.	Low collaboration. Tools and papers.	Visualization of future building.
2000s	Industry 3.0 Web 2.0 KM Gen. 3	BIM Level 1 / 2D digital drafts, 3D digital model. Knowledge-based Model	Partial collaboration. File based collaboration.	Existing conditions models (Laser scanning, Ground penetration radar (GPR)); Safety & logistics models; Animations, renderings, walkthroughs; BIM driven prefabrication; Laser accurate BIM driven field layout
2010s	Industry 3.0 Web 3.0 KM Gen. 3	BIM Level 2 / 4D digital BIM for time management. 5D digital BIM for cost management Ontology-based Semantic BIM (Building Information Model) A minimum standard	Full collaboration. Partial interoperability. File based collaboration and library management.	SCHEDULING Project planning simulations; Lean scheduling (Last planner, Just in time (JIT) equipment deliveries, Detailed simulation installation); Visual validation for payment approval ESTIMATING Real time conceptual modelling and cost planning; Quantity extraction to support detailed cost estimates; Trade verifications from fabrication models (Structural steel, Rebar, Mechanical / plumbing, Electrical); Value engineering (What-if scenarios, Visualizations, Quantity extractions); Prefabrication solutions (Equipment rooms, MEP systems, Multi-trade prefabrication, Unique architectural and structural elements)
2020s	Industry 3.0 Web 3.0 KM Gen. 3	BIM Level 3 / 6D cloud BIM for asset life cycle management. 7D digital BIM for facilities management. Ontology-based Semantic iBIM (Integrated Building Information Model)	Full collaboration. Full interoperability. Cloud based environment. 3D information model sharing collaboratively with the team, outputs as 2D and 3D deliverables.	SUSTAINABILITY Conceptual energy analysis via DProfiler; Detailed energy analysis via EcoTech; Sustainable element tracking; LEED tracking

Year	Industrial Period / ICT Evolution / KM Generation	BIM Maturity Level / BIM Dimensions	Collaboration Level and Tools	Feature
		A wider digital strategy	FACILITY MANAGEMENT Life cycle BIM strategies; BIM as-built; BIM embedded O&M manuals; COBie data population and extraction; BIM maintenance plans and technical support; BIM file hosting on lend lease's digital exchange system	
Near Future	Industry 4.0 Web 4.0 KM Gen. 4	BIM Level 4 / nD digital intelligent model. *e-iBKM (Electronic Intelligent Building Knowledge Model)* *Ubiquitous e-construction*	Full Integration. Integrated web services and BIM Hubs. The future for the construction industry. Single wholly integrated project model obtains real time access to all members of the project team.	INTELLIGENT DIGITAL CONSTRUCTION Future proof; Online; Single and transparent; Self checking; Secure; Automated processes; Artificial Intelligence; Self procured; Market features; Commercial transaction model; Constraint Management; Post occupancy automation and productivity; Big Data; 3D printing

Industry 4.0 is related to Internet of things (IoT) namely; data, people, and services. Industry 4.0 deals with smart buildings, smart homes, social web, business web, smart logistics, smart grid and smart mobility in production. Inter-operability is the connection and communication among machines, devices, sensors, and people in a system. Sensors gather the information within the system with the transparency to create a real world digital visual representation. The created robust knowledge is used, optimized, improved, and reused for a better system and service. This process is achieved with self-learning intelligent machines and system. The system supports humans in decision-making by making simple autonomous decisions by itself. The system should also have the ability to assist humans in realizing difficult and unsafe tasks. Developing data access and digital skills in construction industry may increase production and may reduce onsite and offsite activities. Construction industry is going to catch-up with more digitally developed industries soon. This will revolutionize not only how physical structures are designed, built and maintained, but also how they are subsequently used.

4. BIM Maturity Levels (BIM Level 0 to 3)

BIM is a collaboration-oriented methodology based on data acquisition, data and information sharing, collective knowledge creation among project participants throughout the project life cycle. This information is used to support decision-making process of managers of the project from conception to demolition. The product of this methodology is called building information modelling. This information equipped model serves as a knowledge repository with from 3D to nD data on it. The maturity of the model is determined with the level of information and collaboration it provides to participants. 4th industrial revolution and ICT evolutions improve the ability of BIM in transforming itself from being only a knowledge warehouse to a model communicates knowledge and interacts not only with participants but also with model itself, machines, etc BIM provides digital data throughout the project life cycle within all phases with project and construction management information.

Building information model as a knowledge repository with added abilities like self-optimization, self-configuration and artificial intelligence may lead automation and digitization in construction, which is followed by timely, cost effective and better quality project outcomes. Constantly digital data acquisition and authentication enable project participants to capture and get over inconsistencies with responsive decision making through all processes. Instead of separate models, BIM serves as a platform in establishing feedback and feed-forward loops for continuous improvement in the project, which indeed is a full collaboration level and leads for full integration in construction projects via knowledge intensive models. Succar [22] determined the maturity levels of BIM from "BIM Level 0" to "BIM Level 3". The summary of maturity levels, period, description, output, and feature of levels is presented in table 1. BIM maturity levels identify the level of integration and utilization of added knowledge in building information models. "BIM Level 0" represents the period before BIM that only 2D and 3D CAD drawings which, exist in file and paper formats, which, were not interoperable electronic documents in 1990s. Therefore, collaboration level is very low in "BIM Level 0". "BIM Level 1" focuses on the transition of CAD drawings to 2D and 3D information. 3D digital model functioned in visualization, rendering, clash detection, and quantity lists. There is partial collaboration in this maturity level. "BIM Level 2" includes 4D and 5D BIM models that lead full collaboration among participants. 4D BIM model is a schedule data added developed version of 3D digital model. The new unified BIM model obtains time related information like activity durations, milestones, and progress of activities to participants throughout project life cycle. 5D BIM model is a cost data added developed version of 4D digital model that serves quantity take off data with the help of 3D BIM model's quantity data. "BIM Level 3" includes 6D and 7D BIM models. 6D BIM model is an energy performance data added developed version of 5D digital model. Energy performance analysis, optimization, sustainable object track for LEED is available in 6D BIM model to reduce energy consumption of buildings. 7D BIM model includes facility management data added developed version of 6D digital model. 7D BIM model provides asset data such as; component status, operations and maintenance manuals, specifications, warranty information, etc for managers throughout the project life cycle. "BIM Level 3" offers a fully integrated (iBIM), transparently accessible, and workable common shared model that provides information in a cloud-based environment.

5. KM (1st to 3rd Generation)

The emergent industrial era is called "Industry 4.0 (knowledge era)". KM is a widely studied research area as knowledge is accepted to be a vital strategic asset for the new industrial revolution [24, 25, 26, 27,28]. The summary of KM Generations in relation with industrial period and ICT evolution are presented in Table 1. KM definition consists of activities and processes used for the management of knowledge for obtaining required inquiry in knowledge intensive industries. Webb [23] defines KM as "the identification, optimization, and active management of intellectual assets to create value, increase productivity, and gain and sustain competitive advantage. Many researchers studied KM and their respective suggested process models are generally include acquiring, creating, sharing, storing, and utilizing processes [1, 29, 30, 31, 32, 33, 35, 36, 37, 38]. A few of the researchers slightly differ from others through adding steps such as; modifying, validation, networking processes [6, 34, 35]. The construction industry is a heavily knowledge-based that relies on input of all participants in a project. The fragmented, project-based and task-oriented nature of construction projects complicates KM process. There are variety of practices to manage knowledge in heterogeneous environments, which is made up of diversified professions, occupations, practices, materials, and so on. ICT is perceived to be a tool for enhancing KM in construction industry. However, previous ICT developments do not necessarily trigger people in sharing knowledge. Further, ICT has shortages in some types of knowledge. Computer supported collaborative work leads knowledge sharing. But it is not enough for full-integrated collaboration. The design team prepares the project design. The project design communicates with the construction team by the language of technical drawing. These drawings do not satisfy all virtual image requirements in realizing project. Drawings should consist of detailed design and construction knowledge. Sharing design knowledge over drawings fails in participants' satisfaction. Collaboration among individuals over an appropriate platform is a necessity. Therefore, a knowledge-based model is needed. Human-to-human, human-to-model, model-to-model. Model-to-building construction, model-to-environment, model-to-industry interaction is needed to fully achieve an integrated model. BIM researchers continuously evolve the capability of information models. In recent years, the ability of BIM model transformed the way of managing construction projects. Improvements in BIM implementation help stakeholders to collaboratively work on a multidisciplinary model, which in turn increases the project performance. Grabher [5], states that the processes of creating and sedimenting knowledge accrue at the interface between projects and the organizations, communities, and networks in and through which projects operate. Therefore, studies have evidenced that knowledge is to be shared among all levels industry wide.

Table 2. Researches on KM and BIM

Scope	Contribution	Ref No
Knowledge sharing management in the construction phase	BIM-based knowledge sharing system for project managers and engineers	[40]
BIM-based KM system to aid in capturing and reuse generated knowledge	A foundation for a BIM-based online prototype system named Knowledge Management of Building Maintenance	[41]
Construction of a system as a visual 3D-based knowledge management platform by utilizing the BIM approach and web technology	Proposes a Construction BIM-based Knowledge Management System	[42]
Designing a new methodology for the sharing of construction knowledge by using Building Information Modelling (BIM) technology	BIM-based knowledge sharing system for project managers and engineers	[18]
Presents a comprehensive literature review on BIM-based information/knowledge management	BIM-based knowledge management literature review	[19]
Assessment of the usefulness of a BIM-based social platform for knowledge management	Such platforms provide advantageous visualizations to project stakeholders	[20]
Literature review of, standalone approaches, BIM and KM	Provides recommendations for future research direction by integrating to shift the paradigm from information exchange to knowledge sharing	[21]
BIM, ontology and semantic web technology use to establish an ontology-based methodology/framework for construction risk knowledge management	Highlights the potential benefits and limitations on the deployment of ontology-based methodology/framework for construction risk knowledge management	[43]

6. KM with BIM usage in construction projects

The requirements for 4^{th} industrial revolution trigger the evolution in ICT that is highly accelerated in recent two decades. This evolution affects all industries and construction industry as well. BIM, as knowledge based interaction unit, may be the future of construction industry by complying requirements for 4^{th} industry revolution. BIM maturity levels are very intensely searched by researchers as seen in table.2. Even the bulky environment of construction industry cannot resist the latest opportunities that BIM offers for competitiveness, lesser time and cost requirements and higher quality and scope conformance, higher collaboration, lesser change in construction projects. Therefore, construction industry interested in BIM as a new methodology and tool for construction project management throughout the project life cycle. Ontology-based semantic integrated BIM model promises a better adaptation to knowledge era. Ontology and semantic web technology obtains representation and reuse of domain knowledge [39]. In the near future, industry will experience 4^{TH} Generation KM with BIM Level 4. Integrated information model becomes richer and more integrated with linked data without excessively enlarge the model size while enabling dynamic and flexible knowledge use, assess and reuse. Thus, the amount of knowledge generated will increase in BIM. Furthermore, new ICT developments open the way to socialize the knowledge and to communicate the generated knowledge with online interaction and update opportunities. Internet of things (IoT) and big data analysis and processing methods will be used to feed intelligent systems integrated to iBIM model to increase response speed. The information model will be furnished with knowledge and become an integrated building knowledge model (iBKM). Then the model, which, is integrated with intelligent decision-making and online working systems, will work online and become an electronic intelligent integrated building knowledge model (e-iBKM). The model-based platforms may enhance ease of acquire, create, share, use, reuse, networking, and communicate knowledge over a model for a project life cycle time. Models can also have linked to each other to feed lesson learnt and intelligence. Continuously evolving learning e-iBKMs will emerge in the construction industry with the ability of continuous self-improving. These improvements in ICT, BIM, and KM will enhance the use of learning e-iBKM with using and serving as an agent of (IoT) things, big data, artificial intelligence, augmented reality, virtual reality and 3D printing options. In the light of above mentioned improvements and foreknowledge a conceptual model of BIM usage for KM in construction projects is represented in figure 1.

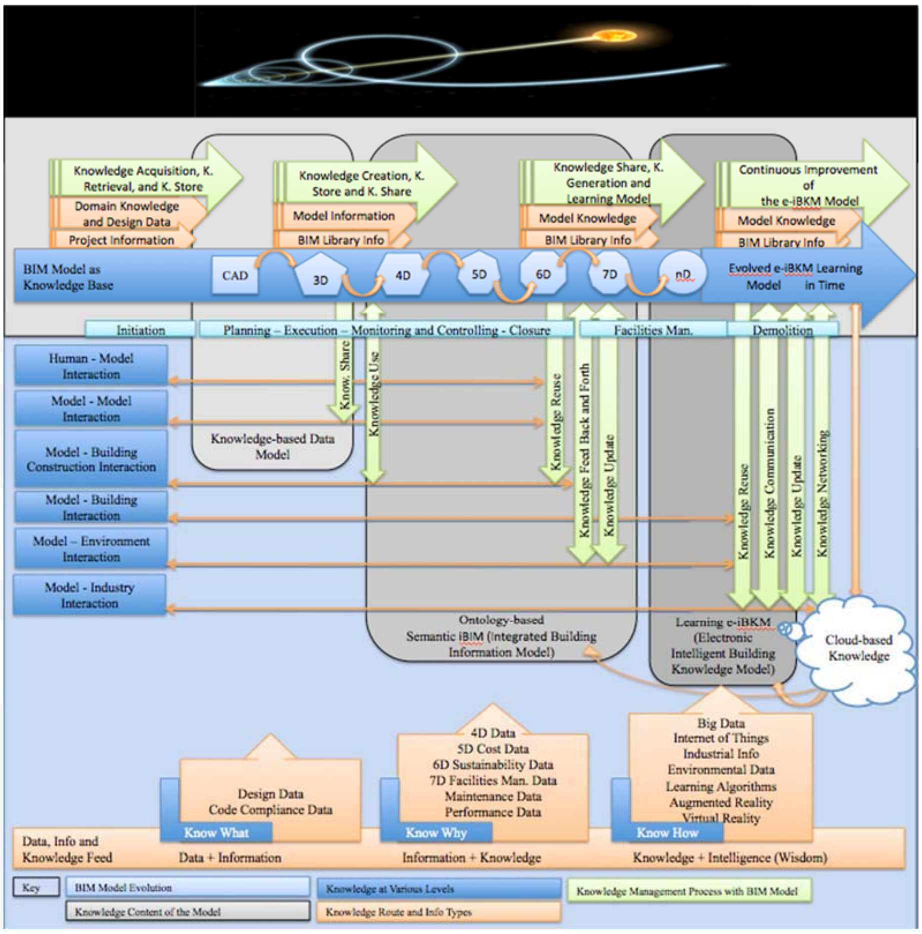

Figure 1. Proposed conceptual model of BIM usage for KM in construction projects

"BIM Level 4" offers an interacting electronic intelligent knowledge model (e-iBKM) that is transparently accessible and workable in a multidisciplinary collaborative environment. The capability of BIM models will increase with emerging technologies such as; artificial intelligence, robotics, the internet of things (IoT), autonomous vehicles, 3D printing technologies, nanotechnology, energy storage, and quantum computing. Following new developments, BIM models will have the ability to review code compliance automatically. This development will enhance international construction companies to satisfy quality and scope requirements. The use of RFID, barcode technology, and GPS will enhance centralized project control and facilitate smart job sites with zero defects. The new technological additions to the model will obtain early phase database program. The data can be directly imported to BIM models. The model provides knowledge in a cloud-based environment. Cloud technology will let to pull knowledge from everywhere. BIM applications on mobile devices can work with the cloud technology so that the mobility of knowledge will be enabled. Data networks will improve the model and ease the share, use, and reuse of knowledge. Knowledge communication will be available with the BIM, virtual reality, and augmented reality technologies' integration. Augmented reality and virtual reality ensures the 3D walk-through experience for project participants, construction team, and marketing professionals. Mobile connection to BIM models through cloud-base environment will let the professionals to update the information on the model and provide the status update of the real time design and construction information. The opportunities the mobile device connection offer through BIM will be unlimited to the construction industry with processing power, high storage capacity, and easy access to knowledge. The Internet of things (IoT) technology connects machines to communicate to each other, which, is machine-to-machine interaction. Communication of knowledge with sensors among technological devices enables computer aided-manufacturing. Theoretically once BIM model pushes the knowledge, the manufacturer's system automatically pulls it and starts activities for production. The system can also work for 3D printing of buildings and other tasks.

Table 3. KM process with BIM usage in construction projects
("KM Generation 4" and "BIM Level 4")

KM Process Steps	Name	Info Type	Interaction Level					
			H-M	M-M	M-BC	M-B	M-E	M-I
Step 1-	Knowledge Acquisition Knowledge Retrieval	Project information, domain knowledge, design data, code compliance data			-	-	-	-
Step 2	Knowledge Creation	Project information, domain knowledge, design data, code compliance data			-	-	-	-
	Knowledge Generation	2D - 3D Model Information						
Step 3	Knowledge Store	2D - 3D Model Information, 3-to-nD Model Knowledge, BIM Library Information						
Step 4	Knowledge Share	2D - 3D Model Information, 3-to-nD Model Knowledge, BIM Library Information						
Step 5	Knowledge Use	2D - 3D Model Information						
	Knowledge Reuse	2D - 3D Model Information, 3-to-nD Model Knowledge	-					
Step 6	Knowledge Feed Back and Forth	3-to-nD Model Knowledge	-					
Step 7	Knowledge Update	2D - 3D Model Information, 3-to-nD Model Knowledge	- -					
Step 8	Knowledge Comm.	IoT Information (Sensor Information), Artificial Intelligence Knowledge, 3D Print Info, Virtual Reality Info, Augmented Reality Info, Learning Algorithms, Environmental Data Servers, 2D - 3D Model Information, 3-to-nD Model Knowledge						
Step 9	Knowledge Networking	Manufacturing Machines' Knowledge, Code Compliance Info, Public Project Control Alliances	-					

[a] Interaction Levels: H-M: Human-to-Model Interaction; M-M: Model-to-Model Interaction; M-BC: Model-to-Building Construction Interaction; M-B: Model-to-Building Interaction; M-E: Model-to-Environment Interaction; M-I: Model-to-Industry Interaction

The promise of e-iBKM model with intelligent decision-making and online working systems, requires new steps in knowledge management process in construction industry. The more the knowledge required, the more complex the knowledge management process is. Intensive interaction among all units will result in the more knowledge to be acquire, retrieve, create, store, share, and use in an e-iBKM model. However, a traditional knowledge management process may not satisfy the 4th industrial revolution's needs. Therefore, new steps of knowledge generation, reuses, feed back and forth, update, communication, and networking are suggested in this paper as seen in table 3.

7. Conclusions

Knowledge management process modified with the latest ICT developments. ICT developments affect the capability of BIM models. The focus on more integrative informative models in construction industry unveils the need for new knowledge management process. BIM models in used in construction industry evolves from 3D to nD. Research intentions in ICT shows that the collaborative studies between ICT and BIM researches will increase the knowledge level and interaction in construction projects. The paper comments on the new knowledge management using BIM in construction projects according to latest improvements. The expanded research framework suggests nine possible steps for knowledge management process. The more interaction will result in the more knowledge BIM models have. The steps of knowledge process including knowledge acquisition, retrieval, creation, store, share, and use is a traditional approach in knowledge management. However, the new 4th knowledge generation extends the content and use of knowledge and changed how it is gathered, generated, stored, shared, and used. Therefore, new additional steps in knowledge management process suggested in this paper, such as; knowledge generation, reuses, feed back and forth, update, communication, and networking are suggested. From theoretical, technological, socio-technological perspectives, the near future promises the enrichment of KM processes and new approach in construction project management activities. Finally, construction industry may become more open for access and transparent to interact with other industries. In turn, the result of stated developments is expected to change the way the buildings and the construction industry works. Future researches' intentions will be more focused on communicative knowledge systems lead learning electronic intelligent building knowledge models evolution. Continuously improved e-iBKM models will adapt to 4th industrial revolution with knowledge era modification on the construction industry.

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