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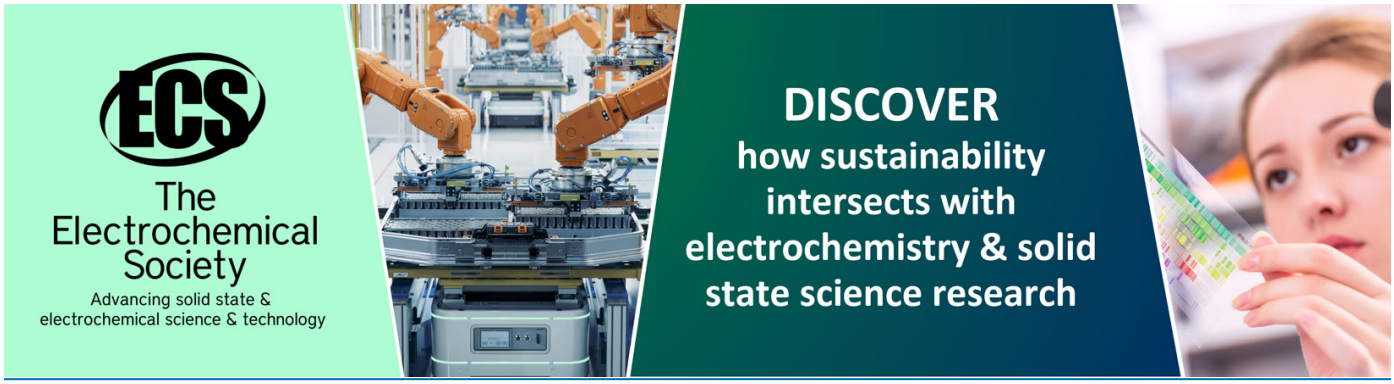

Use of Artificial Intelligence to Improve Knowledge Management in Construction

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Abstract. Considerable progress has been made in the development and deployment of knowledge management (KM) systems in the construction industry. These have included a variety of technology and non-technology-based solutions that have had varying levels of impact on organizational knowledge management. Very few of the technology-based solutions adopted any artificial intelligence (AI) techniques. The current resurgence of AI and data analytics presents a tremendous opportunity to re-engineer knowledge management systems such that they are a much more powerful and critical component of an organization's business infrastructure. This paper starts with a review of the evolution of knowledge management in construction sector organizations, and highlights the potential for AI-based KM. It also discusses the resurgence of AI and data analytics, and highlights the key technologies that could play a role in enhancing construction KM. Drawing on specific KM sub-processes, it describes the applicability of some AI techniques to organizational KM processes and systems. The benefits of the proposed AI-based KM are also presented.

1. Introduction

One of the main reported issues in the construction industry is its fragmentation [1, 2, 3]. Another issue is the short-term project-oriented nature of construction projects [4]. These issues have led to sporadic documentation of project information and losses to many organizations. However, they can be tackled by collecting data and knowledge on the multiple complex systems in construction and creating a formal process for handling and managing them.

Several definitions for Knowledge Management (KM) exist in literature. Among the commonalities in these definitions are: integrated knowledge repository, knowledge funnel from creation to mapping and storage, and knowledge principles that support an organization [5]. Hence, knowledge management seeks to create a method for formally collecting and utilizing data for the benefit of a company. It involves the exploitation of knowledge for accurate and robust decision-making [2]. Previous research has identified two strategies for KM, an information technology approach and a human resource management-centric approach [2, 6]. The information technology (IT) approach uses IT tools to collect and use data while the human resource management-centric approach focuses on the people and how to develop and use their knowledge. The first (IT) approach mainly deals with explicit information rooted in tangible or codable material while the second approach mainly deals with tacit information that is rooted in personal experiences and situations [7]. Methods used to collect and store explicit data include organizational documents, standard operating procedures, lessons learned documentation, and software data. On the other hand, methods used to collect tacit data include

meetings, project debriefing, and peoples' experience. The combined use of these types can aid in the creation of a holistic ontology for the construction industry. Several drivers have been identified for KM adoption in construction including: encouraging continuous improvement, reducing rework, and collecting and sharing tacit information [2, 8, 9].

Knowledge management efforts in a company can span multiple levels. They can be at the project level, intra-organizational level (between stakeholders, e.g. owner, consultant, contractor, supplier, etc.), or inter-organizational level (between multiple departments within a company). All this knowledge is collected to form an organization's Intellectual Capital, which can then be used to create decision support systems [5]. However, knowledge management faces several barriers at the project, company, and industry level. At the industry level, this stems from the heterogeneity of the systems used within and across companies [10]. At the company level, there could be variances in processes among departments regarding data collection and storage or the practices that occur. At the project level, the large number of participants and the diversity in the jobs affects the KM process. Creating a universal ontology would reduce the problems emanating from the heterogeneity of the data [10].

The increasing level of data that manifests in construction projects makes it a knowledge-intensive industry that requires robust systems. This data comes from many sources such as: project documents, BIM logs, site reports, IoT and sensor data. The use of the AI techniques can be for training purposes, safety checks, operation planning, or process optimization. AIoT adds to IoT infrastructures by incorporating AI techniques for analysis and offering insights into an asset's current condition for intelligent decision-making [11]. AI can be used for digital twins to automatically monitor a site/asset, detect problems early-on, and analyze the data collected. 4D printing adds an intelligent layer to 3D printing, which is the possibility of a building to change its shape or behavior over time. Blockchain offers a decentralized method to store data with higher security.

For example, [12] used artificial intelligence to create a model that could predict the outcome of litigation in construction using 132 court cases. While other methods were used by previous researchers, they did not show the same level of accuracy in prediction as using AI. [5] proposed a KM model that combines tacit and explicit knowledge in the macro, meso, and micro levels. [13] identified the factors affecting KM to be the knowledge base, processes, performance measurement, and process shaping factors.

2. Knowledge Management in Construction

Knowledge management has been undertaken in the construction industry from the earliest construction projects, even if it was not called by this name at that time. Early construction projects were led by 'master builders' who had wide-ranging knowledge of the key disciplines required to successfully build a facility. They imparted their knowledge to the various artisans and others that worked on the project primarily by oral means, with varying degrees of assimilation and/or retention by the recipients. They also learned as they moved from one project to another and from other people's projects. There were no formalized mechanisms for managing knowledge, which meant that knowledge capture, sharing and storage were not systematic.

With the growth in awareness of the concept of 'knowledge management' in the nineties, many industry sectors sought to identify ways to better understand and leverage the knowledge resources at their disposal. Nonaka and Takeuchi's seminal publication [14] was an important trigger for many organizations to embark on this journey. Construction organizations were no different with the importance of knowledge management in the industry heightened by structural features of the industry at the time – fragmented project teams, sequential and often discrete project delivery processes, adversarial culture and non-collaborative procurement methods, and lack of a lifecycle perspective to name a few.

KM is particularly relevant given the need for improved innovation and improved business performance required [15] and the reliance on the intellectual assets of project team members [16]. [17] state that knowledge can be managed at different, inter-related levels. These include the management of knowledge within projects (i.e. across different stages of a project and between different stakeholders) and the management of knowledge in individual firms (i.e. between different departments within the same organization). The management of knowledge involves various tasks and

activities that are performed to ensure that knowledge is generated and/or captured, stored, disseminated or shared, and retired. However, this may not necessarily be a linear process, as the context of use and the supporting infrastructure and tools also have to be considered [18, 19]. These interrelated factors can be grouped into four main categories [13]:

- The knowledge base (used in a wider sense) that is to be managed. This includes data, information, and knowledge. The purpose of this knowledge with respect to what it is required for; what it contributes to; who needs it, its criticality etc., also need to be identified.
- The context of use. This includes issues like the factors that initiate the need for knowledge, and how it is managed within the organizational structure and culture.
- The actual processes, procedures and tools required to capture, share and reuse knowledge.
- An indication or measurement of how managed knowledge is contributing to improved business performance, since knowledge management is not an end in itself, but a means to increasing competitive advantage [20, 21].

Over the last twenty years, the construction industry has made tremendous progress in the integration of knowledge management practices and systems into their business processes. Many construction sector organizations have adopted practices and mechanisms that enable them to learn from their projects, embed the learning within the organization, and then share it across the organization and, sometimes, with supply chain or project team members. However, there is a sense that there has not been much further evolution in existing knowledge management systems. There is an opportunity with the re-emergence of AI, for these organizations to revisit their existing practices and systems to identify how best to improve these using the more sophisticated tools now available. Some of these are discussed in the next section.

3. Re-emergence of Artificial Intelligence

AI studies knowledge acquisition, processing, and use. Its applications for knowledge management have spanned several areas including knowledge representation and reasoning, information fusion, natural language processing, and process mining [11]. These areas are fused together to provide a knowledge base and network. Information fusion involves aggregating data from multiple sources, which can include tacit and explicit data types [11, 22].

To increase their competitive advantage, companies have resorted to the use of Artificial Intelligence (AI) to enhance their operations. AI was observed in various applications such as pattern detection, prediction, and optimization [11]. It was used to diagnose and predict project performance in order to identify and quantify potential risks [11]. Several AI technologies have re-emerged over the years for construction applications. According to [23], 24 AI tools were created between 1991 and 2010 while eight new tools were created between 2011 to 2020. Some of these tools have spread into use in the construction industry and have also seeped into Industry 4.0. According to [11] the future directions for AI techniques to support construction 4.0 can be grouped into six categories: smart robotics, cloud VR/AR, Artificial Intelligence of Things (AIoT), digital twins, 4D printing, and blockchain. Another classification that combines AI with Industry 4.0 tools and consists of AI with: IoT, smart cities, augmented/virtual/mixed reality, blockchain, supply chain management, construction contract management, voice user interfaces, and financial audit systems [24].

AI tools offer a fast method of solving complex problems. They have been known to accelerate learning and reasoning from large datasets as well as aid in pattern recognition. AI technologies that have the capacity to influence knowledge management include: 1) data mining and knowledge discovery; 2) machine learning; 3) computer vision; 4) natural language processing; and 5) knowledge-based systems. These are described briefly below and the specific ways in which they can enhance knowledge management are discussed in the next section.

Data mining and knowledge discovery: data mining refers to automated knowledge acquisition and machine learning methods that can analyze raw data [25]. Knowledge discovery is used to extract knowledge from data and identify patterns in construction [26].

Machine Learning (ML): ML is a subset of AI that focuses on creating computer programs that learn from past data or experience in order to model or predict [27]. It offers prescriptive and predictive insights on the data it processes. ML consists of four areas, which are: i) supervised machine learning; ii) unsupervised machine learning; iii) reinforcement learning; and iv) deep learning.

Computer vision: this tool is used to process and understand digital images captured via devices such as cameras and drones. Computer vision offers fast processing, analysis, inspection, and monitoring of visual data. This is especially helpful for site monitoring, which can be automated by capturing images and then processing them to detect anomalies or potential points of clash.

Natural Language Processing (NLP): NLP deals with mimicking the 'linguistic capabilities of human beings' [24] and can analyze 'semantic and grammatical sutures' in text [28]. It has been used for speech recognition, text processing, and information retrieval. However, several limitations are observed such as speech recognition issues or errors in representing certain fragments.

Knowledge-based Systems (KBS): these are computer systems that aid human decision-making based on the knowledge stored stored in the system using a variety of inference mechanisms [29]. They are created to readily provide access to information in a consistent manner. KBS can be classified into four areas, as follows: i) expert systems; ii) case-based reasoning; iii) intelligent tutoring systems; and iv) database management system [24].

4. AI-Based Knowledge Management in Construction

4.1. KM Framework

[30] characterized knowledge management tools as either IT tools (i.e. technologies) or non-IT tools (i.e. techniques). The technologies included tools such as data/text mining, groupware, intranets/extranets, knowledge bases and taxonomies/ontologies. Examples of techniques are brainstorming, communities of practice, face-to-face interactions, recruitment, and training. They argued that key in the effective deployment of these technologies and techniques was understanding the business context for the knowledge management implementation in the organization. One aspect of this involved linking the technologies and techniques to the critical knowledge management sub-processes that organizations deal with: locating and accessing knowledge; capturing knowledge; representing knowledge, sharing knowledge; and creating new knowledge. These are briefly described below:

- Locating and accessing knowledge: this is concerned with identifying where the knowledge an organization needs resides and finding a way to gain access to the knowledge;
- Capturing knowledge: this usually entails acquiring knowledge and putting it in an accessible explicit form that facilitates its sharing;
- Representing knowledge: how the captured knowledge is represented in a system determines how readily it can be retrieved, shared or transferred;
- Sharing knowledge: a key aspect of knowledge management is facilitating the sharing of knowledge, and this can involve very informal methods to highly structured approaches;
- Creating new knowledge: this is one of the expected outcomes from knowledge management and needs to be supported by mechanisms for synthesizing and contextualizing existing knowledge.

The above sub-processes provide a useful framework for exploring how emerging artificial intelligence can provide improved knowledge management in construction organizations.

4.2. AI Support for Knowledge Management Processes

There are numerous ways in which artificial intelligence (AI) can support knowledge management in construction. The key technologies identified in Section 2 will be used to illustrate the potential support – data mining and knowledge discovery, computer vision, machine learning, natural language processing and knowledge-based systems. These are discussed below in relation to the identified knowledge management sub-processes highlighted earlier.

Data Mining and Knowledge Discovery: These can be used primarily for locating existing knowledge but can contribute to the creation of new knowledge as the data mined can be combined or deployed in a way that new knowledge is created. By definition, knowledge discovery generally results in the creation of new knowledge. Construction documents and databases relating to past or current projects can be mined to unearth new insights that can enhance an organization's knowledge base and support knowledge management efforts.

Computer Vision: This is not yet as widely deployed in an active way in construction settings. It has considerable potential for knowledge capture and knowledge sharing. Computer vision systems can capture the knowledge associated with how certain project activities are undertaken and used in communities of practice or training settings for knowledge sharing. Automated analysis of video images is now growing and provide insights into patterns of work activities, worker interactions, equipment operations, project team member on-site activities, and other project elements that can generate new knowledge about the construction project delivery process or a subset thereof.

Machine Learning: There has been a tremendous growth in machine learning algorithms and associated systems in the re-emergence of AI. These can learn from previous process outcomes, experiences, decisions and preferences to suggest new paths forward. As such, they can support all the knowledge management sub-processes by learning from previous approaches to knowledge location/access, capture, sharing, representation and creation to offer significant improvements that improve the quality, accessibility and value of an organization's KM systems. Deep learning can also be deployed on large corporate knowledge repositories to automate the retrieval and customization of knowledge to address new problems.

Natural Language Processing (NLP): There are numerous ways in which NLP can support knowledge management. At a simple level, NLP can be used to facilitate the elicitation or capture of knowledge from people through direct interviews, recording of formal/informal training sessions, or making sense of communities of practice meetings. It also offers the capacity to represent the knowledge captured in audio form, which would be highly useful in many contexts. NLP can also support knowledge sharing by simplifying retrieval requests to spoken queries, with the results also conveyed to the user in natural language, with significantly reduced scope for misunderstanding.

Knowledge-based Systems (KBS): Over the years, numerous knowledge-based systems have been developed for aspects of design and construction. While a few of these have been developed into commercial products either as standalone systems or embedded in larger systems, the vast majority have remained at the unexploited prototype stage. KBS can be integrated into an organization's knowledge management infrastructure such that they enhance the corporate knowledge base and facilitate all the knowledge management sub-processes to varying extents.

Other related technologies that could have an impact include the following:

- Big Data Analytics, which allows for large data sets to be analyzed to identify trends, patterns, relationships, and other information that can enhance an organization's knowledge base;
- Internet of Things (IoT): this builds on the existing internet by allowing distributed objects (also referred to as 'things' in IOT) to be sensed and interconnected across communications networks, thereby enabling them to be centrally monitored and controlled [31];

- Cloud Computing, which provides 'a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g. networks, servers, storage, applications and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction' [32];

When deployed in combination with the previously mentioned AI technologies in knowledge management, the resulting knowledge management infrastructure would be very powerful and could considerably enhance an organization's knowledge base, and both the agility and quality of its decision-making.

4.3. Benefits of AI-based Knowledge Management

The deployment of AI technologies in knowledge management, if done effectively, offers tremendous benefits. Some of these are outlined below:

- there is potential for much faster retrieval of existing knowledge;
- ease of matching existing knowledge to new problems;
- increased capacity to leverage existing knowledge to create new knowledge;
- improved validation of new knowledge before integration into corporate knowledge base;
- more opportunities and mechanisms for knowledge capture, sharing and reuse;
- improved decision making due to ready access to up-to-date, context-specific knowledge;
- increased intellectual capital of construction organizations due to knowing more of what the individuals in the organization know;
- greater flexibility in the representation of knowledge in corporate knowledge bases.

5. Summary and Conclusions

This paper has sought to revisit knowledge management in the construction industry with a focus on the opportunities offered by the re-emergence of artificial intelligence. It first reviewed the evolution of knowledge management in construction and then explored the re-emergence of artificial intelligence and its potential for enhancing knowledge management systems and practices. The specific ways in which AI can support KM in the construction industry are discussed based on the key knowledge management sub-processes of locating and accessing knowledge, capturing knowledge, representing knowledge, sharing knowledge, and creating new knowledge. It was shown that re-emerging AI technologies such as data mining and knowledge discovery, computer vision, machine learning, natural language processing, and knowledge-based systems offer varying degrees of support to the afore-mentioned knowledge management sub-processes. It is evident that there are considerable benefits in the integration of these AI technologies into knowledge management systems and practices. Construction sector organizations stand to benefit considerably from this, and need to invest in upgrading their systems and processes to leverage the power of AI. Future work on this study will involve focusing on the development of a specific use case, with the potential to develop and implement a prototype in a construction-sector organization.

6. References

[1] Anumba C J and Evbuomwan N F O 1997 Concurrent Engineering in Design-Build Projects *Construction Management and Economics* **15** 3 pp 271-281

[2] Carrillo P and Chinowsky P 2006 Exploiting knowledge management: the engineering and construction perspective *Journal of Management in Engineering* **22** 1, 2–10 doi:10.1061/(ASCE)0742-597X(2006) **22** 1(2)

[3] Bhargav D and Koskela L 2009 Collaborative knowledge management—a construction case study. *Automation in Construction*, **18** 7, 894–902. doi:10.1016/j.autcon.2009.03.015

[4] Egbu C, Botterill K and Bates M 2001 The influence of knowledge management and intellectual capital on organizational innovations *Proceedings ARCOM Seventeenth Annual Conference*, ARCOM, University of Salford, Salford, **2** 547–555

[5] Kanapeckiene L, Kaklauskas A, Zavadskas EK and Seniut M 2010 Integrated knowledge management model and system for construction projects, *Engineering Applications of Artificial Intelligence*, **23** 1200–1215. doi:10.1016/j.engappai.2010.01.030
[6] Anumba CJ, Egbu CO and Carrillo PM 2005, Knowledge Management in Construction *Blackwell Publishing*, Oxford, UK
[7] Lei Z and Wang L 2020 Construction of organisational system of enterprise knowledge management networking module based on artificial intelligence. *Knowledge Management Research & Practice*, 1–13. doi:10.1080/14778238.2020.1831892
[8] Egbu CO, Anumba CJ and Carrillo PM 2005 Introduction in Anumba C. J., Egbu C. O. and Carrillo P. M. (eds), *Knowledge Management in Construction*, Blackwell Publishing, Oxford, UK
[9] Robinson HS, Carrillo PM, Anumba, CJ and Al-Ghassani AM 2001 Perceptions and barriers in implementing knowledge management strategies in large construction organizations *Proc., RICS Foundation Construction and Building Research Conference*- COBRA 2001 RICS Foundation Glasgow, U.K., 451-460
[10] Anumba CJ, Issa RRA, Pan J and Mutis I 2008 Ontology-based information and knowledge management in construction, *Construction Innovation*, **8** 218–239 doi:10.1108/14714170810888976
[11] Pan, Y.; and Zhang, L. (2021). Roles of artificial intelligence in construction engineering and management: A critical review and future trends. *Automation in Construction*, **122** 103517 doi:10.1016/j.autcon.2020.103517
[12] Arditi D and Pulket T 2010 Predicting the outcome of construction litigation using an integrated artificial intelligence model *Journal of Computing in Civil Engineering* **24** 73–80 doi:10.1061/(ASCE)0887-3801(2010)24:1(73)
[13] Carrillo P M, Anumba C J and Kamara J M 2000 Knowledge management strategy for construction: Key I.T. and contextual issues. *Proceedings of Construction Information Technology (CIT 2000),* Reykjavik, Iceland, **1**, 155–165
[14] Nonaka I and Takeuchi H 1995 The Knowledge-creating company: how Japanese companies create the dynamics of innovation *Oxford University Press*, New York
[15] Egan J 1998 Rethinking construction *Report of the Construction Task Force on the Scope for Improving the Quality and Efficiency of UK Construction* Department of the Environment, Transport and the Regions, London
[16] Egbu CO 1999 The role of knowledge management and innovation in improving construction competitiveness *Building Technology and Management Journal* **25** 1–10
[17] Kamara J M, Anumba C J and Carrillo P M 2000 Integration of knowledge management within construction business processes in Faraj, I and Amor, B. (eds.), *Proceedings of the UK National Conference on Objects and Integration for Architecture, Engineering and Construction*, 13-14 March, Building Research Establishment Ltd., pp. 95-105
[18] Ludon KC and Laudon J 2000 *Management Information Systems*, Prentice Hall, Sixth Edition.
[19] Webb SP 1998 Knowledge management: linchpin of change The Association for *Information Management* (ASLIB), London.
[20] Drucker P 1993 Post-Capital Society, *Butterworth-Heinemann*, Oxford.
[21] Skyrme D J and Amidon D A 1997 A report on: creating the knowledge-based business. *Business Intelligent Limited*, London, UK.
[22] Khallaf R, Naderpajouh N and Hastak M 2018 A systematic approach to develop risk registry frameworks for complex projects *Built Environment Project and Asset Management*, https:// doi.org/10.1108/BEPAM-08-2017-0051
[23] Momade, M H, Durdyev S, Estrella D and Ismail S 2021 Systematic review of application of artificial intelligence tools in architectural, engineering and construction, *Frontiers in Engineering and Built Environment*, **1** pp. 203-16. https://doi.org/10.1108/FEBE-07-2021-0036
[24] Abioye S, Oyedele L, Akanbi L, Ajayi A, Delgado J M D, Bilal M, Akinade O O and Ahmed A 2021 Artificial intelligence in the construction industry: A review of present status,

opportunities and future challenges *Journal of Building Engineering*, **44** 103299, ISSN 2352-7102, https://doi.org/10.1016/j.jobe.2021.103299
[25] Leu S, Chen C and Chang S 2001 Data mining for tunnel support stability: neural network approach *Automation in Construction,* 10(4), 429–441. doi:10.1016/s0926-5805(00)00078-9
[26] Soibelman L and Kim H 2000 Generating construction knowledge with knowledge discovery in databases. *Proceedings Eighth International Conference on Computing in Civil and Building Engineering (ICCCBE-VIII),* Stanford, USA, pp 906–913. doi:10.1061/40513(279)118
[27] Khallaf R and Khallaf M 2021 Classification and Analysis of Deep Learning Applications in Construction: A Systematic Literature Review *Automation in Construction*, **129** 103760
[28] Zhang F, Fleyeh H, Wang X and Lu M 2019 Construction site accident analysis using text mining and natural language processing techniques *Automation in Construction*, **99** 238–248 doi:10.1016/j.autcon.2018.12.016
[29] Scott D and Anumba C J 1996 An intelligent approach to the engineering management of subsidence cases, *Engineering, Construction and Architectural Management* **3** 233-248
[30] Al-Ghassani A M 2002 Literature review on KM tools. Technical Report, July 2002, Department of Civil and Building Engineering, Loughborough University, UK
[31] Miorandi D, Sicari S, De Pellegrini F and Chlamtac I 2012 Internet of things: vision, applications and research challenges *Ad hoc Networks*, **10** 1497-1516
[32] Mell P and Grance T 2011 The NIST definition of cloud computing (Technical Report), *National Institute of Standards and Technology* U.S. Department of Commerce, doi:10.6028/NIST.SP.800-145. Special Publication 800-145