ICCEPM 2022
The 9th International Conference on Construction Engineering and Project Management
Jun. 20-23, 2022, Las Vegas, NV, USA

'Knowing' with AI in construction – An empirical insight

Shobha Ramalingham[1], Alan Mossman[2]*

[1] *Associate Professor, National Institute of Construction Management and Research (NICMAR), Pune, India. sramalingam@nicmar.ac.in; orcid.org/0000-0003-4026-5866*
[2] *Principal, The Change Business, Stroud, 19 Piccadilly, GL5 1HB, UK. alanmossman@mac.com; orcid.org/0000-0003-1769-9164*

Abstract: Construction is a collaborative endeavor. The complexity in delivering construction projects successfully is impacted by the effective collaboration needs of a multitude of stakeholders throughout the project life-cycle. Technologies such as Building Information Modelling and relational project delivery approaches such as Alliancing and Integrated Project Delivery have developed to address this conundrum. However, with the onset of the pandemic, the digital economy has surged world-wide and advances in technology such as in the areas of machine learning (ML) and Artificial Intelligence (AI) have grown deep roots across specializations and domains to the point of matching its capabilities to the human mind. Several recent studies have both explored the role of AI in the construction process and highlighted its benefits. In contrast, literature in the organization studies field has highlighted the fear that tasks currently done by humans will be done by AI in future. Motivated by these insights and with the understanding that construction is a labour intensive sector where knowledge is both fragmented and predominantly tacit in nature, this paper explores the integration of AI in construction processes across project phases from planning, scheduling, execution and maintenance operations using literary evidence and experiential insights. The findings show that AI can complement human skills rather than provide a substitute for them. This preliminary study is expected to be a stepping stone for further research and implementation in practice.
Key words: Construction process, Artificial Intelligence, Critical Path Method, Last Planner System, Project risks

1. INTRODUCTION

The construction sector is considered slow to adopt new technologies and break conventional barriers. This has hindered its growth and led to extremely low productivity levels when compared to other industries such as manufacturing. Digital technologies have helped other sectors to become more efficient and thereby improve their business operations. In recent years the adoption of Artifical Intelligence (AI) techniques has provided firms with competitive advantage as compared to conventional approaches. The subfields of AI include machine learning, natural language processing, robotics, computer vision, optimisation, automated planning and scheduling [1]. The main purpose for the development of AI was to tackle complex problems and support decision-making. Projects in construction are invariably both unique and complex; construction remains one of the least digitized sectors. Decision making is a primary skill for project managers executing projects in a volatile and dynamic environment. There are few studies that discuss the beneficial adoption of AI and other technologies. Other studies show workers are apprehensive about the potential of AI to make them redeundant. Motivated by these contrasting insights, this study attempts to explore the integration benefits and challenges of AI applications in construction projects. The study is exploratory in nature due to current limited adoption in practice.

Construction is knowledge intensive and AI can play an important role in processing knowledge to enable informed decision-making. Machine Learning (ML), a subset of AI, allows machines to acquire, process and use knowledge to perform various tasks. ML uses experience or past data to model, control or predict using statistical techniques without being explicitly programmed. Thus ML helps to generate predictive and prescriptive insights that can reduce mistakes and omissions, yet its ability to work with live or high-dimensional data is limited [2]. In contrast, knowledge based systems, yet another subset of AI, can work with incomplete data and has the ability to explain reasoning behind the solution. However they suffer from limited representation of fragmented information or speech recognitions issues such as accent variation etc. Preliminary insights such as these intrigue us to explore the AI features that improve communication, collaboration amongst stakeholders and enable enhanced productivity. The rising need for digitization across industries, especially during the pandemic, has also given rise to job insecurity issues with the advancement in technology reaching the capability of human mind to perform tasks. To this end, this study tries to probe the role of AI in construction and the extent of human intervention needed to support the process.

2. METHOD

The study is exploratory in nature due to its inherent novelty in the construction field. Litearary evidences and theoretical insights from the field of construction, organization studies, information technology and communication form the basis for an intuitive and inductive questioning methodology supported with empirical reasoning to explore the integration of advanced digitization including AI with conventional project delivery system. The authors use a narrative approach to highlight the significant role of human interventions needed in the process. The following sections discuss the role of AI in construction projects.

3. AI IN CONSTRUCTION PROJECT PHASES

AI is relevant to the entire life cycle of a project from project planning to execution and in the operations and maintenance phases. Sub-sections 3.1 to 3.3 discuss each of the project phases with literary evidences and experiential insights.

3.1. Preconstruction phase: Planning and Scheduling

Planning starts in the pre-construction phase of a project. Traditional planning techniques are based around the Critical Path Method (CPM) which is developed through a systematic decomposition of the project scope and then sequencing the activities along a timeline based on some (but not all) of their interdependences.

CPM enables planners to test the feasibility of completing a project within a given time frame. In an effort to make it robust, control mechanisms such as earned value are used to monitor the progress of the project and take remedial measures in order to mitigate project risks. While CPM is great for testing the feasibility of a particular project schedule, it is useless for delivering projects on time and within budget for reasons outlined in [3].

As [4] notes, CPM applies reactive control measures rather than using proactive actions to reduce or eliminate time and cost overruns. Second, the sequential planning and execution works with a hand-off approach (wherein one trade hands-off the project deliverables to the next trade for execution) can lead to constant changes in the design to accommodate constructability issues and multi-trade requirements leading to rework and cost over run. Advanced collaborative tools such as BIM aim to mitigate some of the rework issues by simulating the construction sequence in advance and thereby detecting clashes across trades to avoid rework. Third, literature on Alliancing and Lean Integrated Project Delivery have further emphasized the need for collaborative planning during the design development phases of a project to enable earlier detection and and mitigation of project risks [5].

Literature on AI promises benefits to enable efficient planning and progress management of the project tasks. For instance, [6] reports that artificial neural networks can help predict cost overrun based on project size, contract type and competence level of project managers (but note that prediction of a cost overrun gives no indication of the root cause of the potential overrun, though it may be able to do that in the future). Second, provision of adequate resources is yet another planning requirement for successful project delivery (it is absent from CPM). Lack of skilled labour can delay projects. AI can reduce the lead time required to develop the necessary skills. Third, integrating AI with BIM may enable generative design solutions apart from mitigating clashes between structures, MEP and architecture works.

While all these insights are promising to the future of construction projects, yet another school of thought argues on the CPM approach of planning and execution. For instance, studies by Mossman and Sarhan [3] argue that CPM cannot enable end-to-end synchronization and coordination of the trades. They demonstrate the need to focus on process and sub-processes within the project schedule to enable effective project delivery and the need for dialogue and constant conversation through the *Last Planner System* (LPS) to enable shared understanding as the basis for effective project delivery.

CPM is based around the sequence of transformations that are needed. CPM programs are generally used to *push* work into production. LPS is a collaborative learning system based around ensuring that the transformations create value (what the customer wants) in a smooth production flow. As noted above, CPM is a great way to test the feasibility of delivering a project within a given time but it was never designed for managing production. LPS is a production scheduling system based on short-term planning that involves trade crew leaders working together to plan the sequence and handovers of work. As in a relay race smooth handovers are critical to successful project delivery.

Along these lines, the literature on knowledge management further reiterates the need for all parties (including the trades) to effectively exchange explicit, implicit and tacit knowledge on projects for a coordinated outcome. While explicit knowledge is transferrable through rules and procedural information, the challenge lies in transferring the implicit knowledge embedded within tools and technologies. For instance, [6] report the challenges faced by distributed engineering teams working across national boundaries to accurately interpret the symbols transferred through an Excel spreadsheet. Further, construction knowledge is fragmented and the knowledge is tacit and deeply rooted within the trades so that it is not easily codifiable or easily documented. Physicist Michael Polanyi [7] defined "*tacit knowledge*" as a quantifiable or commonly understood outcome that a human achieves by performing a task that can't be codified by a repeatable rule. In construction, trade specific technical knowledge and the local knowledge of a country or region with its cultural differences especially in global projects are pre-dominantly tacit in nature. Studies have also shown the need for effective human communication for transfer of tacit knowledge in projects. This is reinforced by the experience of Training within Industry [e.g. 8] over the last 70+ years.

A pre-requisite for effective communicaton is in-turn creation of shared understanding to add value to the *conditions of satisfaction* for each trade and the overall project. For instance, in one of the projects in a study [9], the contractor and the consultant held weekly meetings and referred to a particular work package in a local dialect. It was observed that the teams that met regularly and shared the common language delivered a more coordinated effort than the teams that were irregular. Thus a mental mode of sharing understanding was necessary for effective transfer of knowledge and project delivery. This tacit dimension forms the basis of decision making and serves as a competitive advantage for the trades, especially when working in a volatile, uncertain, complex and dynamic environment such as in construction where change in plans are unavoidable and constantly changing. Knowledge from past experience, knowledge from past projects and circumstantial know-how form the basis for tacit knowledge which are deep rooted within project teams.

Researchers in the field of information and technology have explored the need for tools to enable knowledge management and knowledge transfer in projects. Understanding the fact that tacit knowledge lies in the minds and muscles of people and tools are limited by their inability to formalize tacit knowledge, organization theorists contend that this would form the basis for distinction beween human and digital capabilities in work and therefore advancement in technologies may not erode the existential proposition of workforce. Citing an example quoted by Polanyi, *'the inarticulate know-how that enables specialists to apply the relevant learning can be imparted only in person and that's why, the world over, students follow doctors on ward rounds. A specialist doctor recognises malignant pigmentation but cannot articulate precisely what leads her to that conclusion'* [7].

Alternatively, if it is presumed that robots can be programmed to acquire tacit knowledge, then AI-powered, centralised and controlled planning might well outperform decentralised interactions in coordinating any form of economic activity. Yet there is good reason to believe that the philosophies of mid-20th-century anti-planners, including Polanyi, were right – even when computers revolutionized the economy. For instance, Hayek [10] was critical of "planners" who capture data (statistics) without the context in which it was created. Construction projects in essence uphold contextual information embedded in the projects. Polanyi argued that this specific local knowledge was irreducible to statistical form through which people filtered information for decision making such as price signals for supply and demand. Tacit knowledge will probably remain the preserve of human beings with large implications for the economy.

In yet another instance, literature documents the algorithmic shortcomings through an illustration of red-blue bus choice decision making [7]. In the example, if a person has a choice to board a car or a bus, the probability of him selecting an option would be 50% each (1/2). If there are two buses of different colours (red and blue) and a car, then the probability of slecting an option according to statistics is 1/3 but in reality to the choice maker would be only ½ for the red or blue color would become immaterial if it had no particular significance. Thus, Polanyi's red/blue bus illustration is a good example of how algorithmic computation can fail. In essence, *AI and computation models cannot distinguish the subtleties of linguistic description which is intuitively possible for human beings*. In sum, while AI might support planning, monitoring and control of projects, AI cannot become all pervasive in the process.

3.2. Construction phase: Execution

In the execution phase of construction projects, the role of AI and other advanced digital tools are notable in literature for maintaining site logistics, enhancing productivity, quality and safety and assessing project performance and risks in projects.

With respect to site analytics, drones can scan and capture 3D site data which can then be fed into deep neural networks and into algorithms to identify the deviation and variation in projects with respect to cost and time and further help the contractors or the project manger to classify site and logistics related issues into minor or major problems when synchronized with the project schedule. Similarly, in the field of automation, a robot can constantly evaluate job progress and assess optimal utilization of resources. Multi-use automation mechanisms can benefit project sites. For instance, if drones (for example) can assess the location of workers and equipment it may be possible to establish which job sites have enough workers and equipment to complete the project on schedule, and which might be falling behind or where additional labor could be deployed. AI could help in training manpower in parallel both remotely and on-the-job.

AI can help mechanize or automate repetitive tasks such as pouring concrete, bricklaying, welding, and demolition works as well as off-site fabrication work (e.g. single or multi-trade prefabricated walls, columns, beams, even whole rooms, for many different project types). This will only improve productivity and effectiveness while reducing production both production time and cost *IF* quality work flows smoothly from trade to trade. Poor quality and interrupted flow add to project duration and cost.

The same condition applies to on-site construction and the opportunites for using AI on-site are currently more limited. This is why it is important to focus improvement activities at bottlenecks in the construction process (on- or off-site) by 1. Establishing the root cause(s) of the bottleneck; 2. Defining countermeasures to address the root causes and 3. Studying the effects of their use and redesigning them if necessary so that *the countermeasures allow the end-to-end process to flow*. See e.g. [10] or The Improvement Kata in [12]. This will help the construction team deliver the projects on-time, within budget to good quality. As Deming [13] pointed out, attending to quality is the only way to both improve productivity and reduce costs.

Using the Last Planner System (LPS) with its focus on crew leaders managing production collaboratively with project superintendents, everyday learning [14] and delivering quality right-first-time [15] enables production flow and the early identification and removal of production constraints and bottlernecks. LPS encourages trade teams to refuse to promise to deliver tasks that they know they cannot complete. AI with its pre-programmed operations could be limited to identifying the constraints that occur dynamically in projects

AI and ML can enable assessmet of the production process to conform to procedures and thereby assure quality of outcome. Further, AI and ML algorithms can help to prioritize risks in projects with respect to project performance measures including quality, safety, cost and time. For example, a Boston-based construction company reports that it created an algorithm that analyzes photos from its job sites, scans them for safety hazards such as workers not wearing protective equipment, not wearing masks during covid etc. and correlates the images with its accident records. The company says it can potentially compute risk ratings for projects so safety briefings can be held when an elevated threat is detected [16].

As Gregory Bateson (or was it Stafford Beer?) noted “Information is that which changes us”. Data generated from images captured from mobile devices, drone videos, security sensors, building information modeling (BIM), and analytical tools flows into the data pool. Integrtaing data from all sources so that it becomes useful information is reported to be yet another challenge in the digitized world [16]. Use of big data and tools such as BIM help to integrate all the data generated on the project to create a dashboard of information that can be synthesized for forecasting trends and mitigating project risks. However, sensing data with experiential insight to inform the decision making process remains a human skill.

People in construction produce unique products for unique customer (client/owner) systems as well as the next trades in line. Each client system and each trade may have different *Conditions of Satisfaction* [17]. This means that the criteria for a quality product can differ both from project to project and, on larger projects, even within the project. In order to consistently deliver quality it is important that the specific customers’ criteria are understood by the producer [14]. This consideration requires attention in the philosophy of AI. We will return to this idea later in the discussion.

3.3. Post-construction phase: Operation & Maintenance

AI is useful for managing assets, for assessing and managing the operation and performance of a building. The first so-called *intelligent building* (IB), City Place, was opened in Hertford, CT, United States in 1984. Since then the idea of an IB has evolved. IBs help building owners, property managers, and occupants realize their goals in the areas of cost, comfort, convenience, safety, long-term flexibility and marketability [18] and they can help maximize the effectiveness of the occupants while at the same time enabling efficient management of resources with minimum life-time costs of hardware and facilities — i.e. IBs take care of us and of themselves.

The Edge, an office building in Amsterdam opened in 2015. Supported by 30,000 sensors the building management system (BMS) is fed with data in real time about: the presence of people in the building (anonymous) – with zero occupancy there is next-to-zero energy use; Heating, cooling, fresh air and lighting are integrated via IoT (Internet of Things) and the BMS independently controls each $20m^2$ of the building based on occupancy, identifies rooms that have not been used so they don't need cleaning; lights that need replacing; printers needing paper; predicts occupancy at lunchtime based on real time and historical data, traffic and weather information to avoid food-waste. With the increase in Working from Home since the start of the Covid pandemic, these 'skills' in an IB, like *The Edge,* can have a significant effect on the carbon footprint of our built environment.

Sensors can be used to assess the strength of structures. Advanced data analytics and AI-powered algorithms can help to gain valuable insights in managing a facilities such as roads, bridges and other infrastructure projects [2]. AI can also be used to identify developing problems and determine when preventative maintenance may be required. In essence, AI supported service can ensure a proactive approach to analyze data, forecast and predict for smoother operation and maintenance.

4. DISCUSSION

The surge in the application of AI in various domains through the pandemic has created feelings of insecurity among humans. After all change is not easily accepted and is predominantly resisted. The thought that AI will outperform human expertise is the premise of this resistance. To this end, we have attempted to analyse the probable role of AI in construction project delivery and probe the role of AI with human aspirations and Conditions of Satisfaction.

The literary evidences and experiential insights discussed in the earlier sections bring out the tremendous possibility of AI in projects. The suite of tools along with AI can enhance the capabilities of project performance. For example, in the design of a hospital building, architects can don virtual reality googles for spatial recognition and optimal allocation of equipments and furniture or send mini robots into the buildings envelop during construction to track the work as it progress. The possibilities are therefore immense. As in the Boston case example, companies are also using AI to identify safety training needs, develop safety training, safety awareness programs or alert supervisors of safety related issues. AI can improve worker efficiency by standardizing production process and enhance productivity issues. AI can analyze large datasets in fraction of seconds with accuracy thereby allowing the workforce to focus on decision making capabilities. Nevertheless, the role of AI in enabling collaboration of multitude of stakeholders, which in turn could enable effective transfer of tacit knowledge embedded in projects and within teams are still debatable.

As a next step, we have attempted to map the role of AI with human aspirations. While researchers predict that AI will foremost improve efficiency in work, AI could also bring possibilities of customization in certain work fronts such as in training and education. These outcomes if mapped to human aspirations then – efficiency can lead to job satisfaction and second, possibilities of customization can create a sense of identity or individualism leading to satisfaction. Such cognitive knowledge are still unexplored. Many criticize the role of AI with respect to ethical issues such as in bringing imbalance in power or foresee misuse of power and so on [10]. Yet, another school of thought observes that barring its disadvantages, it will have a common good. For instance, while 'facebook' is criticized for breach of privacy of individuals, there is larger understanding on the common good due to networking and communication possibilities through such platforms. This is in tune with some of the networking specialists such as Craig Mathias, principal at Farpoint Group who opine that 'roads and highways – will simply be unable to function in the future without AI [2].

As noted earlier, people in construction produce unique products for unique customer systems. How can machines know what the criteria for success for the current project are? If they cannot, they have the potential to guide the production of something other than what the customer wants. In the 2021 BBC Reith Lectures Prof Stuart Russel talked about '*Living with AI*' [19]. In the final lecture Russel asked how we can organize things so that AI cannot become the 'boss' and went on to outline three principles:

- The machine's only objective is to maximise the realisation of human preferences.
- The machine is initially uncertain about what those preferences are.
- The ultimate source of information about human preferences is human behaviour. These principles are really important, as they ensure machines will always have a large amount of uncertainty about our preferences. In the case of construction, they should not assume they can generalise from the preferences of other customers on other projects.

5. CONCLUSION

AI is unlikely to replace the human workforce. Instead, AI would enhance human capabilities. It will alter the way projects are delivered. It will help to reduce expensive errors, reduce worksite injuries and make building operations both more effective and more efficient. AI might get integrated into many aspects of projects and enable efficiencies but at the same time, new roles will be created, such as evident with the BIM platform wherein companies have instituted the role of BIM managers, leaders and coordinators. This will require people to be flexible and adaptive to this cultural change in the sector. In essence, the sustenance of AI would lie in its complementarities with human skills rather than its substitutability. Qualitative and quantitative validation studies are necessary to support the empirical insights.

Research is now needed in several integrated areas of the field. Some of which could be to:

- Explore knowledge transfer through AI.
- Explore the ability of AI to accumulate and use tacit knowledge and to make that knowledge explicit
- Explore the role of AI in understanding the dynamic socio-technical interactions impacting team and project performance.
- Explore ways to ensure that human preferences are at the heart of all operations in construction.

REFERENCES

[1] V. Pratt, *Thinking machines – The evolution of artificial intelligence*, Oxford: Basil Blackwell (1987).

[2] C. Balaguer, M. Abderrahim, Trends in robotics and automation in construction, in: *Robotics and Automation in Construction*, IntechOpen, 2008.
[3] Mossman, A. and Sarhan, S., 2021 Synchronising Off-Site Fabrication with On-Site Production in Construction. *AJCEB* 21(3) 122-141
[4] S. Zhang, et al., BIM-based fall hazard identification and prevention in construction safety planning, *Saf. Sci*. 72 (2015) 31–45.
[5] Engebo, A., Ladre, O., Young, B., Larssen, P. F., Lohne, J., & Klakegg, O. J. (2020). Collaborative project delivery methods: A scoping review. *Journal of Civil Engineering and Management*, *26*(3), 278-288.
[6] P.M. Leonardi and D.E. Bailey, Transformational Technologies and the Creation of New Work Practices: Making Implicit Knowledge Explicit in Task-Based Offshoring, *MIS Quarterly*, Vol,32, No.2, (2008), pp. 411-436
[7] M. Polanyi, *The Tacit Dimension*, Peter Smith Gloucester, Massachusetts, MA, (1983).
[8] Dinero, D.A., 2005. *Training within Industry: The foundation of lean*. Productivity Press.
[9] M. Addis, Tacit and explicit knowledge in construction management, *Construction Management and Economics*, 34(7-8), 2016
[10] Hayek, F.A., 1945. The use of knowledge in society. *Am. Econ Rev*. 35(4) 519-30.
[11] Langley, GJ, Nolan, KM and TW, Norman, CL, and Provost LP., 1996. *The Improvement Guide*. Jossey-Bass. San Francisco.
[12] Rother, M. 2010. *Toyota Kata*. McGraw Hill
[13] Deming, WE., 1985. *Out of the Crisis*. MIT Press.
[14] Mossman, A. and Ramalingam, S., 2021. 'Last Planner, Everyday Learning, Shared Understanding & Rework' In-, *Proc. 29th Annual Conference of the International Group for Lean Construction (IGLC)*. Lima, Peru, 14-16 Jul 2021. pp 697-706
[15] Mossman, A. and Ramalingam, S., 2021. 'One Bad Apple – The arithmetic of quality and the cost of rework.' In *Proc. of Indian Lean Construction Conf. 2021*, Ahmedabad, India.
[16] M. Bilal, L.O. Oyedele, H.O. Kusimo, H.A. Owolabi, L.A. Akanbi, A.O. Ajayi, O. O. Akinade, J.M.D. Delgado, Investigating profitability performance of construction projects using big data: a project analytics approach, *J. Build. Eng*. 26 (2019), 100850.
[17] Fernando Flores. 2013. *Conversations for Action and Collected Essays*. CreateSpace
[18] So, A.T. and Chan, W.L., 1999. *Intelligent Building Systems*. Kluwer Academic Publishers.
[19] Stuart Russell. *Living With Artificial Intelligence*. The BBC Reith Lectures 2021. to listen to the lectures or read the transcripts go to: https://www.bbc.co.uk/programmes/m001216k/ [15Feb22]