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TOWARDS DIGITIZING THE CONSTRUCTION INDUSTRY: STATE OF THE ART OF CONSTRUCTION 4.0

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Having a significant economic impact in country's GDP and being a major workforce, construction industry is yet characterized by low production rate, low technological advancement, minimum automation and robotic usage, and so on. With the visionary idea of Industry 4.0 that focuses on digitization of the value chain of a product and improving productivity through a variety of technologies and automated manufacturing environment, this research aims to develop a framework to adopt Construction 4.0 within a construction company. Current state of the art of the technologies in construction associated with the notion of Industry 4.0 (e.g., Building Information Modelling, virtual reality, augmented reality, Drone, etc.) is explored through extensive literature studies. The proposed framework incorporates current technological advancement related to construction industry, legislative requirements, barriers, enterprise transformation requirements and so on. Construction 4.0 would make a great impact in construction industry through improved value chain of construction projects, productivity improvement, and safe and sustainable construction. Indeed, the proposed framework would contribute to the advancement of new knowledge in the worlds' construction companies and provide potentials of new research focuses.

Keywords: Productivity improvement, BIM, Value chain, Automation, Industry 4.0, Internet of things.

1 INTRODUCTION

The construction industry accounts for 9% world's GDP (gross domestic product) share (Crosthwaite 2000) which indicates its significant impact on the country's economic development. As reported in (McKinsey 2018), global spending in construction was $11 trillion in 2017 and is projected to increase by $14 trillion in 2025. However, the industry is characterized by low productivity with low technological advances, minimum mechanization/computerizations, and robotic usage etc. The digitization, automation, and integration provide opportunities for productivity improvement as well as design and construction quality (Global Industry 4.0 Survey 2016). Nevertheless, embracing new technologies and automation in the construction industry is very slow. For instance, Building Information Modelling (BIM) is becoming the core of information management in the Architecture, Engineering and Construction industry that allows all stakeholders to exchange and manage information throughout the lifecycle of a built facility. Yet, BIM adoption rate in the construction industry has been much slower than anticipated (Walasek and Barszcz 2017).

Because the construction industry is one of the major contributors of the country's economy, the industry must adopt the emerging technologies for effective management of construction projects and improve the productivity and value chain. In recent time, Industry 4.0 has received much attention in manufacturing industries towards increasing digitization, automation and ICT use with an aim to create digital value chain of the lifecycle of the product starting from concept to development, manufacturing, use and maintenance, and recycling (Lasi *et al.* 2014). This aids producing quality product with a decrease in cost and time-to-market as well as overall improvement in enterprise performance (Brettel *et al.* 2017). Despite the benefits that Industry 4.0 offers, construction industries are yet to incorporate these innovative technologies. It is important to understand the major challenges specific to the construction projects that restrain integrating new technologies and be addressed accordingly.

With the visionary idea of Industry 4.0, this study explores the current state of the art of the technologies associated with construction (Construction 4.0) and proposes a framework to incorporate new technologies within construction projects. The framework would help to understand different goal sets of digitization and automation within a construction company.

2 INDUSTRY 4.0 AND CONSTRUCTION INDUSTRY

Industry 4.0 (the fourth industrial revolution) encapsulates future industry development trends to achieve more intelligent manufacturing processes, including reliance on Cyber-Physical Systems (CPS), construction of Cyber-Physical Production Systems (CPPS), Internet of things (IoT) and implementation and operation of smart factories (Zhou *et al.* 2015). The applications of the new concepts related to Industry 4.0 can be applied to the construction arena. The manufacturing of the construction machinery industry can take help from virtual reality to produce construction machinery in a short time, with good quality and at lower cost (Wu *et al.* 2013). The construction industry is quickly adopting Industry 4.0 compliant technologies in the form of BIM, virtual reality (VR), augmented reality (AR) and mixed reality (MR). The maturity level of such technologies is at different levels. BIM, cloud computing, mobile computing, and modularization technologies are relatively mature due to their wide acceptance in the industry whereas AR, VR and MRs are in their formative years.

3 STATE OF THE ART OF CONSTRUCTION 4.0

Industry 4.0 has four main design principles as identified by Gregor (2002) and further explained by Herman *et al.* (2016). Following the same notion, Figure 1 depicts the design principles of Construction 4.0. Though the characteristics of the project in the construction industries are much different than the products in manufacturing industries, the concept of Industry 4.0 can be well matched in the perspective of construction industries. As explored by Oesterreich and Teuteberg (2016), major components of Industry 4.0 such as IoT, IoS (Internet of Services), CPS, Big Data, Cloud Computing, Robotics, etc. are now getting attention to enable a digitized construction environment though the practical applications of Construction 4.0 are still at its infancy. Following subsections describe design principles to understand the current state of the art of Construction 4.0.

The idea of digitization deals with seamless communication technologies that enable interconnected objects and people share information to attain the common goals collaboratively (Hermann *et al.* 2016). BIM has been found to be the prominent digital planning method in construction (Oesterreich and Teuteberg 2016). Along with IoT and IoP (Internet of People), BIM can be used to set the common communication standards between project participants. Though there is a lack of standardized data schema in BIM and lack of protocol that define the

responsibility for information usage (Chen *et al.* 2018), buildingSMART is working towards interoperable standards of BIM.

Sensor data and digitalized plant models are linked together to create a virtual copy of the physical world that helps IoT participants to make informed decisions (Hermann *et al.* 2016). In the context of construction, VR and AR are becoming increasingly popular (Meža *et al.* 2014, Wu *et al.* 2013) that can minimize the gap between the digital (e.g. 3D model, simulation model etc.) and real world (position or condition of materials, equipment).

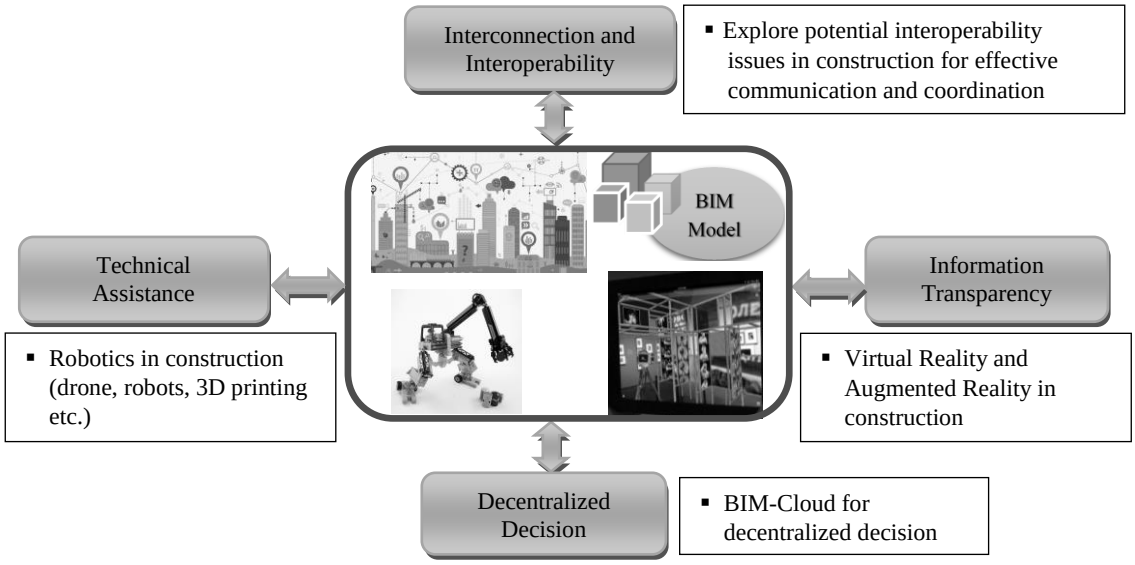

Figure 1. Construction 4.0 design principles.

Decentralized decision making involves the interconnection of objects and people utilizing local and global information to make a better decision and improve productivity (Hermann *et al.* 2016). Construction projects often require collaboration between parties who are geographically placed in diverse locations. Moreover, different participants use different BIM platforms for their models which create interoperability issues (Hossain and Yeoh 2018). There is a growing interest in using Cloud technologies as a means of team collaboration throughout a building's lifecycle in a BIM environment. And, researchers have been investigating to develop specifications for a cloud-based BIM platform (Alreshidi *et al.* 2016).

In an Industry 4.0 environment, the humans' role is changing towards a strategic decision maker instead of the operator of machines (Hermann *et al.* 2016). Unsafe, unpleasant and exhaustive works are assisted by robots for which humans are needed to be trained properly for effective human-machine collaboration (Awais and Henrich 2013). Being a labor-intensive industry, the construction industry has huge potential to improve its productivity by technical assistance (e.g., robot usage), especially for hazardous and unsafe works for a human. In digital construction platform, there are limited uses of robots such as 3D printing, fabricating walls, rebar placement, welding, drones etc. (Chen *et al.* 2018, García de Soto *et al.* 2018, Keating *et al.* 2017, Zhang *et al.* 2018) and all of them are single-application robots. Use of multi-functional and multiple robots should be investigated considering the dynamic site conditions in construction projects.

4 IMPLEMENTING THE CONCEPT OF CONSTRUCTION 4.0

As can be seen from the previous discussions, the design principles of Industry 4.0 can be well aligned with the construction industry's principles and practices. However, the construction industry has not utilized Industry 4.0 on a widespread scale. Digitization and automation of the construction industry to improve the value chain, productivity and sustainable construction are far isolated, focusing on a single point solution. Following the blueprint for digital success (Global Industry 4.0 Survey 2016), Figure 2 presents a framework depicting a step-by-step procedure to implement the concept of Construction 4.0 among construction companies.

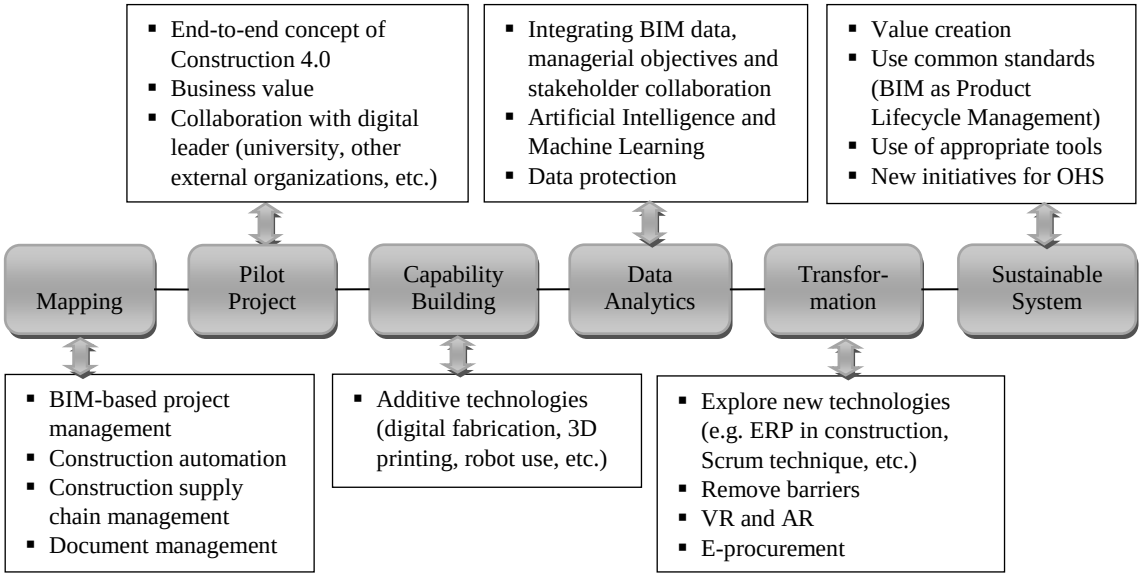

Figure 2. Framework to implement the concept of Construction 4.0.

The implementation steps start with mapping out the Construction 4.0 strategies that consist of evaluating the current digital maturity within the company and setting targets for the next five years. Particularly, the company should have well set BIM-based project management system since BIM is a digital planning method in the construction industry (Li and Yang 2017, Oesterreich and Teuteberg 2016). Other measures are automation in the construction process (Chen *et al.* 2018), Industry 4.0 enabled Construction Supply Chains (Dallasega *et al.* 2018), and a standardized document management system which is key to digitization (Wright 2013).

Next, select pilot projects to establish proof of concept. The company should highlight the end-to-end concept of Construction 4.0 following the notion of Industry 4.0, demonstrate business value and work in collaboration with outside digital leaders and universities to accelerate the digital innovation (Global Industry 4.0 Survey 2016).

While working with the pilot projects, it is important to comprehend lessons learned, develop strategies to improves processes by incorporating new/additive technologies such as digital fabrication (García de Soto *et al. 2018)*, robot usage (Keating *et al.* 2017) etc., and train people to put digitization into place.

Data analytics is the key to decision-making and intelligent systems design by integrating BIM data, managerial objectives, and stakeholder collaborations. In such, IoT enabled Artificial Intelligence (AI), Machine Learning (ML) and other intelligent techniques can be used

(Woodhead *et al.* 2018) while carefully considering the data protection and cyber security issues (Chen *et al.* 2018).

To gain the competitive advantage the company should transform into a digital enterprise with clear leadership and commitment from the top management and financial stakeholders. Continue to explore new technologies such as ERP in construction, Scrum technique, E-Procurement etc. (Costa and Grilo 2015, PRNewswire 2018, Streule *et al.* 2016). The metrics for the transformation are for the positive influences in the construction industry in achieving improved productivity, efficiency, quality and construction processes integration. Furthermore, remove barriers that may hinder digitization of the construction company. As for any business transformation, this will occur under the barriers of political, economic, socio-cultural, technological, environmental, ethical and legal influences (World Economic Forum 2016). For example, the adoption of BIM in the construction industry since the beginning of this millennium has witnessed such influences in terms of the organizational culture and work practices and lack of clarity about the costs and benefits of such adoptions.

Finally, the company should plan for a sustainable system in developing complete product and solutions for customers. Use appropriate tools and standards (e.g., BIM for lifecycle management) (Woodhead *et al.* 2018), build suitable partnerships, and develop a new safety culture for Construction 4.0 (Badri *et al.* 2018). This, in turn, will need more regulatory requirements and compliances to be devised. Several organizations including the government championed BIM in their respective countries; Construction 4.0 needs similar or better support.

5 CONCLUSIONS AND DISCUSSION

There is a huge potential for construction companies to improve productivity through digital value creation, using the notion of Industry 4.0. Nevertheless, the relevant technologies such as CPS, IoT, cloud computing have not been comprehensively considered in construction projects though the demonstration of such technologies to illustrate the best practices exists. This study illustrated the design principles for Construction 4.0 and presented a systematic framework to adopt the concept of Construction 4.0 within a construction company. The construction companies can use the framework to develop capabilities and transform enterprises towards digitalization. Nevertheless, the biggest challenge in attaining the goals of digitization and automation in construction are lack of digital culture and training, especially among SMEs who are the major contributors in the construction industries. Considering the high impact of the construction industry towards the country's economic development, the government should provide adequate support to SMEs who have limited capabilities to invest in new technologies. Further investigations are to be made while the companies use the framework and identify the good practices, lesson learned, and challenges encountered to attain an ecosystem approach.

References

Alreshidi, E., Mourshed, M., and Rezgui, Y., Cloud-Based BIM Governance Platform Requirements and Specifications: Software Engineering Approach Using BPMN and UML, *Journal of Computing in Civil Engineering*, 30(4), 04015063, 2016.

Awais, M., and Henrich, D., Human-Robot Interaction in an Unknown Human Intention Scenario, *Proc., 11th International Conference on Frontiers of Information Technology*, 89-94, 2013.

Badri, A., Boudreau-Trudel, B., and Souissi, A. S., (2018). Occupational Health and Safety in the Industry 4.0 Era: A Cause for Major Concern?, *Safety Science*, 109, 403-411, 2018.

Brettel, M., Friederichsen, N., Kcroseller, M., and Rosenberg, M., (2017). How Virtualization, Decentralization and Network Building Change the Manufacturing Landscape: An Industry 4.0 Perspective, *FormaMente*, 12, 47-62, 2017.

Chen, Q., García de Soto, B., and Adey, B. T., Construction Automation: Research Areas, Industry Concerns and Suggestions for Advancement, *Automation in Construction*, 94, 22-38, 2018.

Costa, A. A., and Grilo, A., BIM-Based E-Procurement: An Innovative Approach to Construction E-Procurement, *The Scientific World Journal*, 2015, 905390-905390, 2015.

Crosthwaite, D. The Global Construction Market: A Cross-Sectional Analysis, *Construction Management and Economics*, 18(5), 619-627, 2000.

Dallasega, P., Rauch, E., and Linder, C., Industry 4.0 As an Enabler of Proximity for Construction Supply Chains: A Systematic Literature Review, *Comp. in Ind.*, 99, 205-225, 2018.

García de Soto, B., Agustí-Juan, I., Hunhevicz, J., Joss, S., Graser, K., Habert, G., and Adey, B. T., Productivity of Digital Fabrication in Construction: Cost and Time Analysis of a Robotically Built Wall, *Automation in Construction*, 92, 297-311, 2018.

Global Industry 4.0 Survey, Engineering and Construction Key Findings, 2016. Retrieved from https://www.pwc.nl/nl/assets/documents/industry-4-0-engineering-and-construction-key-findings.pdf in October, 2018.

Gregor, S., A Theory of Theories in Information Systems, *Proc., Inf. Sys. Found. Workshop*, 1-19, 2002.

Hermann, M., Pentek, T., and Otto, B., *Design Principles for Industrie 4.0 Scenarios*, Proc., 49th Hawaii International Conference on System Sciences (HICSS), 3928-3937, 2016.

Hossain, M. A., and Yeoh, J. K. W., BIM for Existing Buildings: Potential Opportunities and Barriers, *IOP Conference Series: Materials Science and Engineering*, 371(1), 012051, 2018.

Keating, S. J., Leland, J. C., Cai, L., and Oxman, N., Toward Site-Specific and Self-Sufficient Robotic Fabrication on Architectural Scales, *Science Robotics*, 2(5), 2017.

Lasi, H., Fettke, P., Kemper, H.-G., Feld, T., and Hoffmann, M., Industry 4.0, *Business and Information Systems Engineering*, 6(4), 239-242, 2014.

Li, J., and Yang, H. A., *Research on Development of Construction Industrialization Based on BIM Technology under the Background of Industry 4.0*, MATEC Web of Conferences, Vol 100, p 02046 (2017), 02046, 2017.

McKinsey, Construction Industry Spending Worldwide from 2014 to 2025 (in Trillion U.S. Dollars). Retrieved from www.statista.com/statistics/788128/construction-spending-worldwide/ in October, 2018.

Meža, S., Turk, Ž., and Dolenc, M., Component Based Engineering of a Mobile BIM-Based Augmented Reality System, *Automation in Construction*, 42, 1-12, 2014.

Oesterreich, T. D., and Teuteberg, F., Understanding the Implications of Digitisation and Automation in The Context of Industry 4.0: A Triangulation Approach and Elements of a Research Agenda for The Construction Industry, *Computers in Industry*, 83, 121-139, 2016.

PRNewswire, *Alliance Precast Industries Selects Epicor ERP to Support Digital Transformation*, PR Newswire Association LLC, 2018.

Streule, T., Miserini, N., Bartlomé, O., Klippel, M., and de Soto, B. G., Implementation of Scrum in the Construction Industry, *Procedia Engineering*, 164, 269-276, 2016.

Walasek, D., and Barszcz, A., Analysis of the Adoption Rate of Building Information Modeling [BIM] and its Return on Investment [ROI], *Procedia Engineering*, 172, 1227-1234, 2017.

Woodhead, R., Stephenson, P., and Morrey, D., Digital Construction: From Point Solutions to Iot Ecosystem, *Automation in Construction*, 93, 35-46, 2018.

World Economic Forum, Shaping the Future of Construction: A Breakthrough in Mindset and Technology, 2016. Retrieved from http://www3.weforum.org/docs/WEF_Shaping_the_Future_of_Construction_full_report__.pdf in October 2018.

Wright, S., Why would a Construction Business have a Document Management System?, *Credit Control*, 34(10/11), 70, 2013.

Wu, Y.-F., Zhang, Y., Shen, J.-W., and Peng, T., The Virtual Reality Applied in Construction Machinery Industry, Virtual, Augmented and Mixed Reality, *Systems and Applications*, 340, 2013.

Zhang, X., Li, M., Lim, J. H., Weng, Y., Tay, Y. W. D., Pham, H., and Pham, Q.-C., Large-scale 3D Printing by A Team of Mobile Robots, *Automation in Construction*, 95, 98-106, 2018.

Zhou, K., Taigang, L., and Lifeng, Z., Industry 4.0: *Towards Future Industrial Opportunities and Challenges*, Proc., 12th International Conference on Fuzzy Systems and Knowledge Discovery (FSKD), 2147-2152, 2015.