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Barriers to Automation and Robotics in Construction

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Automation and robotics have been widely adopted across many industries, but the construction industry has not achieved the same level of diffusion. Construction is a critical global industry that is challenged to address issues of productivity, safety, quality, and profitability. Automation and robotics have a tremendous potential impact on all these fronts. The objective of this study is to identify barriers to the adoption of automation and robotics in the construction industry as perceived by industry experts and answer the research question: What are the barriers to automation and robotics in construction? We gain understanding through exploratory interviews with industry practitioners and automation and robotics researchers. Semi-structured interviews around construction technologies, implementation and development, perceived barriers, and future trends and opportunities provide insight into those barriers. We expected to find that implementation would be related to company revenue and openness to technology as it is in countries like South Korea and Japan. We found that barriers could be categorized into culture, teams, and technical aspects. Our research contributes to the body of knowledge by addressing the topic beyond just technical aspects providing the perspective of practitioners and researchers who are engaged in innovation. The research indicates that the construction industry, educators, and owners should do more to facilitate the adoption of automation and robotics and address the barriers which are more cultural than technical.

Key Words: Construction, Automation, Robotics, Innovation, Technology Diffusion

Introduction

This paper addresses the barriers to the adoption of automation and robotics technologies in the construction industry. The objective of the paper is to reach a more comprehensive understanding of these barriers and possible solutions as perceived by industry professionals and researchers in the automation and robotics field of study. It is imperative to understand this field because construction itself is a vital economic force. Of the estimated $20.6 trillion in goods and services produced in the U.S. in 2018, construction contributed approximately $840 billion or 4.2% of GDP (AGC, 2019). The industry faces many challenges; construction employed 7.5 million workers in the U.S. last year, yet in an AGC-Autodesk Survey (2019), 80% of contractors reported difficulty finding qualified workers. The report emphasized that labor shortages in the construction industry threatened broader economic growth. In addition to workforce challenges the construction industry faces many issues with quality, schedule, safety, and complex environments that could be solved through the adoption of automation and robotics technologies and processes which have benefited other industries such as automotive, manufacturing, and aerospace. The construction industry is increasingly under pressure due to an aging workforce, lack of skilled tradespeople, and decreasing productivity, all of which could be alleviated through more efficient and streamlined processes that automation and robotics deliver (Bock, 2015). Construction innovation offers a significant company, industry, and societal benefits (Slaughter, 1998).

The literature addresses many aspects relating to the adoption of technology and innovation, generally in the construction industry. Bock (2015) characterizes construction automation as being in the innovation or seed phase. The literature demonstrates how organizational culture motivates innovative behavior in construction when innovation is perceived as an organizational value (Hartman 2007). Specific models of construction innovation and integration of leadership as enablers of innovation have been proffered (Slaughter, 1998, Ozorhorn & Oral, 2016). Innovation has been studied at a project level (Ozorhorn et al., 2016). Constraints for selecting automation techniques such as modularization have been addressed (Azhar, Lukkad & Ahmad, 2013). Certain countries and geographies have received attention Mahbub (2008) studied barriers in Australia, Malaysia, and Japan, finding differences in culture and company revenues influencing the adoption of automation and robotics in construction. Building Information Modeling (BIM), an important stepping stone technology for automation and robotics' diffusion in the architectural, engineering, and construction fields was shown as an innovative practice in the meta-analysis by Hosseini, M. R., Chileshe, N., Zuo, J., & Baroudi, B. (2015). Motivations for BIM implementation in construction projects have been studied extensively (Cao, Li, Wang & Huang, 2017), but there are few studies for the motivations or barriers to adoption of automation and robotics in construction and specifically a gap when considering the points of view of construction practitioners which this study addresses.

The method for this study consisted of semi-structured interviews of industry practitioners and construction automation and robotics researchers. The interviewers employed an institutionally reviewed protocol that included a description of the interview process, verbal consent from the subjects to be interviewed, and prepared questions. The interviews used several structured questions relating to the interviewee's experience of the construction industry, the adoption of innovative technologies at a company level, what areas they perceive as opportunities that are not being taken, and their view of future trends and opportunities. Answers were then coded into first-order concepts, second-order themes and final categories using The Oxford Handbook of Qualitative Research's coding and analysis strategies.

The results of the interviews pointed towards solutions being needed at organizational levels. The need for commitment from owners and other stakeholders was more frequently cited than technical impediments to the implementation of the automation and robotics technologies. Much of the literature addresses technical impediments to construction automation and robotics. This study addresses this gap and contributes to the understanding of barriers to automation and construction by providing the perspectives of practitioners and researchers.

Literature Review

The literature addresses many aspects relating to the adoption of technology and innovation, generally in the construction industry. Organizational culture, diffusion of innovation, models of innovation in construction, innovation at a project level, research frameworks for construction innovation, constraints to technologies, geographical differences, and many other issues have been addressed in innovation and construction research. The literature addresses technologies that are essential to construction automation. Bock (2015) identifies five key technologies: 1: robot-oriented design, 2: robotic industrialization, 3: construction robots, 4: site automation, and 5: ambient robotics. While this work identifies thematic fields where automation and robotics are making advances it does not broadly address the impediments to these technologies. The literature also demonstrates how organizational culture motivates innovative behavior in construction firms. Hartman (2007) drew on organizational behavior, behavioral psychology, innovation, and management theory and literature in his case study of a Swiss construction firm.

Theoretical foundations address motivational groundwork for organizational commitment and how to encourage employees to invest behavioral energy in innovative activities. Organizational culture defined as a pattern of taken for granted, underlying and mostly unconscious assumptions, values and beliefs shared by members of an organization (Kotter and Heskett, 1992; Schein, 2004). The paper emphasized the interchange between motivation and commitment to organizational outcomes and the grounding force of culture. Innovation mechanisms such as communication, recognition, participation and symbolism are framed as being important to inducing commitment and motivation drawing parallels to the operationalization of these mechanisms through innovation.

In reviewing managerial actions, Hartman (2007) points out one of the important motivations for innovation is that it is necessary as focusing on the long term ensures the survival of organizations. The results of the study show the company was motivated to innovate by the goal of higher client satisfaction and for advantages in competition. Innovation is focused on services and processes. Generally, the subject company studied by Hartman was risk-averse and not willing to adopt innovations until they were proven, which is seemingly antithetical to innovation. This construction company, with 1500 employees, was also more prone to adopt incremental over radical change.

An interesting takeaway from Hartman's literature review was the theme of innovation being important to the long-term survival of the firm. Certainly, at the firm level, automation and robotics will address labor shortages, quality, safety, and economic advantage. As Automation and robotic are more widely adopted, individual firms will need to adopt them at a minimum to keep clients happy and achieve an economic advantage in the market-place. This informs the following hypotheses:

H1: Construction firms are reluctant to adopt unproven technologies such as automation and robotics unless there is an economic advantage.

H2: Construction firms adopt innovative technologies to satisfy client expectations

Specific models of construction innovation and integration of leadership as enablers of innovation have been extended (Slaughter, 1998; Ozorhorn & Oral, 2016). Sara Slaughter points out the “many macroeconomic benefits attributed to innovation,” citing Schumpeter's (1934) arguments on economic growth and Schmookler’s (1952) work on increases in productivity that result from innovation. These same arguments could be made for Automation and Robotics in construction. Slaughter offers five models of construction innovation based on management and economic theories of innovations. The model takes into account the scale, complexity, and longevity of the facilities to be constructed as well as their social and organizational contexts. Innovation is examined by its degree of change from existing practices and links to other existing systems. The five models are incremental, modular, architectural, system and radical innovations. The goal of categorizing innovations in this manner is to help companies understand the "implementation activities with respect to the timing of commitment, coordination among the project team, special resources, and level of supervisory activity.

Ozohorn & Oral (2016) detail how innovation is driven at the project, firm, and industry level. They begin by pointing out that traditional input measures of innovation such as expenditures on R&D and the resultant output of patents and trademark applications (Archibugi and Pianta 1996) don't align with construction innovation. They also revisit the fact that construction is one of the least innovative industries (Nesta, 2007). In their study, they identify components of the construction innovation process, including drivers, inputs, and outputs. The drivers were project level, firm, level and industry level. Inputs of innovation included investment, human resources, internal knowledge generation, knowledge transfer and consultancy. The outputs of the model are a decrease in project duration, cost, increased productivity and increased client satisfaction

The models are of interest when relating the current adoption of innovative technologies in construction, which tend to be incremental and not have high requirements related to timing, coordination, special resources, organizational supervision, types of supervision or supervision competencies. In this way, Slaughter's research captures the preference for incremental changes in construction firms. Hartman's research also highlighted common themes around construction firms' reluctance to adopt innovation until it is proven and the industries risk-averse tendencies. These observations motivate hypothesis three.

H3: Adoption of automation and robotics by construction will be addressed at the firm level and will be incremental.

Methodology

The research aims to explain the barriers to the adoption of automation and robotics in the construction industry. The objective is to understand existing opportunities and barriers to automation and construction by conducting semi-structured interviews defined as "an interview with the purpose of obtaining descriptions of the life world of the interviewee in order to interpret the meaning of the prescribed phenomena" (Kvale & Brinkman, 2008 p.3).

The interviewers made initial contact within their professional and academic networks. Twelve subjects were considered because of their organizational roles, knowledge of innovative practices, area of professional practice, or research. Subjects were contacted via email, using a prepared template to ascertain if they would be open to an interview on their perceptions related to automation and robotics in construction. Five subjects completed the interviews. The parties agreed to a time period of up to one hour for the interview and made an appointment for the interview. The interviewers employed an institutionally reviewed protocol that included a description of the interview process, verbal consent from the subjects to be interviewed and prepared questions.

Although the sample size was small, the interviewees were diverse. Two of the interviewees work for large general contractors. One a regional contractor with approximately 350 million dollars in annual revenue and one national contractor with approximately 3.5 billion dollars in annual revenues. Two were researchers in the field of construction automation and robotics with faculty appointments at international institutions. One interviewee was a specialty consultant and practitioner in Building Information (BIM) Technologies catering to regional contractors with revenues under 100 million dollars and up to 1.5 billion dollars in revenue. There were four male interviewees and one female interviewee. The interviewees' titles included Project Engineer, Principal, Professor, Virtual Design and Construction Manager.

These interviews were conducted by telephone, skype, and using what's app mobile. The interviews consisted of seven structured questions. The goal was to understand the parties' experience of automation and robotics construction technologies as they relate to the construction industry, and the questions were created to focus on the subject's perceptions of current barriers, current opportunities, project-level concerns and future opportunities and applications of automation and robotics in construction. The interviewees were asked the primary question and allowed to answer. The interviewees asked clarifying questions, and the researcher also asked a limited number of follow up questions or made clarifications concerning the line of questioning. The scope was focused on the prepared questions. The methods were suited to addressing the research question as to the questions allowed for a broad perspective from the practitioners and researchers. The following questions were asked:

1. What do you think are the main problems associated with the use of automation and robotics technologies in construction?
2. What aspects of a project would make it more suitable for using automation and robotics?
3. What do you think are possible barriers to the implementation of automation and robotics technologies in construction?
4. How do you think barriers can be minimized or overcome?
5. Describe a technology related to automation and construction that you think is innovative and how it has been implemented or not, and what you see as the key drivers?
6. What do you think the future of construction automation and robotic technologies is in the next ten years?
7. What do you think are opportunities available to construction companies for the use of automation and robotics in construction projects?

Semi-structured interviews allow the interviewees to express their views on their own terms (Brinkman, 2014). The interviewer registers their answers; in this case, the answers were written contemporaneously. Using coding and analysis strategies from The Oxford Handbook of Qualitative Research (Saldana, 2014) responses were coded into first-order concepts highlighting the key concepts and terms. The responses were then grouped into second-order themes. For example, all the answers related to technology, culture, job sites and other issues that elicited commonalities were grouped together. These groups were then further reduced to main categories that encompassed all the topics that arose as first-order concepts and second-order themes. In this case, it resulted in three categories related to barriers to automation and robotics in construction: cultural, technical and teams.

Results

There were many common themes across the interviews when it came to barriers to the adoption of automation and robotics technologies. The interviewees who worked for General Contractors (GC Group) pointed to the importance of addressing potential processes in the design phase of a project. They pointed to the importance of Building Information Modeling (BIM) and the quality of design. The GC group also pointed out the importance of owner "buy-in" to using technologies. They pointed to a reluctance of owners to be first users of novel or untested technologies, which confirms what was discovered in the literature. While the GC group identified the attitudes or perceptions of the owners as barriers, researchers pointed to the general contractor's attitudes and perceptions as potential barriers. All parties recognized the complexity of on-site construction, the diversity of sites, and the many trades, operations, and processes happening at once as potential barriers to technologies that may require a more fixed and predictable operating environment. Themes across parties and professions pointed towards "buy-in" from owners, designers, contractors, subcontractors and trade partners as being important. Diffusion of knowledge and practice with these technologies was also identified as a barrier and solution. Technologies are either unknown, novel or not fully tested thus not widely implemented. As noted above in the methodology section, three categories of barriers to automation and robotics arose after coding first-order concepts, second-order themes and final categories. Culture, technology, and teams were the final categories after coding and analyzing the responses to the seven questions. Organizational culture of contractors and owners were sited. Technical impediments were identified from design to operations and from basic automation to fully automated construction sites. The category of teams encompassed everything from the challenges in the construction of new teams being assembled for each project to team propensity to innovate.

The following are examples of coding of some of the first-order concepts, second-order themes, and categories from the research:

First Order Concepts

Question 1. What do you think are the main problems associated with the use of automation and robotics technologies in construction?

- Knowledge Base- Technologies are available but unknown to industry
- Uncontrolled/Undefined Sites
- Complex Environment
- No Software available that can process complex environs
- The aptitude of changing teams of architect, contractor, subcontractors
- Finding the right technologies
- Scalable
- Repetition
- The mentality of Industry, Sector, Engineers, Professors (Brazil)
- Societal Barriers (Aging Population)
- Difficulty selling owners of construction companies on the idea
- Most technologies are prototypes

Second-Order Themes

The first order concepts led to a grouping of second-order themes:

- The complexity of Job Sites
- Team make-up
- Cultural Buy-in
- Maturity of technologies
- Design issues
- Knowledge and know-how
- Diffusion of Technologies

Categories of Barriers to Implementation of Automation and Robotics Technologies

This led to three main categories of barriers to the implementation of automation and robotics technologies: Culture, Technical, and Teams.

Discussion

The interviews pointed towards solutions being needed at organizational levels. Commitment from owners and other stakeholders was more frequently cited than technical impediments to the implementation of the automation and robotics technologies. The literature demonstrates how organizational culture motivates innovative behavior in construction firms (Hartman 2006). This research further demonstrates that the organization motivates the adoption of innovative technologies such as automation and robotics technologies in construction and this was consistent with the two predominant categories of culture and team barriers to automation and robotics in construction.

The small sample clearly limits the study; however, the diversity of knowledge and location gave interesting insights. The researchers were based out of Europe and South America. The South American researcher cited the large unskilled labor force and politics as barriers. Both researchers juxtaposed this to Japan, where a cultural shift is leaving the society without laborers; therefore, industry and government are mobilizing to overcome the problems of an aging population and shrinking workforce. In Brazil, construction is seen as a good industry for workers and employed workers in construction as a politically stabilizing factor; therefore, the political and governmental support is not present for promoting automation and robotics in the Brazilian construction industry.

It also highlights the importance of diffusion of innovative technologies and the reluctance among owners and contractors to be the first to adopt novel technologies. While the practitioners were more likely to cite design or culture as barriers, researchers were almost equally as likely to cite these organizational or cultural barriers. These findings supported Hypotheses one and three: H1, Construction firms are reluctant to adopt unproven technologies such as automation and robotics unless there is an economic advantage, and H3, Adoption of automation and robotics by construction will be addressed at the firm level and will be incremental.

Researchers also cited technological barriers such as software not being able to handle data or the need for more standardized protocols in the industry. The complexity of the construction sites was a theme across respondents. From a technological perspective, the European researcher felt that machine learning or deep learning was not enough to manage the complexity on sites, but that Artificial Intelligence that could learn and adapt would be required to have a fully automated construction site. These and other insights made up the second category of barriers which were mostly technical.

Practical implications for construction firms, educators, designers, and owners are that organizations must adjust their cultures to support innovative technologies such as automation and robotics in construction. Educators send increasingly technologically adept graduates into the field each year. It is important for them to understand organizational culture and potential roadblocks to the implementation of innovative technologies in the field. An understanding of organizational dynamics, as well as technical acumen, is important for educators to deliver to students. Understanding organizational values and how to promote and foster an organizational culture of innovation should be addressed by all project participants. Practical implications for business are that contractors and owners must recognize what Kotter and Heskett (1992) refer to as the grounding force of culture and consider commitment to organizational outcomes, especially as it relates innovation and adoption of innovative technologies such as automation and robotics.

Finally, Hypothesis 2: Construction firms adopt innovative technologies to satisfy client expectations warrants further study and lends itself to quantitative measures and analysis of the firm as well as linking to measures of innovation or adoption of automation and robotics. The study of firm characteristics provides company demographic measures that function as variables of interest when linked to the present study as do the measures of Ozohorn & Oral (2016). In this context, the current study serves as preliminary research and motivates a mixed-methods approach to the research question. Further research on innovation in construction more widely is also supported by this qualitative study.

Conclusion

There is a great deal of research and literature available concerning innovation in construction, adoption of technologies, sustainability, building information modeling, and diffusion of other advances. Many of the same threats to construction that are addressed in existing literature such as a lost generation of skilled construction workers during the great recession, a lack of skilled tradesman, a general shortage of labor, escalating prices and safety concerns share commonalities and similarly show the need to adopt automation and robotics in construction. Doing so will improve schedule performance, cost, quality, safety, and owner's satisfaction.

While this study echo's the technical challenges to adoption of automation and robotics in construction that are widely addressed in the literature, it points to the importance of culture at organizational levels as barriers much as existing literature on construction innovation does. The importance of teams also rises as a barrier emphasizing the importance of team building, team buy-in and team structure in construction projects. Current literature addresses technical aspects extensively, but the practitioners and researchers interviewed for this study highlight the important organizational and cultural barriers that aren't always addressed in technical literature. Much innovation starts at the important firm-level and is executed by teams. This study highlights the importance of the firms and teams that will foster radical advances in construction.

References

AGC. (2019). Fact Sheet, 2014. Retrieved from https://www.agc.org/learn/construction-data/state-fact-sheet

AGC-Autodesk (2019). Eighty Percent of Contractors Report Difficulty Finding, Qualified Craft Workers to Hire. Retrieved from: https://www.agc.org/news/2019/08/27/eighty-percent-contractors-report-difficulty-finding-qualified-craft-workers-hire-0

Archibugi, D., & Planta, M. (1996). Measuring technological change through patents and innovation surveys. *Technovation*, *16*(9), 451-519.

Azhar, S., Lukkad, M. Y., & Ahmad, I. (2013). An investigation of critical factors and constraints for selecting modular construction over conventional stick-built technique. *International Journal of Construction Education and Research*, *9*(3), 203-225.

Bock, T. (2015). The future of construction automation: Technological disruption and the upcoming ubiquity of robotics. *Automation in Construction*, *59*, 113-121.

Brinkmann, S. (2014). Unstructured and semi-structured Interviewing. *The Oxford handbook of qualitative research*, 277-299.

Cao, D., Li, H., Wang, G., & Huang, T. (2017). Identifying and contextualizing the motivations for BIM implementation in construction projects: An empirical study in China. *International journal of project management*, *35*(4), 658-669.

Hartmann, A. (2006). The role of organizational culture in motivating innovative behavior in construction firms. *Construction Innovation*, *6*(3), 159-172.

Hosseini, M. R., Chileshe, N., Zuo, J., & Baroudi, B. (2015). Adopting global virtual engineering teams in AEC Projects: A qualitative meta-analysis of innovation diffusion studies. *Construction Innovation*, *15*(2), 151-179.

Kotter and Heskett, 1992: *Corporate culture and performance*. Free Press.

Kvale, S., & Brinkmann, S. (2008). *Interviews: Learning the craft of qualitative research interviewing* (2nd ed.). Thousand Oaks, CA: Sage.

NESTA (National Endowment for Science, Technology and the Arts). (2006). The innovation gap: Why policy needs to reflect the reality of innovation in the U.K., London.

NESTA (National Endowment for Science, Technology and the Arts). (2007). Hidden innovation, London. Nunally, J. (1978). Psychometric theory,

Mahbub, R. (2008). *An investigation into the barriers to the implementation of automation and robotics technologies in the construction industry* (Doctoral dissertation, Queensland University of Technology).

Ozorhon, B., & Oral, K. (2016). Drivers of innovation in construction projects. *Journal of Construction Engineering and Management*, *143*(4), 04016118.
Schein, 2004

Saldana, J. (2014). Coding and Analysis Strategies. The Oxford handbook of qualitative research.

Schmookler, J. (1952). "The changing deficiency of the American economy, 1869-1938." *Rev. of Economics and Statistics*, 34, 214.

Schumpeter. J. (1934). The theory of economic development. Harvard Univ. Press. Cambridge, Mass.

Slaughter, E. S. (1998). Models of construction innovation. *Journal of Construction Engineering and Management*, *124*(3), 226-231.