IDENTIFYING PAIN-POINTS AND OPTIMAL OPPORTUNITIES FOR AUTOMATION IN COMMERCIAL CONSTRUCTION: A QUALITATIVE ANALYSIS

A THESIS

BY

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ABSTRACT

The scope of automation in the construction field is broad and requires collaboration across multiple disciplines. But the adoption of technology in the construction sector has been lagging in comparison to the other sectors. Lean Construction researchers and practitioners aim to apply principles gleaned from lean manufacturing to create similar rates of flow for the sequence of all activities on the construction job site. The lean construction community has identified eight resources or flows that must be available for any activity to take place, namely: information, equipment, materials, labor, prior work, external conditions, space (head/time/physical), and shared understanding. Currently, these flows suffer from constraints on a typical construction job site, and so are in large part responsible for the poor performance typically observed in terms of time, cost, quality, safety, and morale.

The primary objective of this research is to determine pain-points for stakeholders primarily in the commercial construction industry and explore how these pain-points can be alleviated through the application of automation and robotics. This research uses qualitative research methods to engage in a "listening tour" to learn from those now working in the industry. Industry experts were asked to respond to the following question: "What do you think are the biggest headaches in your respective roles that could potentially be aided by the development of automation and robotics? For example, if you could ask someone or something to figure out a way to make part of your job easier and more productive, what part would that be?". Semi-structured interviews with industry experts were conducted to determine bottlenecks in construction, their experiences with automation, perceived barriers, and potential for improvement to provide insights into where innovation in automation for construction should be prioritized.

Key words: construction automation, robotics, line-of-balance, takt time, pain-points

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NOMENCLATURE

LOB	Line of Balance
PM	Project Manager
TTP	Takt Time Planning

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CHAPTER 1

Introduction

The degree of automation and robotics in the construction sector is significantly less than other sectors such as manufacturing. For the purpose of this research, *automation* is defined as use of computer software, machinery, or other technology to partially or fully complete an activity that would typically be performed by a human worker; this can range from fully virtual to fully mechanical, and very simple to very complex. *Robotics*, however, may be defined as an interdisciplinary field where devices with motors, sensors, and controllers, are programmed to perform a physical task that is carried out autonomously. Automation and robotics overlap but automation can happen without robotics (there can be no physical machine or computer program involved). Also, robotics can happen without automation (i.e., there can be autonomous operation of a robot but with no specific task performed) (Hankiewicz 2018).

A scan of existing literature suggests that productivity has been declining in the construction sector worldwide in recent decades (Arditi et al. 2000; McKinsey 2017). This may, in part, be responsible for low rates of productivity and poor safety in construction. The existing challenges of the construction sector can be addressed successfully by prospects of automation. One way to approach automation and robotics in construction is to identify top pain-points and bottlenecks that are most frequently observed. However, a fundamental lean principle is to optimize the whole over the parts. It is therefore the intent of this research to develop a holistic understanding of interruptions to construction flows to ensure that time, cost, quality, safety, and morale are simultaneously improved – hallmarks of lean construction.

The goal of this research is to identify how and where efforts towards application of automation and robotics in construction should be prioritized, based on discussions with current practitioners about perceived bottlenecks and pain-points. Published research indicates that productivity in construction significantly lags behind non-farm related industries (McKinsey 2017). This research is aligned with lean construction principles that show removal of activity constraints will significantly enhance rates of productivity.

The intent of this research is to relate sequential activity flows to potential automation by exploring the relationship between needs of the industry, and current innovations in construction automation. Until now most explorations have offered a piecemeal understanding of observed bottlenecks in construction activity flows, or separately on the topic of experimentation in automation and robotics; however, the two topics need to be systematically reviewed and linked to ensure that efforts toward application of automation are applied to the greatest productivity and frustration hurdles.

The data for this research were collected from a series of interviews conducted with personnel working in the construction industry who have expertise in activities including—but not limited to—commercial construction. The interviews were digitally transcribed and confidentiality throughout the interview reporting process was maintained.

A qualitative analysis of the data collected by conducting these interviews was intended to help suggest areas where needs to introduce robotics and automation may be highest.

Problem Statement

McKinsey et al. (2017 p.2) stated "Globally, labor-productivity growth lags that of manufacturing and the total economy." Productivity has been steadily increasing in other sectors in the last five decades; however, productivity in the construction sector has barely improved, and it may have even decreased (Arditi and Mochtar 2000).

The productivity level of construction has decreased over the past few years while average economy productivity level has increased exponentially indicating increased efficiency (Figure 1).

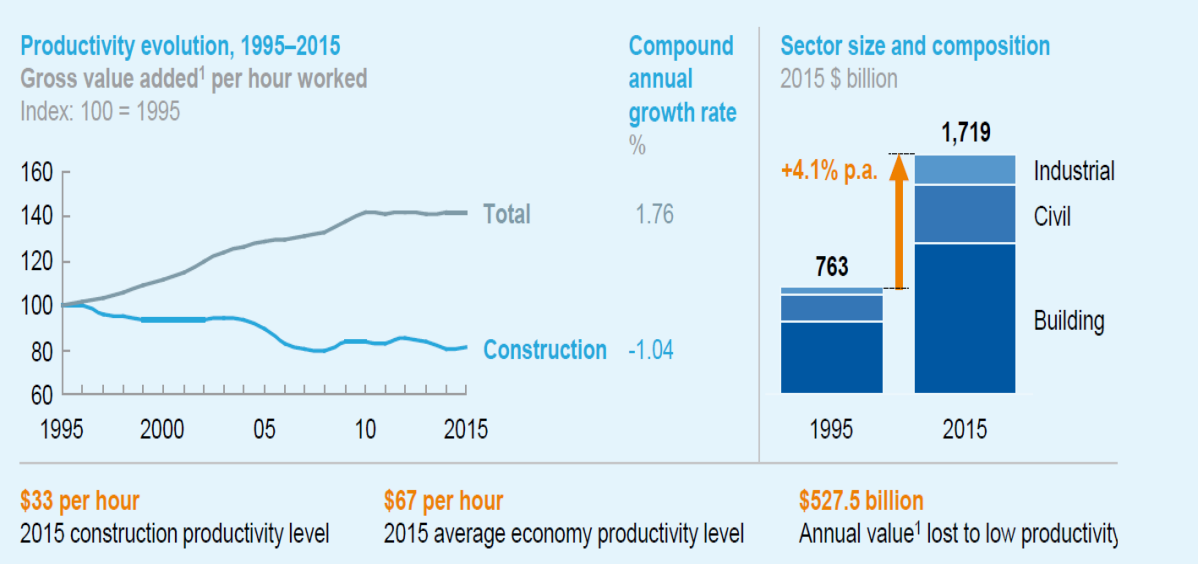


Figure 1: Evolution of productivity between 1995-2015; Reprinted from McKinsey (2017), p. 32.

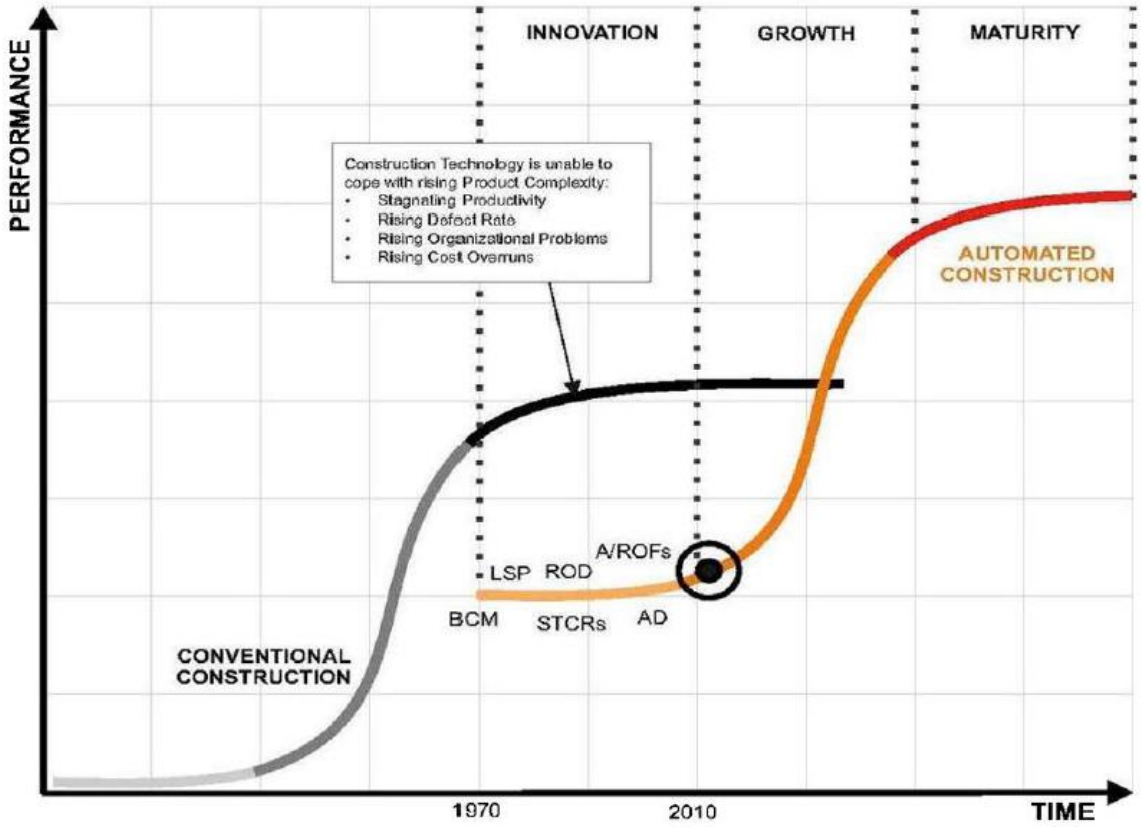
Robotics and Automation offer potential solutions. However, extant literature does not discuss systematic links between priority pain-points faced in projects and ways to potentially alleviate those pain-points with automation and robotics. The purpose of this research is to help fill that gap. A study conducted by Bocks (2015) suggested that the growth of conventional construction has reached an impasse and the only way to overcome these constraints is consequent automation (Figure 2).

Research Questions

The intent of this research was to address the following questions:

- What are the primary challenges faced by the commercial construction sector?
- Which activities have the potential to be streamlined with automation?
- How will automation affect each of the eight flows needed to complete an activity, as identified in lean construction theory, namely: information, equipment, materials, labour, prior work, external conditions, space (head/time/physical), and shared understanding.

The potential implication is that the findings of the research will serve as proof-of-concept for additional sectors in the construction industry as part of future work.



BCM	building component manufacturing
LSP	large-scale prefabrication
STCRs	single-task construction robots
ROD	robot-oriented design
A/ROFs	automated robotic on-site factories
AD	automated deconstruction

Figure 2: An S-Curve representing relation between Conventional construction and Automated Construction Reprinted from Bocks (2015), p.113.

CHAPTER 2

Literature Review

A review of the literature revealed to some extent bottlenecks involved in the construction sector and the pain-points involved in application of technology in the construction industry. Bottlenecks faced in the commercial sector include factors for delay, reduced productivity, constraints to application and adaptability of technologies. In a study conducted by McKinsey (2017), they authors proved that productivity of construction industry has remained either unchanged or decreased over the past few years and is lagging behind manufacturing industries. By contrast, productivity in the manufacturing sector increased over 1.7 times that of construction industry from 1994 to 2012. This literature review addresses how technological advances may potentially aid in increasing the construction productivity.

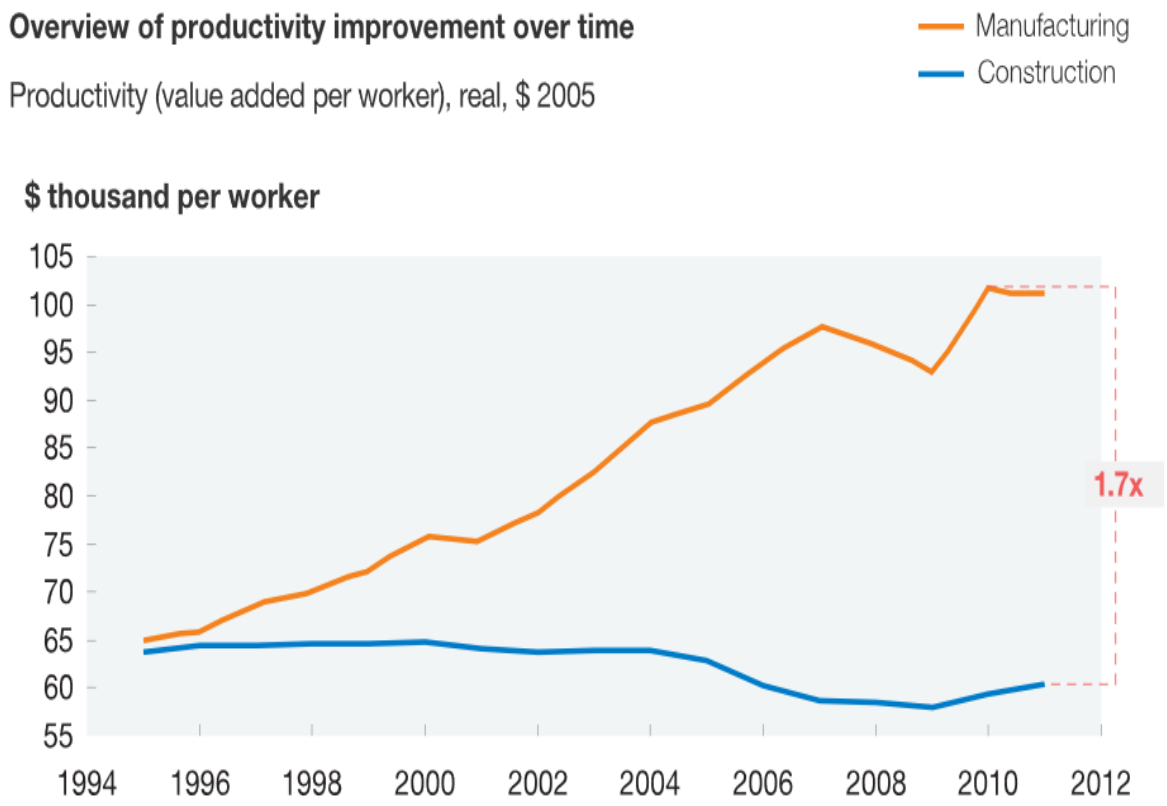


Figure 3 Productivity improvement over time in Construction industry vs Manufacturing industry. Reprinted from McKinsey (2017).

Barriers in the construction industry

In the construction industry some common barriers faced are labor shortages, economic disadvantages, reduced morale, safety, and quality. In a case study by Merrow et al. (1988) on megaprojects in the construction industry, the authors found that only four out of forty-seven mega projects were on budget, averaging a cost overrun of 88 per cent. The reasons and nature of delays in a construction project and their impact costs may also vary amongst the developing

and developed countries (Shebob et al. 2012). Some of the most common reasons for delays and cost overruns discussed were skilled labor shortages, materials quality, and supply, last minute changes and fluctuating costs of materials and labor (Al Karashi et al. 2009). Figure 4 represents results from a survey of contractors regarding problems faced in construction. During the years 2018 and 2019, the top three reasons remain unchanged, indicating the primary pain-points in the construction sector remain nearly unchanged.

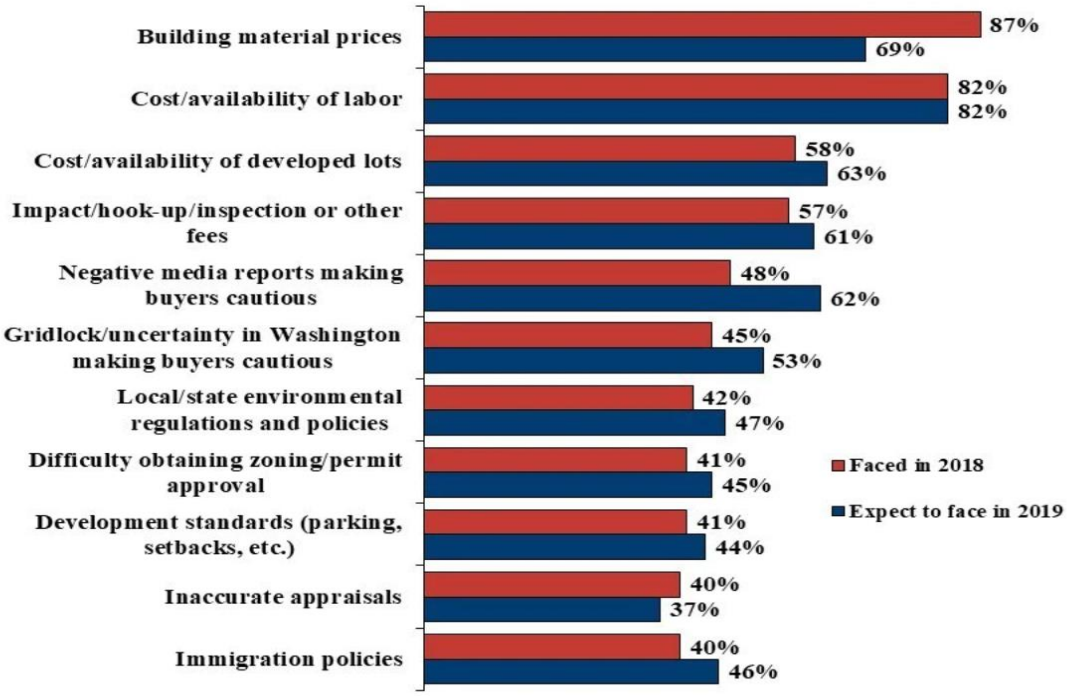


Figure 4: Top 10 Significant problems faced in 2018 and expected to face in 2019. Reprinted from NAHB (2019).

Along with the increased demand for skilled labour in construction, the construction industry in US has been facing challenges in finding craft laborers (Olsen et al. 2012). Many studies have tried to pinpoint the possible factors responsible for such shortages and their effects on the projects. For example, Kashiwagi and Massner (2002) suggested that the low income is a main reason for the shortage in skilled labour in our industry.

Tezel et al. (2017), conducted explorative research about lean thinking and implementation barriers in the heavy civil (highways) construction sector. Reduced margins for profit and increased performance targets encourage construction organizations to review lean thinking as a solution. Hartmann (2006) found that one of the most important reasons for innovation in the construction industry is the need to focus on the future. This ensures an organization will survive long-term. Results from this research showed that a goal of increased customer satisfaction and advantages in competition motivate companies to innovate.

Due to the size of construction projects and the repetitive tasks present within the activities, productivity changes can affect the national productivity and economy of the US (Allmon et al. 2000). Labor productivity plays a significant role in a project's success but is challenging to accomplish.

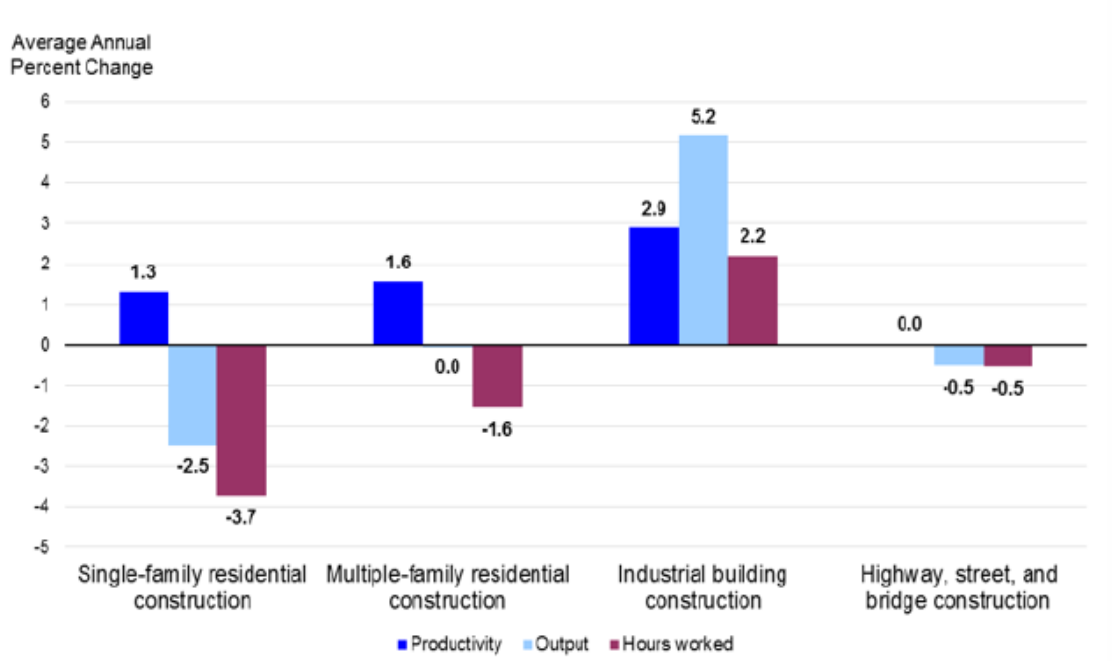


Figure 5: Labor Productivity Trends (2007-2017). Reprinted from U.S. Bureau of Labour statistics, Office of productivity and technology.

The following sections discuss line-of-balance and takt time scheduling to make process inefficiencies more visible. In the words of Taiichi Ohno, making problems visible is a way to "lower the river to reveal the rocks" (Ohno 1988)—a first step toward identifying bottlenecks—and therefore opportunities for improvement.

Line-of-Balance in Construction

A line-of-balance schedule (Figure 6) is a linear technique that facilitates balance so that each activity is performed continuously and efficiently (Arditi et al. 2001). Line-of-balance (LOB)—also called location-based-scheduling and velocity scheduling—is a method of scheduling suitable for projects containing activities that are repetitive and linear in nature. Using LOB on construction projects is not new (e.g., Seppanen and Aalto 2005), but for managers who are unfamiliar with LOB, its adoption has faced resistance in the construction industry, as have other innovations perceived as "new"; nevertheless, it is appropriate to apply LOB scheduling in the construction industry since a typical project consists of numerous repetitive tasks.

The objective of a line-of-balance schedule is to smooth-out peaks and troughs while keeping the initial project duration unchanged (Hariga and El-Sayegh 2010). There have been several benefits to applying LOB on a project. Soini and Seppänen (2003) implemented line-of-balance (LOB) on a project located at Finland and their benefits were qualitatively determined by assessment of risk, overall project durations, schedule feasibility, and optimization of control (Figure 6).

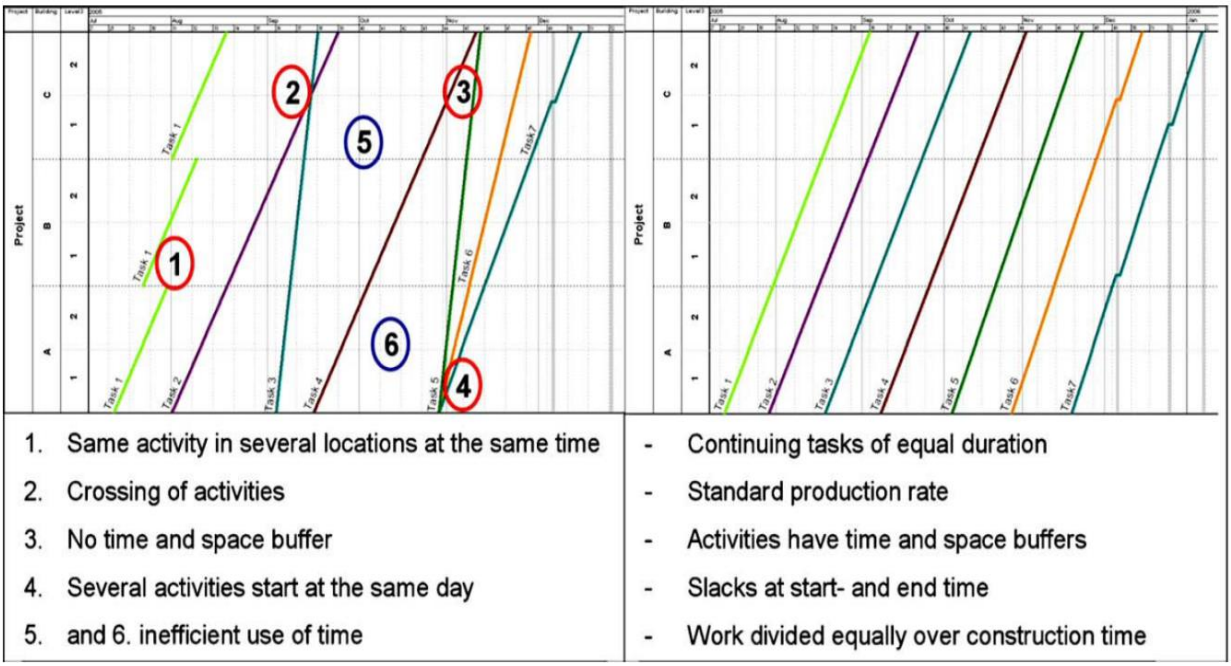


Figure 6: Example of Line-of-Balance Diagrams. Reproduced from Jongeling and Olofsson (2007), p.191.

Takt Time

Determining a production rate to optimize time is not a new concept. In takt time planning, activity duration is calculated by optimal production rates and adding actual durations; buffers are then added for steady flows through activities. Takt time is used in resource management, time, quantity takeoff, work delay, tracking progress, forecasting and the identification of problems that are then jointly resolved and controlled (Frandson and Seppänen 2003).

The intention of takt time planning is to decrease overall reducing waste, which increases the productivity (Figure 7). This goal is accomplished by optimization of the activities and crew/unit sizes to achieve a desired rate of production (Vatne and Drevland 2016). Takt time planning includes coordination between a team to create a plan that is considered best, improving time by development towards a balanced strategy and a comprehensive, realistic schedule for production.

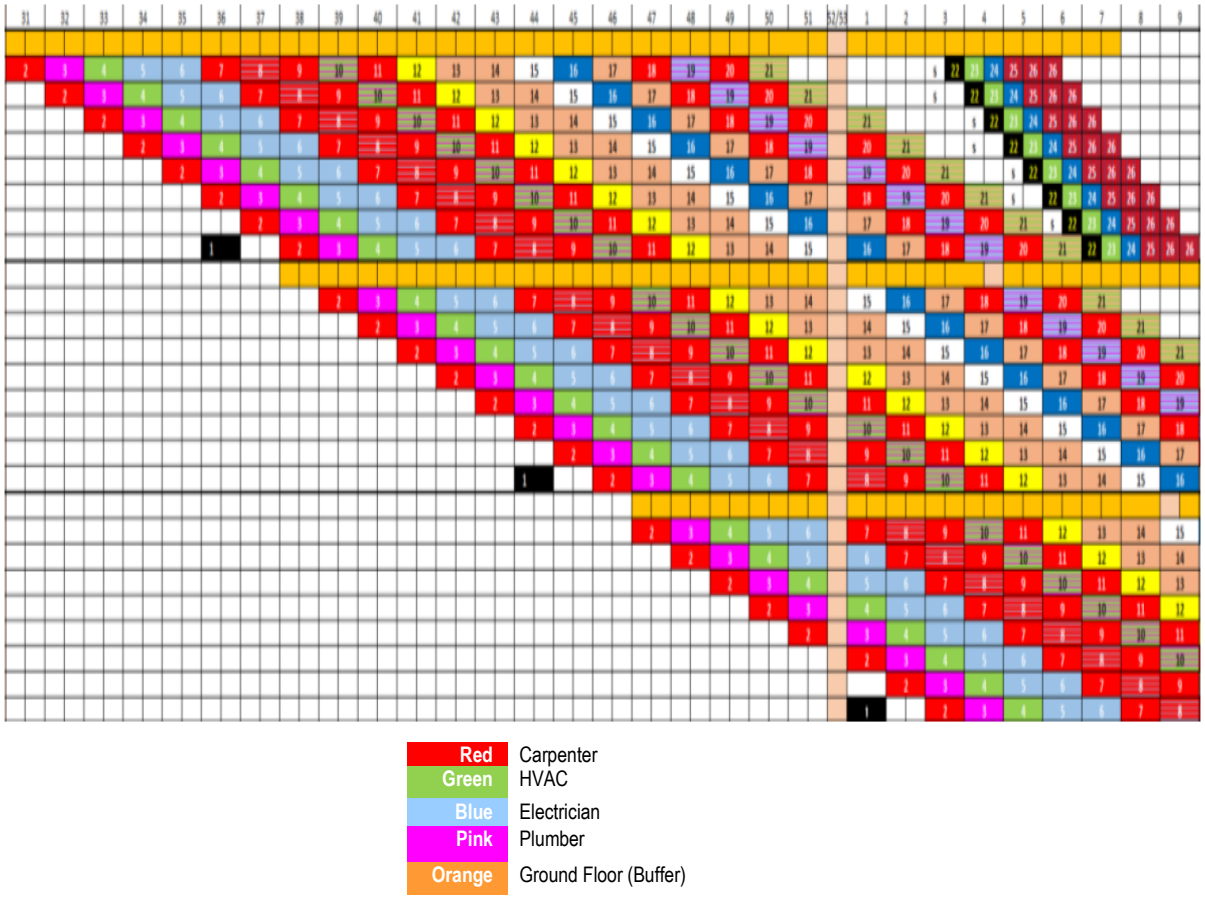


Figure 7: Example of takt time plan. Reproduced from Vatne and Drevland (2016) p. 178.

Bulhoes et al. (2006) showed that the controlled production of a concrete structure using small repetitive cycles resulted in improved productivity rates, reduced cycle times and reduced waste. For a project in Sacramento, California, the overall duration was reduced to 5.5 months from 11 months using a four-day takt. This case study demonstrated that by using takt time planning, one can successfully address productivity challenges (Frandson and Tommelein 2014).

Automation and Robotics in Construction

Robots and technology for the construction industry have been under development since the 1960s and 1970s—at the same time as other sectors, such as the automotive industry; however, the construction industry has been slow to adopt innovative technology despite its suitability for adoption (e.g., repetitive, labor-intensive tasks) (Bock 2015). Robots for construction were first developed in Japan to improve the building components quality used in modular homes. Later, robots started to make appearances on construction sites, and automated construction systems emerged (Bock 2008).

In a paper presented at International Symposium on Automation and Robotics in Construction (ISARC) Son et al. (2010) analyzed the contents of 1671 papers from 1990 to 2008 to identify future needs and trends of automation and robotics technology in construction. Maas and van Gassel (2005) discussed about automation and technology and their impact on construction engineering, and construction management. A literature review about automation has proved that in certain projects and conditions the barriers associated with construction work

such as hidden costs, decreased quality, labor shortages, safety, and external condition of projects have been overcome by use of new innovative technologies such as automation which has the potential to improve the quality, safety, and productivity of the construction industry (Dakhli and Lafhaj 2017).

Gambao and Balaguer (2002) made it evident that use of automation and robotics in various fields of construction are beneficial. They proved there is a need for advancement by briefly covering different applications of robotics and technological aspects in civil infrastructure and the house building sector of the construction industry.

Zhang et al. (2016) published a paper about metro tunneling and how it affects surface road operations and proposed a decision tool for dynamic safety assurance in a construction environment. Apart from safety concerns, many construction workers also suffer from work-related musculoskeletal disorders as a negative side-effect of working in the industry (Cho 2018). This can be avoided by use of robots and semi-automated devices, such as exoskeletons. They proved that a wearable robot could keep construction workers safe while also increasing efficiency and enhancing the load-bearing capacity of the workers.

Another application of automation in construction is in monitoring progress and updating plans and surveillance in transportation (Li and Liu 2019). Several aspects such as land surveying, demolition, on-site construction, logistics and maintenance have been evaluated and reviewed. The research done by Li and Liu (2009) revealed that the main outcomes of using a drone on a project are safety, overall cost reduction, and reduction of carbon emissions.

CHAPTER 3

Methodology

This research aimed to determine key pain-points and hurdles in various activities performed on projects in the commercial construction sector by conducting a series of 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 and Brinkman 2008 p.3). The intent is to develop a better understanding of where priorities should lie with respect to development and application of automation and robotics.

Recruitment methodology

An initial contact with the interviewees was made by engaging the Construction Industry Advisory Council (CIAC) network that advises the Department of Construction Science at Texas A&M University. The subjects (interviewees) were considered because of their knowledge and experience within the commercial sector. Subjects were contacted via email sent by the department's Industry Relations Coordinator. Further recruitment of interviewees was done through contacts given by the interviewees at the end of each interview (a form of snow-ball sampling); additional interviewees were recruited by identifying appropriate individuals and reaching out to then via LinkedIn. We noticed that the likelihood of the subjects accepting the invite to the interview increased after we started sending the primary question with the invite. The interviews started on 09/29/2020 and ended on 02/23/2021.

A link to a survey (Appendix 1) was sent to participants after they accepted the invitation; their responses were automatically collated. The survey collected demographic data such as years of experience, highest level of education, area of expertise, etc. The intent of these data was to potentially correlate pain-points to roles and experience.

Participants who completed the survey and who were open to sharing their perceptions and experiences were sent a sample questionnaire, and a time window to participate in an interview. One to four interviewers conducted the interviews, based on availability. The interviews were scheduled for at least 20 minutes and an appointment was created based on mutual convenience. The interviews were conducted by the researchers by following the protocol approved by the TAMU Institutional Review Board (IRB) that included a description of the interview process, information sheet (consent form) and the primary question to be asked of subjects to be interviewed. Interviews were recorded and automatically transcribed using Zoom.

Interview questionnaire

All interviews were conducted by using a Zoom platform. The goal was to understand the interviewees perception as related to automation and robotics as they relate to the construction industry, and common hurdles faced, based on an individual's experience working in the field of construction. The question was designed to focus on the experience of interviewee's pain-points, and potential opportunities for improvement through applications of technology in the construction industry. The interview question was asked, and interviewees were invited to respond. The researchers and interviewees had a conversation based on the questions asked

and shared their experiences and opinions. The researcher also asked follow-up and clarification questions, as needed.

The primary questions asked were:

- What do you think are the biggest headaches in your respective roles that could be potentially aided by development of automation and robotics? For example, if you could ask someone or something to figure out a way to make part of your job easier and more productive, what part would that be?

After responding to the primary questions, interviewees were shown—using Zoom's *screen share* function—a graphic (Appendix 2) of the eight resources/flows required for any activity to take place and asked to think about and then verbally share additional bottlenecks they may have observed while working on a job site in their respective roles. The intent of this follow-up exercise was to serve as a prompt to motivate respondents to brainstorm any additional observations about bottlenecks to flows they might have missed earlier.

Delimitations

- This research is focused primarily—though not exclusively—on the commercial construction sector.

Limitations

- Despite efforts to ensure uniformity with each interview, this research's quality is potentially dependent on skills of the researchers and the interviewee and has the potential to be influenced by personal biases and idiosyncrasies.
- The sample size of this research was limited to interviews with 30 industry professionals; the qualitative study examined experts of the field having varying levels of experience in predominantly US construction companies. It is acknowledged that the final sample size may be considered inadequate to generalize results.

CHAPTER 4

Results

Tables 1a and 1b are compilations of demographic information collected through the surveys sent to interviewees before the interview started. A total of thirty interviews were conducted. The interviewees were in North America and Europe. Both males and females volunteered to be interviewed; there were 3 women and 27 men. The interviewees came with varying types and levels of experience in the construction industry, ranging from 2 to 40 years. Examples of interviewee roles and titles include: Director of Business Development, Senior Director Innovation, Construction Risk Assessment Manager, Project Engineer, Structures Division PM, Project Manager, Operations Manager, Senior Project Manager, Virtual Design and Construction Manager, etc. (Figure 8).

Figure 8: Roles of interviewees

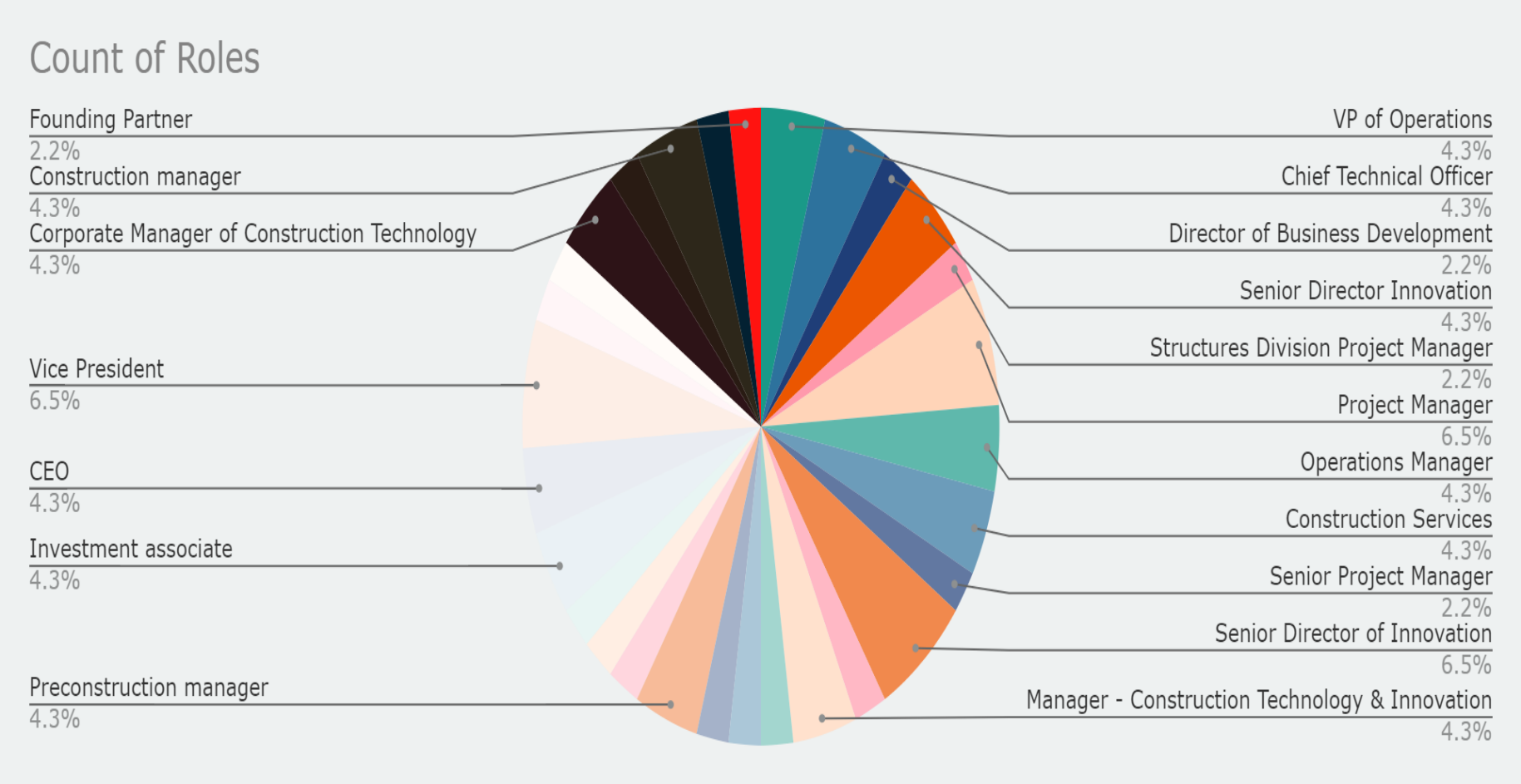


Table 1(a) Interviewee demographic information

Serial number	Please specify your ethnicity.	What gender do you identify as ?	What is the highest level of degree/education you have completed ?	What is your current role in the company you are working with/for ?	What is your area of expertise ?	What is your current employment status ?	Which sector are you most experienced in ?
1	Caucasian	Male	Bachelor's Degree	VP of Operations	Project Management - Commercial Construction	Employed Full-Time	Commercial
2	Caucasian	Male	Master's Degree	Chief Technical Officer	Technology and Training	Employed Full-Time	Commercial
3	Caucasian	Female	Bachelor's Degree	Director of Business Development	Commercial Construction and Architectural Business Development	Employed Full-Time	Commercial
4	Caucasian	Male	Bachelor's Degree	Senior Director Innovation	Construction & Innovation	Employed Full-Time	Commercial
5	Prefer not to say	Male	Bachelor's Degree	Structures Division PM	Heavy Civil Construction	Employed Full-Time	Heavy civil
6	Caucasian	Male	Bachelor's Degree	Project Manager	Building/Construction Operations	Employed Full-Time	Commercial
7	Latino or Hispanic	Male	Trade School	Operations Manager	Walls and Ceilings Industry/Drywall	Employed Full-Time	Commercial
8	Prefer not to say	Male	Bachelor's Degree	Construction Services	Multi-Family/Commercial	Employed Full-Time	Commercial
9	Caucasian	Male	Bachelor's Degree	Senior Project Manager	Commercial & Multifamily Construction	Employed Full-Time	Commercial
10	Asian	Male	Bachelor's Degree	Senior Director of Innovation	Supporting Innovation Process	Employed Full-Time	Commercial
11	Caucasian	Male	Bachelor's Degree	Operations Manager	Mechanical Contracting	Employed Full-Time	Commercial
12	Caucasian	Male	Bachelor's Degree	Vice President, Construction Technology & Innovation	Construction Management, Project Technology & Innovation	Employed Full-Time	Commercial
13	Caucasian	Male	Ph.D. or higher	Manager - Construction Technology & Innovation	BIM/VDC and Construction Technology	Employed Full-Time	Industrial
14	Prefer not to say	Male	Bachelor's Degree	Director, Construction Technology and Innovation	Construction Technology	Employed Full-Time	Commercial

Table 1(b) Interviewee demographic information

Serial number	Please specify your ethnicity.	What gender do you identify as ?	What is the highest level of degree/education you have completed ?	What is your current role in the company you are working with/for ?	What is your area of expertise ?	What is your current employment status ?	Which sector are you most experienced in ?
15	Caucasian	Male	Bachelor's Degree	Project engineer	DOS International Projects	Employed Full-Time	Commercial
16	Latino or Hispanic	Male	Master's Degree	Senior Project Coordinator	Architecture & Construction	Employed Full-Time	Commercial
17	Caucasian	Male	Master's Degree	Preconstruction manager	Preconstruction	Employed Full-Time	Commercial
18	Caucasian	Male	Ph.D. or higher	Managing Director	Commercial Insurance	Employed Full-Time	Commercial
19	Caucasian	Male	Master's Degree	Director	Digital, Manufacturing and Technology in Construction	Prefer not to say	Infrastructure and Construction
20	Caucasian	Male	Master's Degree	Lean Manager	Continuous improvement	Employed Full-Time	Heavy civil
21	Asian	Female	Bachelor's Degree	investment associate	construction technology investing	Employed Full-Time	Commercial
22	Asian	Male	Master's Degree	CEO	Digital Construction	Employed Full-Time	Residential
23	Caucasian	Male	Bachelor's Degree	Vice President	Commercial Construction	Employed Full-Time	Commercial
24	Caucasian	Female	Bachelor's Degree	Sr. VP. Construction Technology and Manufacturing	Mechanical/Plumbing Contractor	Employed Full-Time	Commercial
25	Asian	Male	Master's Degree	Managing Director - Global Head of Construction	Insurance in construction sector	Employed Full-Time	Insurance
26	Caucasian	Male	Bachelor's Degree	Corporate Manager of Construction Technology	Construction / Innovation	Employed Full-Time	Industrial
27	Caucasian	Male	Master's Degree	Head of Product , Author	Construction Technology	Employed Full-Time	Commercial
28	African-American	Male	Ph.D. or higher	Construction manager	Construction Management	Employed Full-Time	Commercial
29	Caucasian	Male	Master's Degree	Co-Founder & CEO	Construction Robotics	Employed Full-Time	Industrial
30	Caucasian	Male	Law	Founding Partner	Construction Lawyers	Employed Full-Time	Construction

Data Analysis

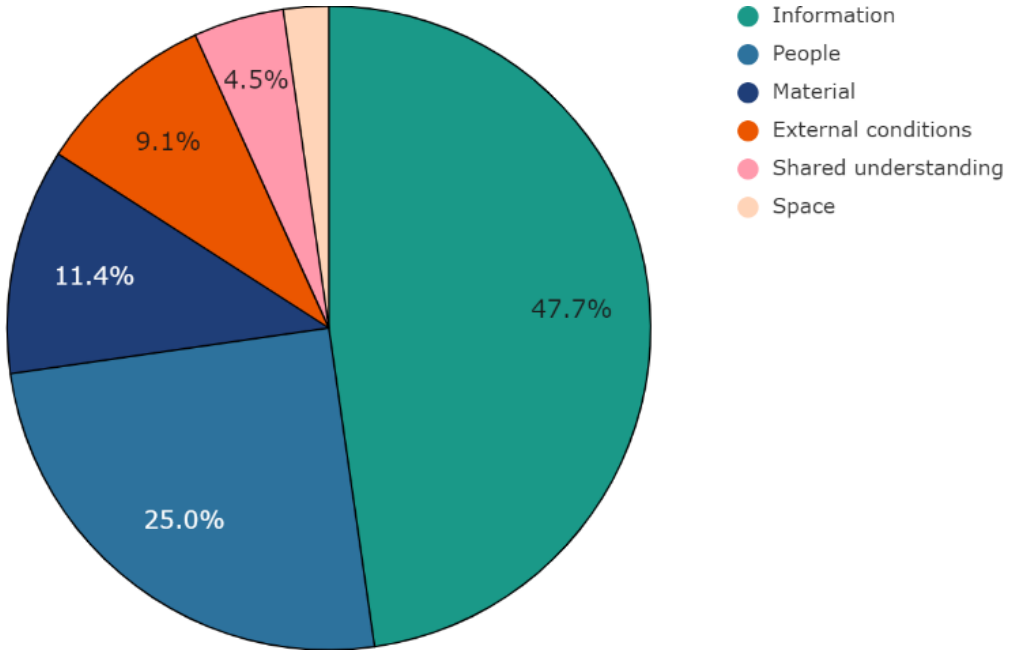
Brinkmann (2014) indicated that semi-structured interviews let the interviewees express their opinions on their own terms. The interview took place in two stages; during the first stage the primary question was asked, and responses were collected. During the second stage an image depicting the lean principles involved in construction activities was shown (Appendix 2) and the interviewees were asked to express their opinions about the image. The pain-points mentioned were recorded, with summaries tabulated as shown in Tables 2; in conformance with IRB protocol and to protect interviewee privacy, personal information of the interviewee was removed (e.g., de-identified and a serial number was used instead).

At the end of each interview, pain-points were summarized and classified, based on the lean principle of eight categories of flow, namely: information, equipment, materials, people, prior work, external conditions, space (head/time/physical) and shared understanding. Appendix 2 shows the figure depicting the eight flows. For example, responses related to weather, shortage of project funding, etc. were classified as "external conditions."

Once consolidated into a chart, the frequency of specific pain-points and potential correlations were identified. The pie chart (Figure 9) shows the percentage of interviewees who mentioned a specific pain-point.

The most frequently cited (47.7 %) pain-point among interviewers was information i.e., the majority of interviewees found reasons related to information to be a primary hurdle for activity completion of activities (Figure 9).

Figure 9: Pie chart of the pain-points mentioned in the interviews.



Discussion

The interviews pointed towards the pain-points that are in serious need of solution in organizational levels. Commitment from interviewees to implement automation and robotics was frequently noticed during these interviews. As a result, a whole new industry of construction technology and robotics is emerging to fulfill this need. Soon construction companies would have lesser to no need of certain staff instead they might need to hire a contractor or a subcontracting company which uses robots or autonomous vehicles to complete an activity.

Major companies have already recognized information as a major problem and are trying to overcome it by using image/information capture technologies as solution. One of the interviewees mentioned that they use an image capturing and reality capturing services for updating their schedules and BIM models.

Companies with multibillion-dollar revenue have started a new virtual platform called next coalition to discuss about the possibilities and application of innovative solutions for current day construction challenges. On this platform people from varying backgrounds can submit a solution that they think might solve the painpoints and also provide a way to make these solutions available for market use. Some of the technologies that are being tested by next coalition are heat sensing cameras, digital incident and inspections, mobile apps, digital inspection etc.

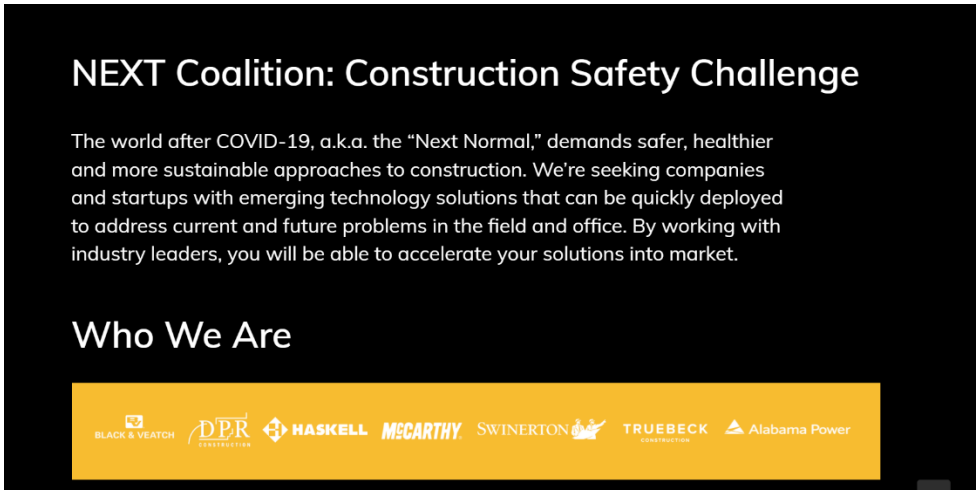


Figure 10: Screen print of Next Coalition website. Image source: Next Coalition

The following are examples of the types of technology and automation mentioned by the interviewees:

In an interview with the CEO of a start-up construction technology company, the interviewee described his solution for robotic assembly of scaffolding. The solution consists of smart robotic elevators that improve the scaffolding assembly process by delivering the parts needed for "Just-In-Time" and "Just-In-Place" assembly. The interviewee stated this technology not only reduces the time needed for assembly but also the number of laborers required, potentially enhancing onsite safety and efficiency.

Figure 11: Screen print of Next Coalition website. Image source: KEWAZO.

An interviewee mentioned that in a project involving installation of wind turbines they found it hard to find qualified heavy equipment operators willing to relocate to remote locations; this led to experimentation with automated vehicles (e.g., hole diggers, bull dozers, and soil compactors) to prepare the earth required to construct wind turbine farms.

Figure 12: Image of autonomous (operator less) vehicle. Image source: Construction Junkie.

One of the interviewees described their experimentation with drywall installation robots and using reality capture robots such as "spot the dog" to keep schedule and BIM models up to date by using a scanning tool atop the robot. One drawback they observed with reality capture robots was battery life and mobility of the robot.

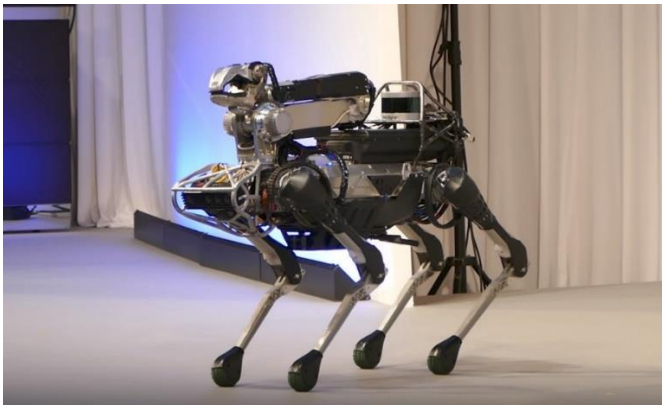


Figure 13: Image of Reality capture robot. Image source: Kamila medium.

Some interviewees expressed skepticism about implementation of technology and automation for construction. According to at least two of the interviewees, automation may introduce more problems because of the unique complexity of each construction site, as well as the time and effort it takes to train employees to become proficient. For example, one financial investor who agreed to be interviewed argued it may still be easier to have a human move a camera mounted on stick-on-wheels through a job site than to program the path of a quadruped robot, for example.

The interviewees discussed potential solutions for challenges that are being faced by those in the construction sector. By prioritizing specific pain-points/ hurdles that disrupt overall flows, potential solutions can be developed that will facilitate individual activity flows. The LOB schedule shown in Figure 14 makes visible constraints to activity flows. Variable activity velocities, flow conflicts, and constraints can potentially be resolved by experimenting with automation and robotic technologies. The LOB schedule can help a project manager know where to focus his or her efforts when considering whether to introduce a specific type of technology.

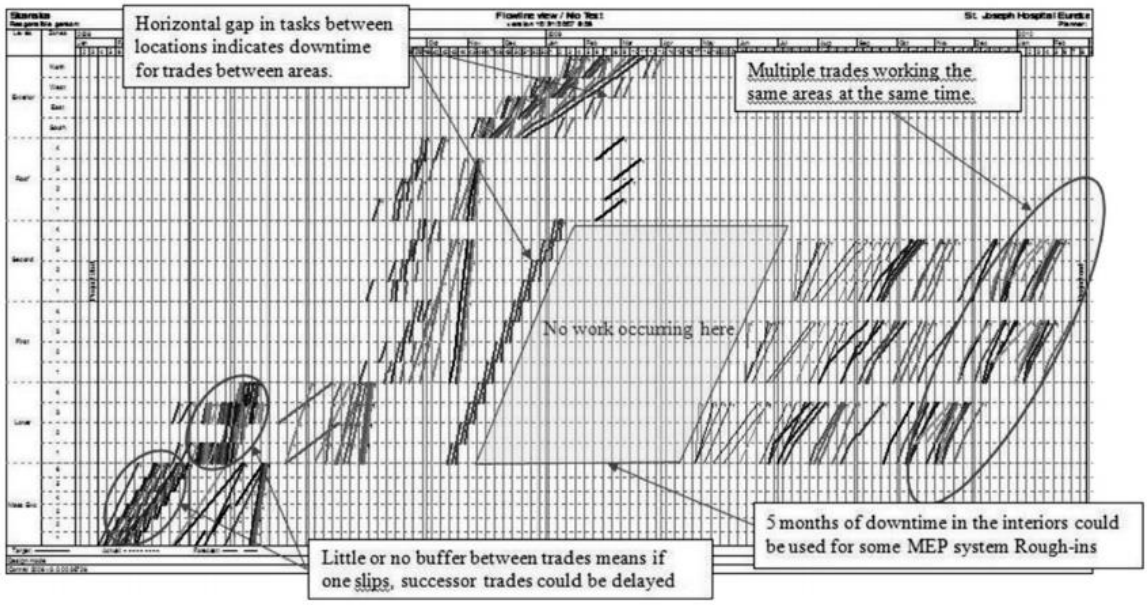


Figure 14. A CPM schedule that has been converted to an LOB schedule make explicit opportunities to address conflicts and productivity gaps that would otherwise be difficult to identify (Kenley and Seppanen 2010, Fig 16.2, p. 510).

Conclusion

This research involved interviewing 30 construction stakeholders about their perceptions of how automation and robotics can help them reduce the pain-points of their work. Figure 15 depicts that up to seventy five percent of the interviewees chose two flows (i*nformation* and *people*) as their primary pain-points. The interviewees were categorized according to their specific roles.

Most of the interviewees pointed to the importance of *information* at different stages of a project and described examples of challenges that arise because of delayed and incomplete information. Several expressed concerns about challenges they have with respect to finding the required number of experienced people to work on a site; skilled labor shortages and safety concerns have been increasing. Most interviewees who worked on job sites, such as project managers and general contractors, chose factors relating to *people* as a primary pain-point while interviewees involved in the planning phase and management sector chose *information uncertainty* as their primary pain-point; this suggests that selected pain-points appear to vary depending on the role of the interviewee.

Additional pain-points mentioned were delayed and insufficient supply of *materials*, weather-related concerns (*external conditions*), and miscommunication problems between the various parties involved in a project (e.g., *shared understanding*) etc. Nearly all interviewees recognized the complexity involved in the construction sector and its ever-changing needs.

A number of interviewees mentioned some existing solutions under development that can potentially reduce or eliminate perceived pain-points. A detailed spread sheet (Table 2) was created to categorize specific pain-points mentioned and these were then mapped to potential opportunities involving robotics and automation now on the market or under development.

Figure 15: Pie chart of the painpoints mentioned vs the roles of the interviewees.

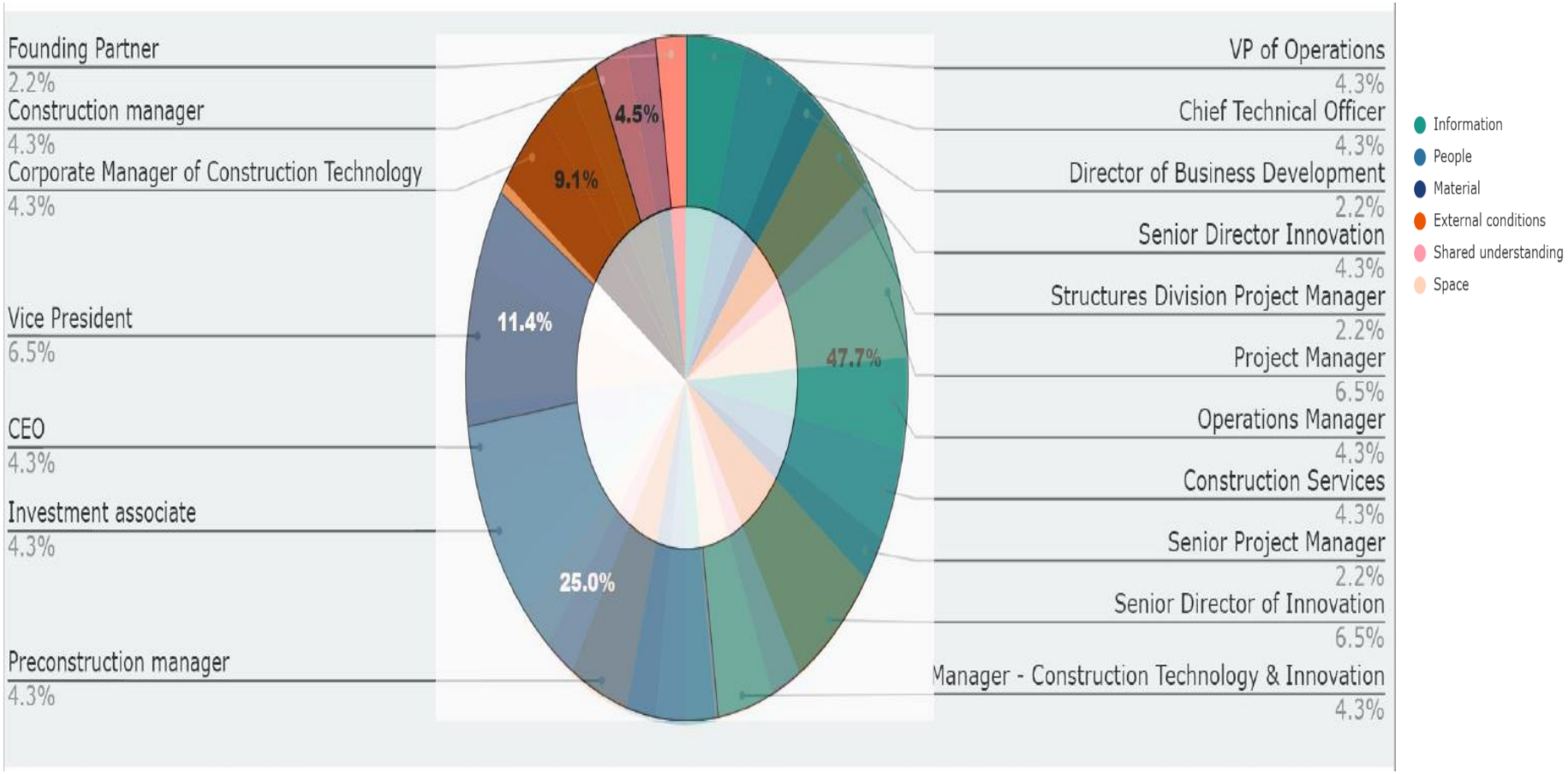


Table 2 Categorization of pain-points mentioned by interviewees and potential solutions using automation and/or robotics.

Flows mentioned	Pain Points mentioned/ hurdles to overcome	ID no.	What they mentioned	Potential solution to pain-point	Link to an example of technology solution
Information	Acquiring information from other areas	1	"One of the biggest limitations is that a model is as good as somebody who's creating it, so you know if the data is not there then the technology cannot do anything because required information is not yet there."	Software for data tracking	https://www.procore.com/
Information	Client resource management, documentation	3	"I think it would be very helpful to have some way to keep client information up to date on an automated basis, I think another thing that would help from an automation standpoint is an automated way for us to receive our bid information."	Software for documentation and CRM	https://www.procore.com/platform/document-management,
Information	Up to date information on material supply and the work completed	5	"When I open the job folder and the immediate question is, well, where's my purchase order? I can't, you know, get with my vendors and subs and push on them if we haven't even given them a subcontract or purchase order. I can't ask them for shop drawings. If we haven't committed to them that, hey, this job is actually to yours and now we need you to run. So, that it's been a very cumbersome process for us."	Software for data tracking and purchase order delivery tracking	https://www.procore.com/
Information	Up to date information	6	"So, when the contracted looks at the information he has it looks perfect but meanwhile you receive a new set of change orders and now it's completely different or it changed everything about it."	Collaborative software, BIM	https://www.oracle.com/industries/construction-engineering/primavera-p6/
Information	The gap between people at office and on site	7	"The problem with information has been that we haven't been able to bridge the gap between the office personnel and the field personnel and understand exactly who the audience is that is trying to decipher this information."	Software for data tracking	https://www.procore.com/
Information	Transfer of information when a leak is detected in a high-rise building	8	"But in a way, how can we have things like AI to help us in the field to detect the leaks in the building and this will really cut down on the loses."	Leak detection devices with ability to turn off the main when a leak is detected	https://www.nationalpumpsupply.com/7240-lb1-taco-leakbreaker-sensor/
Information	Information overflow and deficits	10	"For some activities permission is what causes the delay and for some extra equipment. So that's the aspect that we want to know. The information we get is also a very massive variable, we get information from various contractors and will get spec information. And then we got to go shop it out to multiple vendors."	BIM work packages	https://www.autodesk.com/solutions/bim
Information	Connectivity	13	"The part that we're seeing a lot of struggle with is the communication between back and forth between office environments and the field. They, it's almost like they're talking completely different languages at sometimes, and I'm just having that ability and we're going to like the digital phase of construction right now everything is digital, we don't want to print we don't want to kill trees right and that's all great. And I'm rooting for that all the way except that when you get to the job site. The biggest bottleneck for that flow of information is connectivity."	Software for data tracking	https://www.procore.com/

Table 2 Categorization of pain-points mentioned by interviewees and potential solutions using automation and/or robotics continued…

Flows mentioned	Pain Points mentioned/ hurdles to overcome	ID no.	What they mentioned	Innovative solution i.e., Automation name	Link to an example of technology solution
Information	Defect detection	14	"The process we have for tracking issues identifying issues locating issues is tough, we still use the same. That was work so we did 10 years ago."	Leak detection devices	https://www.tomsguide.com/best-picks/best-water-leak-detectors
Information	Up to date information on material supply and the work completed	15	"We need some kind of program that could automate tracking of tasks and like requirement items that would be huge. We have a lot of projects, a lot of materials that are kind of complex and take a lot of symbols and coordination and things to complete. So, I spend a lot of my time tracking where we actually are in the process of completing a task or getting that material ready to ship and where we are in this middle process. So, if we could somehow automate the email process to get that streamlined and have something track the progress, rather than having an individual attractive process."	Collaborative software, BIM	https://www.oracle.com/industries/construction-engineering/primavera-p6/
Information	Up to date information delays	17	"I think if you're waiting on information that always seems to be a, an excuse for not meeting your goal in that meeting your, your tasks, whether it's information from designers' owners or internal information. To me, the biggest constraint is information that we run into that seems to be one of the highest, you know, indicators of task not getting complete when we go back and look at things, is a lack of information. So, and that's probably the hardest one to overcome."	Software for data tracking	https://www.procore.com/
Information	Information needed to estimate	19	"But for different reasons, you know as an estimator. pricing from first principles, you absolutely need to understand the people, the materials the equipment, and the prior work. But actually, I also need to know that as a planner as well. From a from a time perspective. But actually, a lot of the time culturally those, those two individuals or several individuals don't necessarily work in tandem. They work with their own databases and historical experience and in actually in conflict in terms of their own productivity."	Collaborative software	https://www.oracle.com/industries/construction-engineering/primavera-p6/
Information	Data collection and data usage, Production tracking	20	"Data collection and data usage in construction, compared to manufacturing is very, Very much so in its infancy. Production tracking schedule management data are all those are all things that construction is still learning about and there's a huge explosion right now in the software industry trying to serve construction companies because they're aware of this and there's a multitude of platforms because of that, and Turner is serving themselves."	Software for tracking purchase order delivery	https://quickbooks.intuit.com/quickbooks-commerce/
Information	Information on resources	21	"I mean I probably be biased but I would say information just because that's kind of been my biggest pain point in the projects I have worked on."	Software for data tracking	https://www.procore.com/

Table 2 Categorization of pain-points mentioned by interviewees and potential solutions using automation and/or robotics continued…

Flows mentioned	Pain Points mentioned/ hurdles to overcome	ID no.	What they mentioned	Innovative solution i.e., Automation name	Link to an example of technology solution
Information	Information on resources	22	"Information on people are critical most critical headaches, in the construction side if you're working on an activity."	Collaborative software	https://www.oracle.com/industries/construction-engineering/primavera-p6/
Information	Planning aspect	24	"Because, you know...a lot of this. [is] information [about] your equipment, your materials, your people. That's everything I consider planning that happens prior to [working] right. And so, you know, to sit down with your team and talk about how you want things delivered, what materials are we going to install, you know on a plumbing underground you can have PVC, or you can have cast iron. You can even have extra heavy cast iron right, so what is that material going to be? How are we going to deliver it? What are we going to fabricate? You know, or is there any constraint?"	Software for data tracking	https://www.procore.com/
Information	Insurance claims and processing data	25	"Quite a lot of press around a product that relates to a larger scale insurance policy similar to blockchain where as soon as you buy something, you're on the ledger, there's no claims process it's automatic it's done within a few numbers of days, but from an operational point of view, it can really help with claims because it's essentially matching up policyholders with claims and what not. And I think it could be much more efficient because insurance is an older industry, I would say it somewhat inefficient in many areas and it's just kind of really entered into the digital world."	Collaborative software	https://www.oracle.com/industries/construction-engineering/primavera-p6/
Information	Planning aspect	26	"I think that it's a combination of information, materials, and prior work. so, if you think the design is right then it's okay, but if the designs not right you obviously can't do the work. You know what we've been trying to do is get a lot more detail into the design so that we take the, the unknowns out so you're not having to improvise as much as a field installer, if we can model it, and we can tell you where it needs to go we should do that because of the time that's spent in the field, performing rework around things that aren't acceptable by code or whatever is significant."	Collaborative software	https://www.oracle.com/industries/construction-engineering/primavera-p6/
Information	Up to date information delays	27	"So, picture this...as an analogy...The mechanical contractor is getting ready to, you know, install something and they realized that something was underspecified, so they go do an ROI, it's [a] valid one so that comes to change the design. [The] design is changed, moved around and now they've now the electrical conduit or somewhere else but that didn't get to the electrical contractor who went and off-site manufacturer the conduits as a role that they can.... So that information not being real time is still a big problem in the big guys [companies]... like DPR and Mortensen."	Software for data tracking	https://www.procore.com/

Table 2 Categorization of pain-points mentioned by interviewees and potential solutions using automation and/or robotics continued…

Flows mentioned	Pain Points mentioned/ hurdles to overcome	ID no.	What they mentioned	Innovative solution i.e., Automation name	Link to an example of technology solution
Information	Data storage	2	"We're trying to figure out the age of a piece of equipment. But it was just rusted and bleached out. So, the nameplate telling us what the equipment it there isn't, so we have no way of telling the data stored."	RFID	https://gaorfid.com/construction-industry-rfid-solutions-2/
People	Labor	1	"People is really the shortage."	Autonomous vehicles, Robots, and increased use of prefabrication	https://www.sarcos.com/products/guardian-gt/
People	Risk management, safety	4	"They could standardize on means and methods and really reduce the labor required for building these projects. The safety of the craft and improve the productivity of the craft."	Apps for real time location and condition, robots	https://staysafeapp.com/lone-worker-solution/lone-worker-app/
People	Skilled labor shortage	10	"Oddity is the metro areas are booming because of the macro trend of urbanization so urbanization is starting to drive lack of skilled labor and the lack of skilled labor is critical for us."	Robots, exoskeletons and autonomous vehicles for increased productivity	https://www.sarcos.com/products/guardian-gt/
People	Safety	11	"Safety is a huge concern. You know anytime a company has 1600 employees, many of which are working in the field so anything we can do to streamline our installation and make it easier, and really just safer we would be interested in it."	Apps for real time location and condition, robots	https://staysafeapp.com/lone-worker-solution/lone-worker-app/
People	Skilled labor shortage	12	"In activities. we're having a hard time filling craft worker of the industry. People just don't want to do anymore."	Robots, exoskeletons, drones, and autonomous vehicles for increased productivity	https://www.sarcos.com/products/guardian-gt/
People	Safety	13	"A lot of times, workers like to take shortcuts and kind of get the job done. We always have to keep a safety personnel on the job site looking over that and stopping work sometimes which creates bottlenecks they're not doing it the right way."	Apps for real time location and condition	https://staysafeapp.com/lone-worker-solution/lone-worker-app/
People	Skilled labor shortage	21	"I guess, decreased number of skilled labors in the industry so that kind of you know, leads us to the you know about robotics, and where we see the industry heading there."	Autonomous vehicles, Robots and increased use of prefabrication	https://www.sarcos.com/products/guardian-gt/
People	Skilled labor shortage	23	"People is always the shortage and mainly shortage of skilled labor. So, this idea that you need to have more resources to complete more work efficiently is flawed thinking so for us it's really about Hey, how about you this instead of putting 20 guys out here sporadically you give a six men that can do this amount of production every day and we can show you, to a model that, if that you're going to make more money and we'll get just as much work done, you know."	Robots, exoskeletons, drones, and autonomous vehicles for increased productivity	https://www.sarcos.com/products/guardian-gt/
People	To reduce long term effects of working on field	4	"If the workers were not picking up 50 pound of materials, tool, big screws or move big materials, the risk of injury goes way down."	Exoskeletons for additional strength	https://www.sarcos.com/products/guardian-gt/

Table 2 Categorization of pain-points mentioned by interviewees and potential solutions using automation and/or robotics continued…

Flows mentioned	Pain Points mentioned/ hurdles to overcome	ID no.	What they mentioned	Innovative solution i.e., Automation name	Link to an example of technology solution
People	Efficiency	29	"You know efficiency in construction which is going down. And of course, this is like everybody who deals with construction information also knows about this. And I mean efficiency of people is a huge problem. It's like, we see everything is being developed. Recently we, you know, we have like startups in the area of like space technology right now like building rockets, but we still have almost no use of technology."	Robots, exoskeletons, drones, and autonomous vehicles for increased productivity	https://www.sarcos.com/products/guardian-gt/
People	Mishap causing people being tied up in other works for longer or delated material	6	"I might have an updated set of drawings and I might have people, but they do not have the right stuff to install."	Software for tracking purchase order delivery, Autonomous vehicles, Robots and increased use of prefabrication to overcome people shortage	https://www.sarcos.com/products/guardian-gt/, https://quickbooks.intuit.com/quickbooks-commerce/
People	Accidents occurring while installation of stairways/safety	9	"I'm the most interested in installation of stairs and elevators because...when you don't have those stairs early in place, you got guys coming up and down the building on ladders, and that's just not efficient and it's not safe."	Prefabricated stairs and elevator shafts with minimum installation	https://www.phoenixmodularelevator.com/hoistway/
Material	Delayed supply	6	"I might have an updated set of drawings and I might have people, but they do not have the right stuff to install."	Software for tracking purchase order delivery	https://quickbooks.intuit.com/quickbooks-commerce/
Material	Material quality	18	"The material, because certain policies will have exclusions for certain type of material effects. So, if you're familiar with certain insurance policies that if it's being used on a project, they would charge more money to ensure some of this information. They do get down to specifics and it's all taken into account when pricing a project for major effects"	Supplier quality management software	https://www.capterra.com/quality-management-software/
Material	Material supply fluctuations	23	"...materials fluctuates as you know, because there's so many things that we can't control. Hey, all of a sudden, the steel, you know that there's an embargo or, you know, there's a shortage and, you know, we thought we'd get structural steel on this date, but now we're not going to get till this date. I mean those are just things that projects can't recover from when they come to critical things. So, materials are a big deal for us."	Supplier quality management software	https://www.capterra.com/quality-management-software/
Material	Delay and quality	28	"I'll say material sometimes it's hard to get some materials and because of the lead time. It takes a bit of time, some of the materials takes around about eight to twelve weeks minimum and up to sixteen weeks to arrive dependent on the season, on what you are constructed on the volume.... So, materials also play an important role."	Software for tracking purchase order delivery	https://quickbooks.intuit.com/quickbooks-commerce/
Material	Delay and quality	28	"I'll say material sometimes it's hard to get some materials and because of the lead time. some of the materials takes around about eight to twelve weeks minimum and up to sixteen weeks to arrive dependent on the season, on what you are constructed on the volume.... So, materials also play an important role."	Software for tracking purchase order delivery	https://quickbooks.intuit.com/quickbooks-commerce/

Table 2 Categorization of pain-points mentioned by interviewees and potential solutions using automation and/or robotics continued…

Flows mentioned	Pain Points mentioned/ hurdles to overcome	ID no.	What they mentioned	Innovative solution i.e., Automation name	Link to an example of technology solution
Material	Delay and quality	26	"Getting the materials on site when you need them, making sure that you're working with your suppliers to make sure that the fabrication makes sense. But then also ensuring that...when something is finished at the shop that it's right. We spend a lot of time trying to fix things whether it's structural steel or pipe. Like I mentioned before, trying to get it within compliance so that we can actually join it together."	Software for calculating quantities / estimating software	https://quickbooks.intuit.com/quickbooks-commerce/
External conditions	Weather uncertainty	17	"The external conditions, nobody can control. If weather is going to affect your schedule and you know it delays, a week because the conditions weren't right for you to do the works, it's too hot, too cold too windy."	Companies that provide solutions for weather uncertainty	https://weatherbuild.co/
External conditions	Weather	22	"External conditions just because that's probably the highest risk right, it's the things that you can't control, and then you know as construction is looking at manufacturing and trying to adopt manufacturing."	Companies that provide solutions for weather uncertainty	https://weatherbuild.co/
External conditions	Weather and site conditions	28	"I would say external condition and also existing condition. I'm dragging this into my own area of operations, or the kind of projects that I do, existing conditions play a huge role in being successful in delivering the project. Sometimes you go into a new site you have to clear up, you have to do this and that and it takes time before you tackle the existing conditions."	Companies that provide solutions for weather uncertainty	https://weatherbuild.co/
External conditions and Equipment	Equipment sensitive to climatic conditions	10	"We use weather sensitive machinery, so they're putting lots of efforts in protecting their equipment which adds a lot more weight which increases motor requirements which increases power requirements which affects its battery life."	Waterproofing the equipment	https://www.vectorsecurity.com/blog/3-ways-to-protect-outdoor-security-equipment-from-severe-weather
Shared understanding	Up to date transfer of information and other materials from one sector to another	8	"I think shared understanding is probably the biggest, making sure everyone has the most up to date information but also making sure that we all have the same info. So sometimes some tasks have to take a backseat to others and hopefully you're able to work that out in your pool binding"	Software for data tracking	https://www.procore.com/
Shared understanding	Shared understanding	23	"Where the misalignment comes from, is this shared understanding of what our conditions of satisfaction, what are we trying to achieve. How are we going to do the work."	Regular communication and hurdles	https://intellectualapps.com/2019/12/08/5-ways-to-improve-shared-understanding-in-software-teams/
Shared understanding	Shared understanding	30	"I think communication and understanding between different trades people is probably the most difficult one."	Regular communication and hurdles	https://intellectualapps.com/2019/12/08/5-ways-to-improve-shared-understanding-in-software-teams/

Table 2 Categorization of pain-points mentioned by interviewees and potential solutions using automation and/or robotics continued…

Flows mentioned	Pain Points mentioned/ hurdles to overcome	ID no.	What they mentioned	Innovative solution i.e., Automation name	Link to an example of technology solution
Space	For transportation and storing	16	"So that is one area where I see transportation is a big waste material are always getting moved around left and right, some jobs have the luxury of storing materials on site, others don't wear it just needs to be on delivered and put into place on time. Where it just needs to be on delivered and put into place on time so automation, I think could really help out that way."	Autonomous vehicles	https://www.mortenson.com/newsroom/builders-finding-substantial-value-in-robotics

APPENDIX A

Interviewee Appointment Form

* Required

1. Name *
   First and Last Name

2. Preferred phone number for contact *

3. What gender do you identify as ? *

   Mark only one oval.

   - ◯ Male
   - ◯ Female
   - ◯ Prefer not to answer.

4. Please specify your ethnicity. *

   Mark only one oval.

   - ◯ Caucasian
   - ◯ African-American
   - ◯ Latino or Hispanic
   - ◯ Asian
   - ◯ Native American
   - ◯ Native Hawaiian or Pacific Islander
   - ◯ Two or More
   - ◯ Other/Unknown
   - ◯ Prefer not to say

5. What is the highest level of degree/education you have completed ? *

   Mark only one oval.

   - ◯ Some High School
   - ◯ High School
   - ◯ Associate's degree
   - ◯ Bachelor's Degree
   - ◯ Master's Degree
   - ◯ Ph.D. or higher
   - ◯ Trade School
   - ◯ Prefer not to say

6. What is your current role in the company you are working with/for ? *

7. What is your area of expertise ? *

8. Name of the current company you are working for/with ? *

_____

9. What is your current employment status ? *

Mark only one oval.

- ◯ Employed Full-Time
- ◯ Employed Part-Time
- ◯ Seeking opportunities
- ◯ Retired
- ◯ Prefer not to say

10. Which sector are you most experienced in ? *

Mark only one oval.

- ◯ Commercial
- ◯ Residential
- ◯ Environmental
- ◯ Industrial
- ◯ Heavy civil
- ◯ Other: _____

11. How many years of construction experience do you possess ? *

Mark only one oval.

- ◯ less than 5 years
- ◯ 5-10 years
- ◯ 10-15 years
- ◯ 15-20 years
- ◯ more than 20 years

12. When are you available for a 20 minute call with our team? Kindly provide up to 3 preferred days and time windows. *

_____

_____

_____

_____

_____

APPENDIX B

- Line-of-Balance is a graphical scheduling method which considers location explicitly as a dimension. This allows for easier planning of continuous resource use, which in turn enables cost savings and less schedule risk as subcontractor crews can be kept on the site (Seppanen and Aalto 2005).
- Takt time planning is work planning based on the time set for the supply of a certain process (takt) that is derived from the rate of customer demand. It forms the basis for single-piece flow in lean philosophy (Frandson and Tommelein 2014).

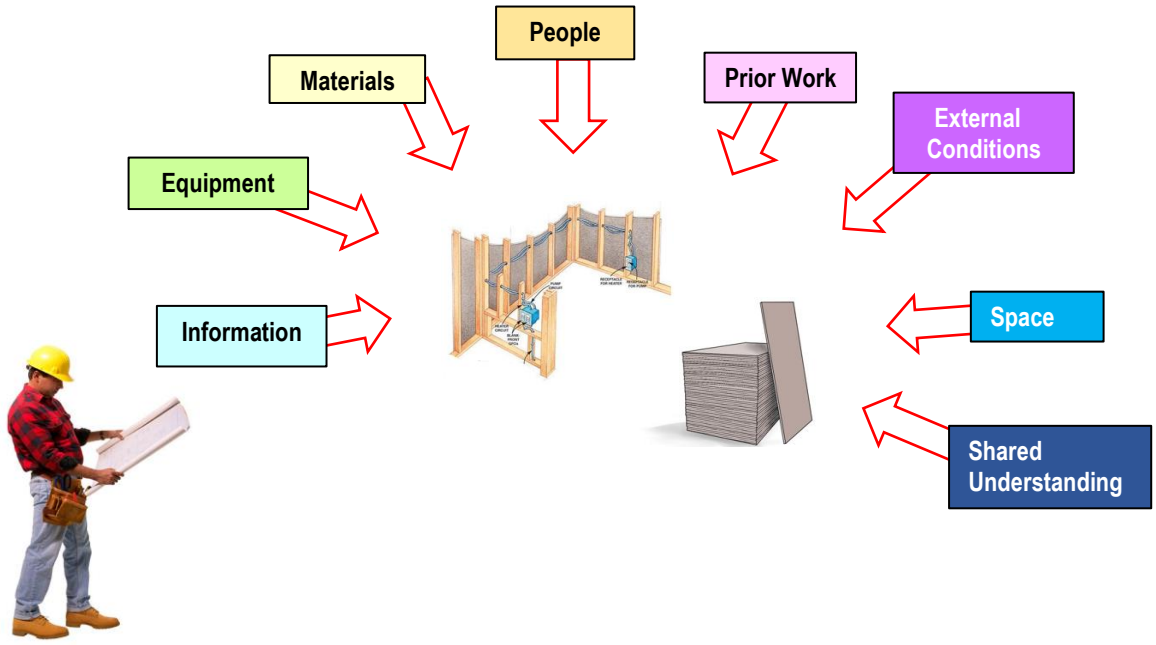
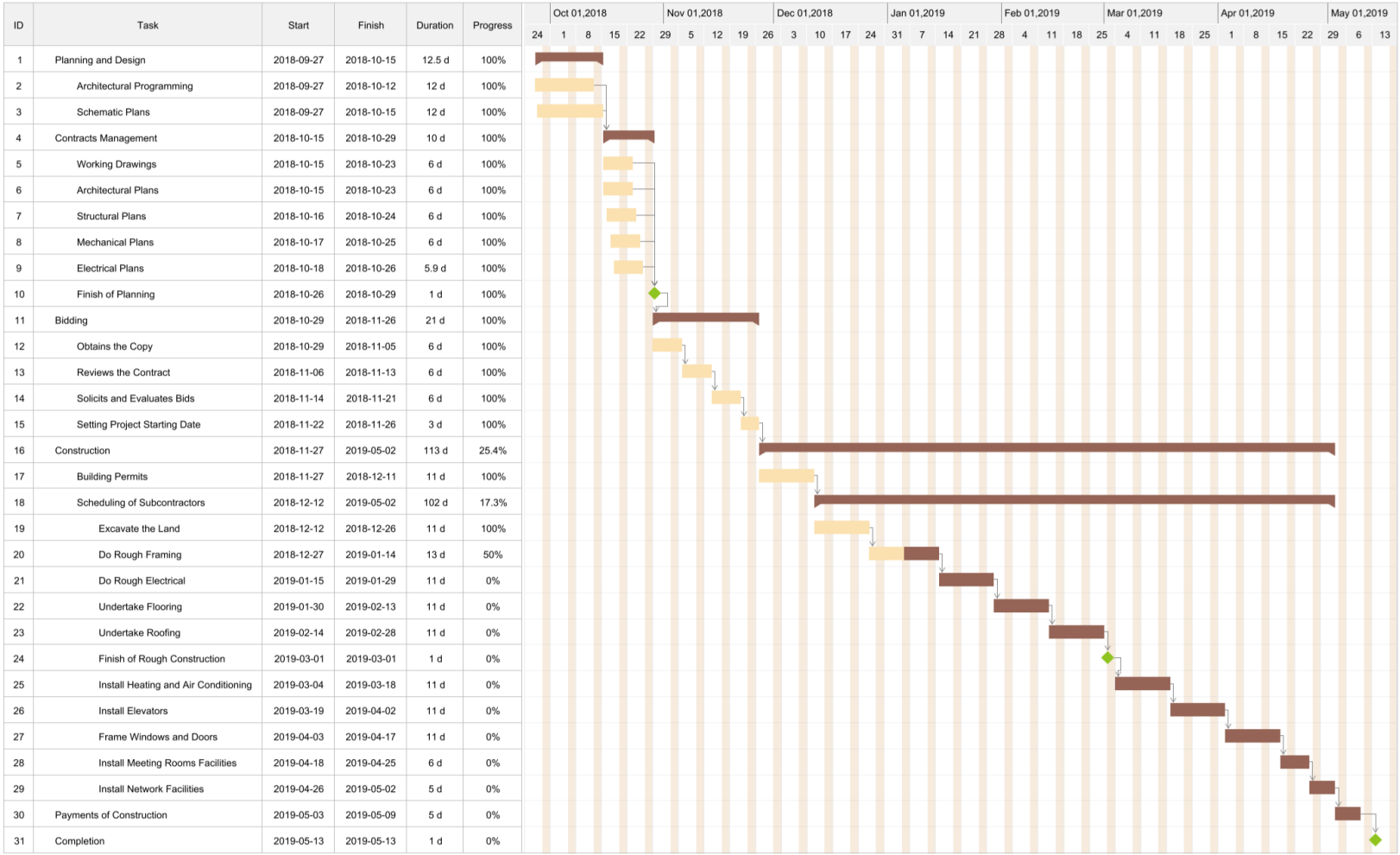


Figure 16: Eight flows: Resources needed to complete a task.

Image sources: Wonkeedonkeetools (2020); Touch Wood Construction (2021)

Figure 17: Example of a commercial construction project's Timeline and activities (gnatt chart).

Image source: Commercial Building Construction Gantt Chart Template, (n.d.).



ID	Task	Start	Finish	Duration	Progress
1	Planning and Design	2018-09-27	2018-10-15	12.5 d	100%
2	Architectural Programming	2018-09-27	2018-10-12	12 d	100%
3	Schematic Plans	2018-09-27	2018-10-15	12 d	100%
4	Contracts Management	2018-10-15	2018-10-29	10 d	100%
5	Working Drawings	2018-10-15	2018-10-23	6 d	100%
6	Architectural Plans	2018-10-15	2018-10-23	6 d	100%
7	Structural Plans	2018-10-16	2018-10-24	6 d	100%
8	Mechanical Plans	2018-10-17	2018-10-25	6 d	100%
9	Electrical Plans	2018-10-18	2018-10-26	5.9 d	100%
10	Finish of Planning	2018-10-26	2018-10-29	1 d	100%
11	Bidding	2018-10-29	2018-11-26	21 d	100%
12	Obtains the Copy	2018-10-29	2018-11-05	6 d	100%
13	Reviews the Contract	2018-11-06	2018-11-13	6 d	100%
14	Solicits and Evaluates Bids	2018-11-14	2018-11-21	6 d	100%
15	Setting Project Starting Date	2018-11-22	2018-11-26	3 d	100%
16	Construction	2018-11-27	2019-05-02	113 d	25.4%
17	Building Permits	2018-11-27	2018-12-11	11 d	100%
18	Scheduling of Subcontractors	2018-12-12	2019-05-02	102 d	17.3%
19	Excavate the Land	2018-12-12	2018-12-26	11 d	100%
20	Do Rough Framing	2018-12-27	2019-01-14	13 d	50%
21	Do Rough Electrical	2019-01-15	2019-01-29	11 d	0%
22	Undertake Flooring	2019-01-30	2019-02-13	11 d	0%
23	Undertake Roofing	2019-02-14	2019-02-28	11 d	0%
24	Finish of Rough Construction	2019-03-01	2019-03-01	1 d	0%
25	Install Heating and Air Conditioning	2019-03-04	2019-03-18	11 d	0%
26	Install Elevators	2019-03-19	2019-04-02	11 d	0%
27	Frame Windows and Doors	2019-04-03	2019-04-17	11 d	0%
28	Install Meeting Rooms Facilities	2019-04-18	2019-04-25	6 d	0%
29	Install Network Facilities	2019-04-26	2019-05-02	5 d	0%
30	Payments of Construction	2019-05-03	2019-05-09	5 d	0%
31	Completion	2019-05-13	2019-05-13	1 d	0%

Figure 18: Visual representation of the Eight flows of lean in each activity.

Date of this version: September 11 , 2020								
Example								
Description	**Information**	**Equipment**	**Materials**	**People**	**Prior Work**	**External Conditions**	**Space** (Head/Time/ Physical)	**Shared Understanding**
Planning and Design								
Architectural Programming								
Schematic Plans								
Contracts Management								
Working Drawings								
Architectural Plans								
Structural Plans								
Mechanical Plans								
Electrical Plans								
Finish of Planning								
Bidding								
Obtains the Copy								
Reviews the Contract								
Solicits and Evaluates Bids								
Setting Project Starting Date								
Construction								
Building Permits								
Scheduling of Subcontractors								
Excavate the Land								
Do Rough Framing								
Do Rough Electrical								
Undertake Flooring								
Undertake Roofing								
Finish of Rough Construction								
Install Heating and Air Conditioning								
Install Elevators								
Frame Windows and Doors								
Install Meeting Rooms Facilities								
Install Network Facilities								
Payments of Construction								
Completion								

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Title of Research Study: Identification Of Automation Needs In The Construction Industry

Investigator: Zofia K. Rybkowski

Funded/Supported By: This research is funded/supported by Construction Industry Advisor Council (CIAC).

Why are you being invited to take part in a research study?

You are being asked to participate because you are currently working in because of your expertise in Construction Industry.

What should you know about a research study?

- Someone will explain this research study to you.
- Whether or not you take part is up to you.
- You can choose not to take part.
- You can agree to take part and later change your mind.
- Your decision will not be held against you.
- You can ask all the questions you want before you decide.

Who can I talk to?

If you have questions, concerns, or complaints, or think the research has hurt you, talk to the research team at Department of Construction Science, P.I. Dr. Zofia Rybkowski by email at zrybkowski@tamu.edu or call at 979-446-2228 (m). Co.P.I Dr. Manish Dixit by email at mdixit@tamu.edu.

This research has been reviewed and approved by the Texas A&M Institutional Review Board (IRB). You may talk to them at 1-979-458-4067, toll free at 1-855-795-8636, or by email at irb@tamu.edu., if

- You cannot reach the research team.
- Your questions, concerns, or complaints are not being answered by the research team.

- You want to talk to someone besides the research team.
- You have questions about your rights as a research participant.
- You want to get information or provide input about this research.

Why is this research being done?

Identify opportunities to improve the overall time, cost, quality, safety, and morale on a project through automation by using Value Stream Mapping.

How long will the research last?

We expect that you will be in this research study for 20 minutes.

How many people will be studied?

We expect to enroll about 100 people in this research study at this site. Approximately 150 people in the entire study nationally will be enrolled.

What happens if I say "Yes, I want to be in this research"?

- The research will be performed by conducting a series of interviews including personnel of varying expertise and the data collected will be analyzed to find bottlenecks present in the construction industry which can be improved
- The length and duration of interviews is between 20 minutes or more based on your availability.
- The participant will interact with either Dr. Zofia Rybkowski, Dr. Manish Dixit, Ms. Nicole Shumaker or Ms. Rajeswari Obulam.
- The research will be conducted through interviews conducted via Zoom or other suitable video conferencing tools.
- The research will begin in August via video conferencing tools.
- All the interviews may be subjected to audio or video recordings. If you choose not to consent for recording a live transcript will be made hiding your identity.
- The researcher may audio or video record me to aid with data analysis. The researcher will not share these recordings with anyone outside of the immediate study team or TAMU Compliance.
- The researcher may audio or video record me for use in scholarly presentations or publications. My identity may be shared as part of this activity, although the

researcher will attempt to limit such identification. I understand the risks associated with such identification.

- The researcher may contact me in the future to see whether I am interested in participating in other research studies by the principal investigator of this study.

What happens if I do not want to be in this research?

You can leave the research at any time and it will not be held against you.

What happens if I say "Yes", but I change my mind later?

You can leave the research at any time and it will not be held against you. If you decide to leave the research midway and withdraw any data collected from you, contact the investigator so that the investigator and further instructions will be provided.

What happens to the information collected for the research?

Efforts will be made to limit the use and disclosure of your personal information, including research study and other records, to people who have a need to review this information. We cannot promise complete privacy. Organizations that may inspect and copy your information include the TAMU HRPP/IRB and other representatives of this institution.