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AIC

Accelerating Constructor Excellence

The Professional Constructor

Journal of the American Institute of Constructors

IN THIS ISSUE:

The Professional Constructor

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Founded in 1971, the American Institute of Constructors mission is to promote individual professionalism and excellence throughout the related fields of construction. AIC supports the individual Constructor throughout their careers by helping to develop the skills, knowledge, professionalism and ethics that further the standing of the construction industry. AIC Members participate in developing, and commit to, the highest standards of practice in managing the projects and relationships that contribute to the successful competition of the construction process. In addition to membership, the AIC certifies individuals through the Constructor Certification Commission. The Associate Constructor (AC) and Certified Professional Constructor (CPC) are internationally recognized certifications in the construction industry. These two certifications give formal recognition of the education and experience that defines a Professional Constructor. For more information about the AIC please visit their website at **www.aic-builds.org**.

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- A qualifying body to serve the individual in construction, the Constructor, who has achieved a recognized level of professional competence;
- Opportunities for the individual constructor to participate in the process of developing quality standards of practice and to exchange ideas;
- Leadership in establishing and maintaining high ethical standards;
- Support for construction education and research;
- Encouragement of equitable and professional relationships between the professional constructor and other entities in the construction process; and
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Knowledge Management: General Contractors vs. Specialty Contractors – An Insight into Culture and Perception in the SE United States

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Abstract

The challenges experienced due to the workforce shortage that results in knowledge loss have been studied in various industries. To deal with the knowledge loss caused by the current and projected retirement rate, companies must retain the knowledge and experience gained by the current workforce and successfully transfer it to the next generation of employees. The focus of the study is to address the issue of retention of knowledge and experience. Thus, this paper studied the awareness and implementation of knowledge transfer strategies and the perception of knowledge management culture and programs in the southeast region of the U.S. The data was collected through a background study and survey distribution among the industry partners of this study. According to the study, knowledge loss is a critical issue for businesses since the pool of future talent is insufficient to replace the retiring workforce. Furthermore, disparities were observed between the awareness and implementation of knowledge transfer strategies at the company and employee levels in general contractors (GCs) and trade partners or specialty contractors (S.C.). These differences suggest that knowledge management implementation should be studied at the employee level to better understand knowledge management in construction companies. According to data analysis for the perception of knowledge management culture, it was observed that most of the surveyed employees had access to knowledge management tools and were aware of knowledge management strategies; however, their implementation was not sufficiently encouraged. Through these analyses, this study lays the groundwork for pursuing knowledge management on a deeper level by increasing collaboration opportunities that benefit industry partners.

Keywords: Implementation, Knowledge loss, Knowledge management, Workforce demographics.

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Introduction

Multiple researchers have studied knowledge loss and challenges faced due to workforce shortages in varied sectors. As the baby boomers approach retirement age, organizations are experiencing critical knowledge loss regarding company services, products, relationships, and invaluable how-to organizational strategies (Ippoliti, 2016). With highly experienced employees leaving in a mass, companies recognize the need for business-critical and experience-based knowledge retention (Daghfocus et al., 2013; Leonard et al., 2014; Urbancova & Linhartova, 2011). Knowledge and knowledge management hold the same value as tangible corporate resources such as people, land, buildings, capital equipment, and financial resources (Ansoff et al., 2019; Helm-Stevens, 2010). Current and forecasted rates of retirement result in knowledge loss, and to cope with this challenge, companies are required to retain the knowledge and experience gained by the present workforce and transfer it successfully to the newer generation of employees (Calo, 2008; Brčić, 2015; Glick, 2007; Helm-Stevens, 2010). According to Mclaughlin & Paton (2008), knowledge loss due to the retirement of baby boomers is a growing concern amongst several organizations. Approximately forty-one percent (41%) of the current workforce, primarily in management positions, is estimated to retire by 2031 (NCCER, 2017). Therefore, losing valuable knowledge and know-how would require a significant effort on the part of the companies to recover.

Workforce Demographics and Knowledge Loss

The workforce demographic is distributed into the following generational categories based on their birth year: the veterans (Before 1945), the baby boomers (1946-1964), generation X (1965-1979), generation Y (1980-1996), and generation Z (1997-2012). As recorded in 2019, about 70 million people, or twenty-one percent (21%) of the total U.S. population, are the baby boomer generation. Generation X comprises only 65 million individuals, or twenty percent (20%) of the country's population (Statista, 2022). According to the report by BLS (2017), the generational distribution of the current workforce consisted of approximately ninety-two percent (92%) veterans, twenty-five percent (25%) baby boomers, thirty-three percent (33%) generation X, and thirty-five percent (35%) millennials. This data shows that future talent is insufficient to reinstate the retiring workforce.

Since knowledge of the company's know-how is critical for organizations (Jennex & Durcikova, 2013), the risk of losing invaluable learning and expertise occurs from losing experienced and knowledgeable employees. According to Massingham (2018), Knowledge loss due to the loss of an employee has three significant effects:

- Loss of contribution to the organizational memory
- Loss of relational knowledge with the internal and external social network (fellow employees and customers)
- Loss of work performance results in decreased organizational productivity (a decrease in the organization's ability to perform the tasks it completed before the employee left).
- In conclusion, employee loss leads to a significant loss of an organization's know-how and know-what (Sumbal et al., 2018).
- Impact of workforce demographics on knowledge retention

Knowledge can be defined as "a fluid mix of framed experience, values, contextual information, and expert insights that provides a framework for evaluating and incorporating new experiences and information – it originates in and is applied in the minds of knowers" (Davenport & Prusak, 1998). Furthermore, according to Tsoukas & Vladimirou (2002), "organizational knowledge is the capability members of an organization have developed to draw distinctions in the process of carrying out their work, in particular concrete contexts, by enacting sets of generalizations whose application depends on historically evolved collective understandings." Organizational knowledge has two categories - tacit and explicit. The knowledge gained from personal experience is tacit knowledge (Nonaka, 1994). Contrarily, explicit information can be encoded, maintained in a single location, and transferred across time and space without engaging specific individuals (Lam, 2020). Organizations' most strategically significant resource is a mature workforce's explicit and tacit knowledge (Calo, 2008). On the one hand, knowledge management can expedite the transfer of lessons learned within and across projects (Patton, 2001); on the other hand, appropriate use of knowledge management can convert tacit knowledge into explicit knowledge. The definition of knowledge retention has been as "maintaining, not losing, the knowledge that exists in the minds of people (tacit, not easily documented) and knowing (experiential action manifesting in behavior) that it is vital to the organization's overall functioning" (Martins & Meyer, 2012). The field of knowledge retention, which deals with preserving the expertise of departed employees, is relatively new. Knowledge retention, a branch of knowledge management, has not received enough attention from academic studies, according to Levy (2011).

Changing workforce demographics affects organizations significantly in various industries (Lesser et al., 2006; Sumbal et al., 2018). Therefore, organizations have become attentive to the critical challenges of knowledge management. Across myriad industries, in the wake of labor shortages, the challenges of workforce management range from knowledge loss to maintaining employee productivity. As studied by the American Society of Training and Development (ASTD) and the International Business Machines (IBM), most company executives project that a maturing workforce combined with labor shortage issues will have a significant impact on their respective organizations (Lesser et al., 2006).

Literature Review

The construction industry in the United States has private spending surpassing 977 billion dollars as of 2019 and 11.2 million employees, making it one of the most significant sectors in the world. The construction industry has also contributed to 4.1 percent of the gross domestic product in the U.S. By 2023, the anticipated investment in new construction is 1,449 billion U.S. dollars (Raynor, 2021). According to the Bureau of Labor Statistics (BLS) data from 2017, employment in the construction sector is predicted to increase by 1.2% from 2016 to 2026, closely following the growth of the top three industries (1.9% for healthcare, 1.4% for mining, and 1.3% for educational services) (BLS, 2017). The Department of Labor pointed out the need to replace the retiring workforce or workforce leaving the industry (Kim et al., 2020). Much like other sectors, the construction industry experiences knowledge loss and a gap between the rate of retirement and the recruitment of new employees.

Rate of Retirement and Workforce Shortage Perception

According to Sharma et al. (2022), approximately nine percent (9%) of the current workforce in construction has passed the age of retirement, i.e., sixty-five (65) and thirty-seven percent (37%) of the surveyed workforce is expected to retire in the next twenty (20) years. From an understanding of the perception of workforce shortages by the employees in the management and field/skilled labor positions, the correlation between the retirement rate and the workforce shortages needs to be further supported by studying the supply and demand in the construction industry.

In the precedential research of this study, the perception of workforce shortage for the past five years, within the last year and the next five years, was analyzed through a survey instrument (Sharma et al., 2022). The results indicated significant workforce shortages for management and field/skilled labor positions in the past five years. Although the current and future workforce shortage seemed slightly better than in the past, it still indicated a significant workforce shortage. Moreover, results regarding the perception of workforce shortages in the next five years indicated that the perception of management recruitment difficulty is expected to decline from sixty-three percent (63%) in the past to fifty percent (50%) in the next five years (Sharma et al., 2022).

A study by Kim et al. (2020) validates the findings as it states that an aging workforce is one of the four most important reasons the construction industry faces workforce shortages. The future perception of the workforce shortage indicates that the construction industry is reasonably optimistic about workforce shortage challenges in the future. The retirement rate of the workforce and the perception of workforce shortage in the industry need to be evaluated together to understand the gravity of the workforce challenges resulting in knowledge loss.

Knowledge transfer strategies in construction

Organizations need to facilitate the process of knowledge transfer since the knowledge gained over time is essential in promoting processes and overall firm performance (Daghfous et al., 2013). As the construction industry recognizes the importance of dealing with a retiring workforce and labor shortages resulting in knowledge loss, Appendix A explains the knowledge transfer strategies and their respective definitions currently employed by organizations (Caldas et al., 2014). The background study on the subject matter has focused on workforce challenges on a national platform; however, workforce challenges are led by the regional construction market. Studies addressing knowledge transfer are not necessarily unique to the construction industry and are primarily theoretical. Previous research (Sharma et al., 2022) has successfully studied the workforce challenges that come with employee retirement rates and the impact of COVID-19 on the current workforce demographics in the southeast region of the United States. In continuation of the same research, this paper elaborates on the state of implementing knowledge transfer strategies on an organizational and employee level in the southeast region of the United States. The perceptions of knowledge management programs and the knowledge management cultures are also studied to understand the differences in results on a company level and an employee level for the G.C. and S.C. companies separately.

This study focuses on the overall southeast region, irrespective of the contracting practices of the companies (G.C. vs. S.C.) and the construction sector they serve (Industrial or Residential). The main objectives of the paper are as follows:

To understand the correlation between employee retirement rate, workforce shortages, and knowledge management through background study.

To evaluate the level of knowledge transfer strategies implementation and awareness amongst the existing workforce for the overall southeast region, G.C. and S.C. companies separately.

To gauge the implementation and perception of knowledge management culture across G.C. and S.C. organizations.

Methodology

This research was conducted through a successful partnership between the Industry Advisory Board (IAB) and the researchers' team to foster collaboration between the academic world and the construction industry. The fundamental objective of this initiative, which was created by and for the industry, was to share expertise through developing creative ideas, improving business outcomes, and finding answers to the most common issues in the construction industry. The academic-industry partnership was built upon the goals of identifying areas of improvement in knowledge retention and workforce development. The basis of these goals was ensuring: i) the continuation of high standards of education for students, ii) opportunities for professional growth for the faculty, and iii) strengthening the collaboration of the academic world with the construction industry. The approach of this study was distributed into two main phases (Figure 1):

> Phase 1: Establishing a steering committee and identifying several crucial focus areas to select one key area for this study.
>
> Phase 2: Designing a study based on the selected area of focus from phase one – Workforce Demographics and knowledge transfer in the southeast region of the United States. The designed research included a background study on the subject matter, survey development & distribution, and data analysis based on the survey responses.

The steering committee also evaluated other vital areas such as close-out / warranty and safety performance; however, phase one concluded with the selection of workforce demographics and knowledge transfer in the southeast region of the United States as the focus of this study. The corporate partner Program consisted of sixty-six (66) organizations from the construction industry. Furthermore, the steering committee for this research consisted of nine (9) IAB member companies and two (2) academic researchers from Clemson University. This study focused on the southeast region of the United States, as the participating IAB member companies were primarily based in the southeast region of the United States.

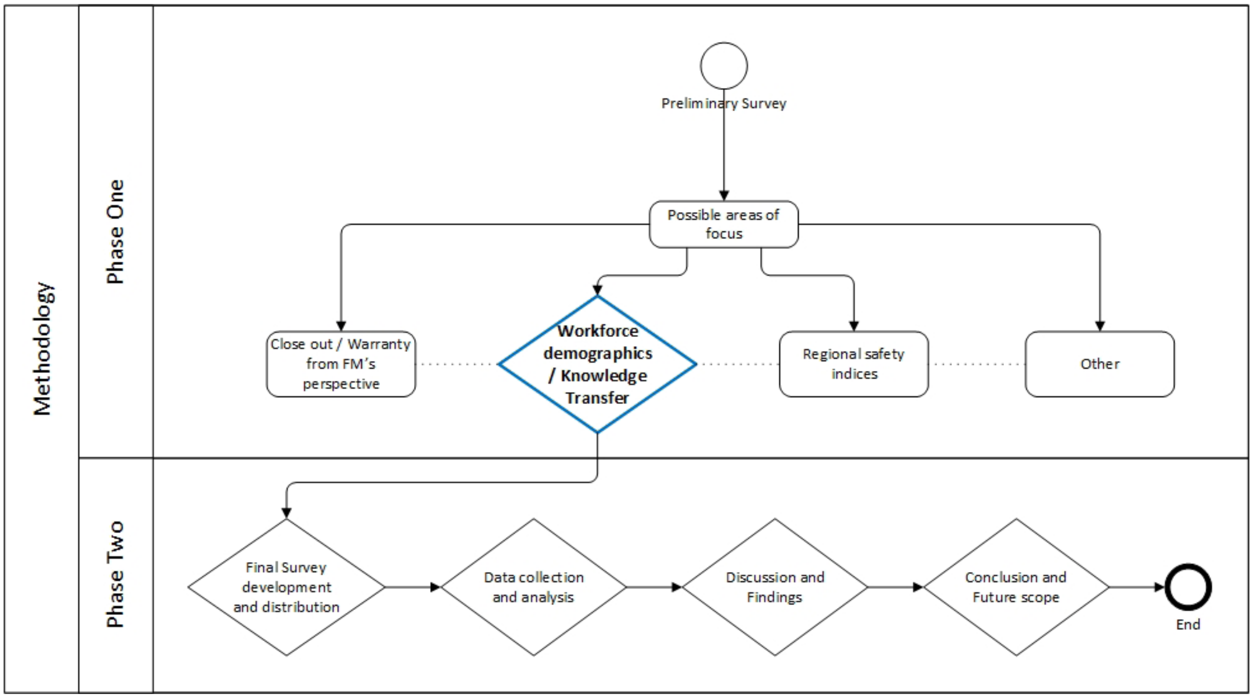

Figure 1: Research methodology

Survey Development and Distribution

In phase one, a preliminary survey was distributed amongst the IAB member companies to gauge various focus areas, resulting in 'Workforce demographics and knowledge transfer in the southeast region of the United States as the critical area to focus on in this study. A survey focusing on workforce and knowledge management was developed through a collaboration of the steering committee and the research team. The survey was further distributed amongst IAB member companies in the southeast region to collect data on the industry's perception and current status of workforce shortages and knowledge management. The survey focused on the following elements for accurate data collection.

> *Background information*: Company type, location, industry sector, company presence, and annual sales.
>
> *Workforce demographics*: Total number of employees within the regional division, number of employees and their position in the company – management or field, age or generational distribution, gender distribution, and perception of workforce shortage.
>
> *Impact of COVID-19*
>
> *Knowledge management/knowledge transfer strategies:* Current use of knowledge transfer strategies and perception of knowledge transfer culture.

The final survey was developed based on the same guidelines through continuous feedback from the steering committee and validation of the study approach. The survey was distributed amongst H.R. managers and owners of various IAB member companies via electronic means. The total duration of the survey distribution was eight months, including follow-up correspondence letters requesting participation. As a result, a total of sixteen (16) IAB member companies responded to the survey instrument; however, only thirteen (13) member companies responded to the request to provide information on the distribution of their employees. Therefore, the survey responses represented 5,183 employees representing thirteen

(13) companies.

Data Analysis

The data collected from survey responses of sixteen (16) participating companies were organized to precisely gauge the current status of distribution of employees in individual respondent companies for managerial or field position personnel. The survey questionnaire collected data in forms of qualitative as well as quantitative variables. A previous study on the subject matter analyzed the survey responses in terms of age & gender distribution, retiring workforce, and the impact of COVID-19 on the perception of workforce shortage. Hence, this study analyzed the collected data on implementing knowledge management strategies for the southeast region. Further, the data for knowledge management programs and perception of knowledge management was analyzed separately for the overall southeast region, general contractors (GCs), and specialty contractors (SC). The data analysis intended to understand the difference between implementation and awareness of knowledge management on a company and employee level.

Discussion and Findings

Sample Distribution

The survey gathered data on the proportion of employees working in management and skilled/field labor positions in each respondent company. The workforce in the management positions was sub-categorized as executive positions (Owner, President, VPs, Director, operations manager, etc.), manager positions: (Estimator, Project manager, Assistant project manager, project engineer, etc.), administrative staff positions (Human Resource manager, accountant, etc.) and other management positions (QA/QC manager, safety manager, etc.). The workforce in the field/skilled labor positions was sub-categorized as senior superintendents, assistant superintendents, field project engineers, forepersons, journeymen/skilled laborers, and other field personnel. The survey responses noted that positions such as foremen, journeymen, and other skilled labor were part of the general contractor's self-performing crew.

The overall workforce count was calculated regardless of the employees' managerial or field position. This count was later used for understanding the implementation and awareness of knowledge transfer strategies on an employee level for the overall southeast region, G.C. and S.C. companies separately, as illustrated in Table 1. When the data was analyzed to gain results on a company level, the number of companies that responded to the requested information was considered as a total sample size. However, three (3) responding companies did not provide data for employee distribution. Therefore, when the data was analyzed to gain results on an employee level, the sample size was considered as the total count of employees from thirteen (13) companies only. As all three of these companies were G.C. companies, the sample size for company-level evaluation was twelve (12); however, the sample size for employee-level evaluation was from nine (9) companies only.

	No. of companies	No. of employees
Overall southeast region	16	5183*
General contractors	12	4231**
Specialty Contractors	4	952

* = count of employees for 13 respondent companies only

** = count of employees for 9 general contracting companies only.

Table 1: Sample distribution

Overall Southeast Region – Knowledge Transfer strategies

The alarming rate of retiring workforce combined with the perception of continued challenges of labor shortages establish the need for knowledge retention. With most baby boomers approaching retirement, the institutional and tacit knowledge needs to be retained and transferred to the incoming workforce to prevent knowledge loss, potentially becoming an excellent investment for companies in training. Various studies on workforce shortages have identified the implementation of existing knowledge transfer strategies as one of the knowledge management methods. The survey instrument collected data from participating organizations regarding their perception, awareness, and implementation of the current knowledge transfer strategies. The data for the overall southeast region was analyzed to understand the percentage of the surveyed organizations that implement knowledge transfer strategies and how this value differs from the percentage of the workforce that is aware of knowledge transfer strategies. The total number of employees considered for this analysis included the number of employees in management and field positions in each organization.

The total number of companies that responded to implementing knowledge transfer strategies within their respective organizations was sixteen (16). Therefore, the sample size for analyzing the implementation of knowledge transfer strategies on a company level was sixteen (16). Based on this sample, the top three (3) knowledge transfer strategies currently implemented by respondent companies were: job shadowing, attending meetings as an observer, and lessons learned in the descending order of their implementation. The three (3) least utilized knowledge transfer strategies were: the community of practice, standardized college program/course, and narrative database, as illustrated in Figure 2.

Furthermore, the same data was analyzed to evaluate the number of employees aware of the knowledge transfer strategies. The data for the distribution of employees was only available for thirteen (13) companies; therefore, the implementation of knowledge transfer strategies was only analyzed for the total number of management and field position employees in thirteen (13) companies, making the sample size for the employee level analysis 5,183. Survey responses for each organization were evaluated along with the number of employees in corresponding organizations to understand which strategies were known to most of the G.C. workforce. Based on this sample, the top three (3) knowledge transfer strategies were: attending meetings as an observer, Lessons learned, and Mentoring/Coaching in the descending order of their implementation. The three (3) knowledge transfer strategies known to the least number of G.C. employees were: Community of practice, Outsourcing/acquisition, and Simulations, as illustrated in Figure 2.

At this stage, the authors calculated the difference between the percentage of the surveyed organizations implementing knowledge transfer strategies (company level) and the percentage of the workforce aware of the knowledge transfer strategies (employee level).

The top three strategies with the slightest difference were: Community of practice, simulations, and standardized college programs/courses, in the ascending order of the % difference. The three strategies with the most difference were: Young Executive leadership, peer group networks, and job rotation, in the descending order of the % difference.

General Contractors

Knowledge Transfer Strategies

The data collected from the G.C. companies was organized to analyze the perception and awareness of the current knowledge transfer amongst the participating G.C. companies and the total number of G.C. employees. The total number of employees for each G.C. organization included the number of employees in management and field positions.

The total number of G.C. companies that responded to implementing knowledge transfer strategies within their respective organizations was twelve (12). Therefore, the sample size for analyzing the implementation of knowledge transfer strategies on a company level was twelve (12). Based on this analysis, the top three (3) knowledge transfer strategies currently implemented by respondent companies were: job shadowing, lessons learned, and mentoring/coaching in the descending order of their implementation. The three (3) least utilized knowledge transfer strategies were: standardized college programs/courses, narrative database, and community of practice, as illustrated in Figure 2.

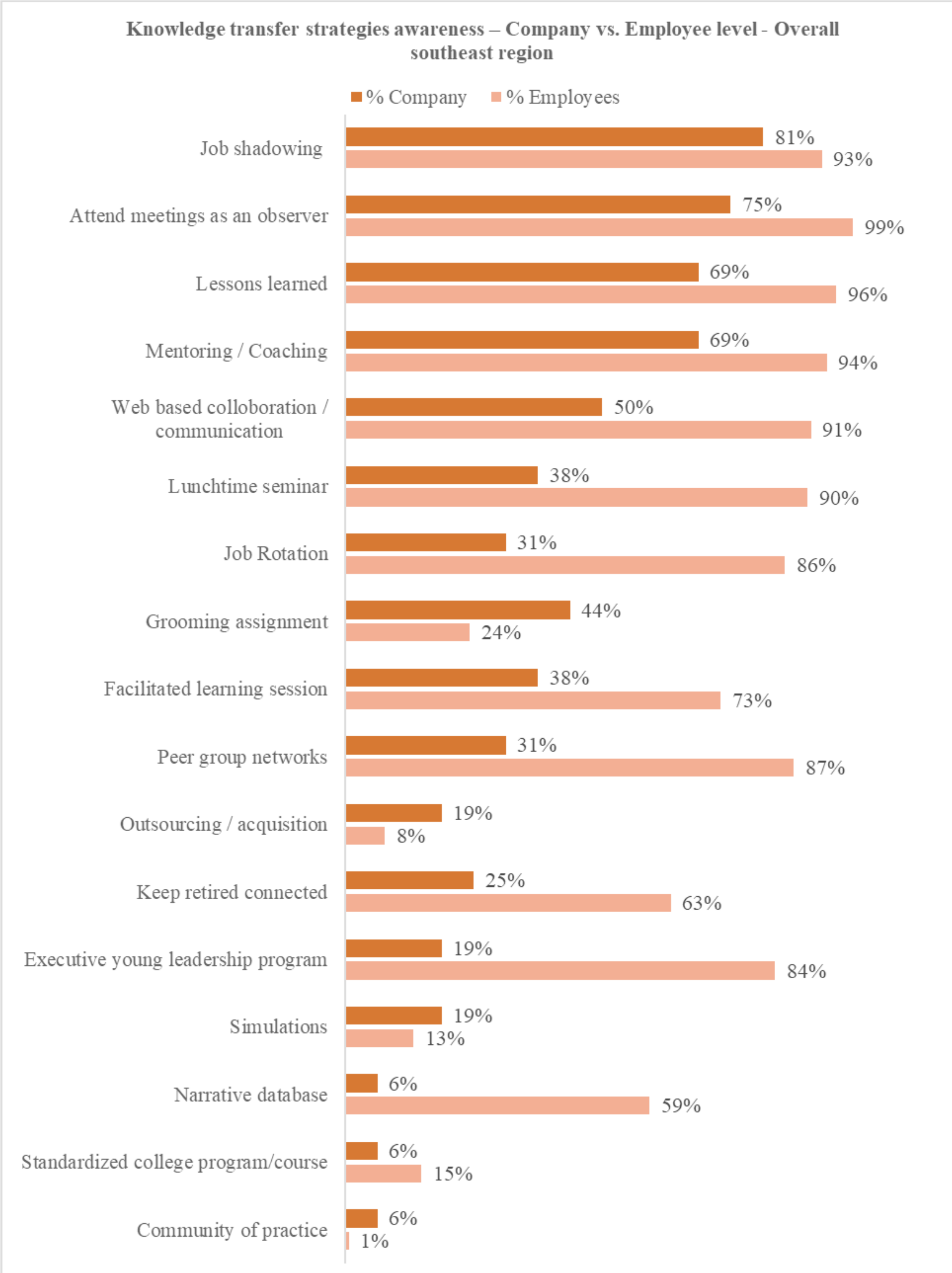

Figure 2: Knowledge Transfer Strategies - Overall

Furthermore, the data for G.C. companies was analyzed to evaluate the actual number of employees who are aware of the knowledge transfer strategies. The data for the distribution of employees was only available for nine (9) companies; therefore, the implementation of knowledge transfer strategies was only analyzed for the total number of management and field position employees in nine (9) companies. Therefore, the sample size for the employee-level analysis was 4,231, as shown in Table 1. Survey responses for each organization were evaluated along with the number of employees to understand which strategies were known to most of the G.C. workforce. Based on this criterion, the top three (3) knowledge transfer strategies currently known to the G.C. workforce were: attending meetings as an observer, lessons learned, and mentoring/coaching. The three (3) knowledge transfer strategies that demonstrated the least awareness amongst the G.C. workforce were: standardized college program/course, a community of practice, and outsourcing/acquisition, as illustrated in Figure 3.

At this stage, the authors calculated the difference between the percentage of the surveyed G.C. organizations that implement knowledge transfer strategies (company level) and the percentage of the G.C. workforce that is aware of the knowledge transfer strategies (employee level).

The top three strategies with the least amount of difference were: standardized college programs/courses, simulations, and community of practice, in the ascending order of the % difference. The three strategies with the most difference were: Young Executive leadership, narrative database, and job rotation, in the descending order of the % difference.

Knowledge Management Perception and Program:

The data from the survey instrument was evaluated for the responding G.C. companies' perception concerning the knowledge management culture. The analysis took place in two sections. As illustrated in Figure 4, the study was conducted to understand the respondents' perceptions of proactive knowledge management culture, awareness of knowledge management strategies, and support for organizational leadership and culture. In section one, as illustrated in Figure 4, the analysis of the perception of knowledge management exhibited the percentage of responses that do not strongly agree with the concepts of knowledge management. The analysis results were compared on a company and employee as well.

As a result, sixty-seven percent (67%) of the respondent companies disagreed with having a proactive knowledge management plan or awareness within their organizations, as opposed to the percentage of employees, i.e., ten percent (10%). Further, when asked whether the companies were aware of any knowledge management strategies within their organization, sixty-seven percent (67%) of the responding G.C. companies and only eleven percent (11%) of the total G.C. employees disagreed. Approximately fifty-eight percent (58%) of the G.C. companies believed that strong support for knowledge management was lacking among the leadership. In an employee breakdown, it was observed that only ten percent (10%) of the employees believed that strong support for knowledge management was lacking among the leadership. Seventy-five percent (75%) of the companies and eighty-four percent (84%) of the total G.C. employees believed that the knowledge management culture was lacking in their organizations altogether.

	% Of strong agreement - Company level	**% Of strong agreement – Employee level**
Proactive K.M. plan	33%	89%
K.M. awareness	33%	89%
Strong support for K.M.	42%	90%
K.M. oriented culture	25%	16%

Table 2: Knowledge Management Perception – Company vs. Employees – General Contractors

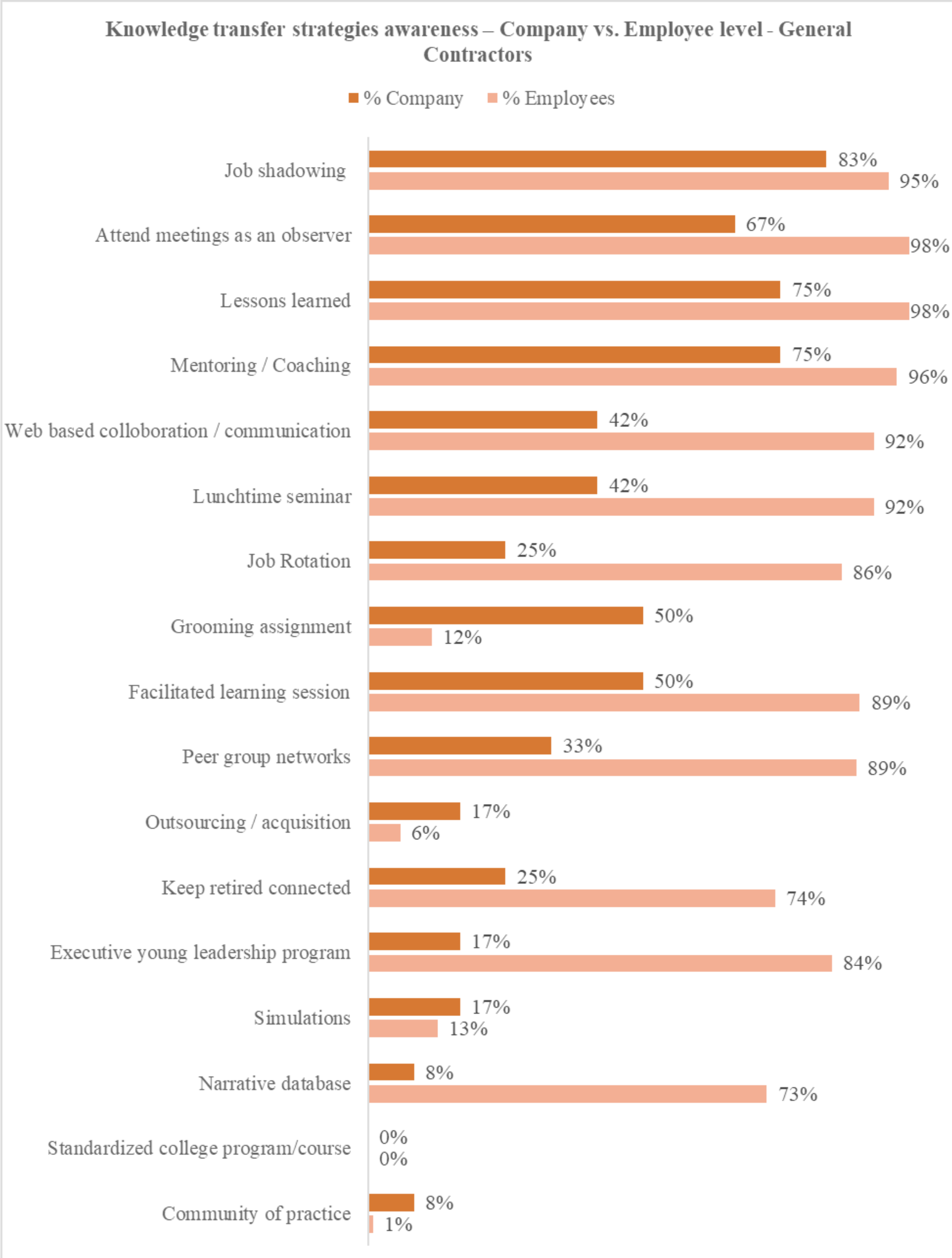

Figure 3: Knowledge transfer strategies - company vs. employee level - General Contractors

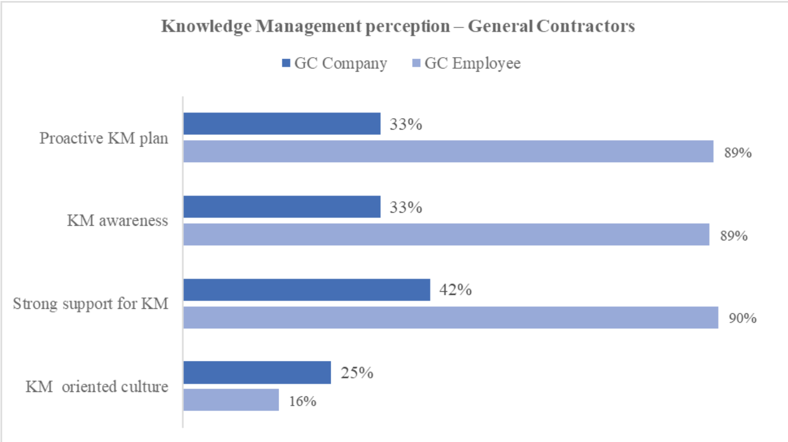

Figure 4: Knowledge Management Perception – Company vs. Employees – General Contractors

As a follow-up in section two, the survey instrument requested additional information on the accessibility of knowledge management tools and databases within each G.C. organization (Table 3 and Figure 5). The respondents were asked if their companies implemented an official knowledge management program or assigned specific knowledge management personnel within their companies. The results show that only twenty-five (25%) percent of the companies believed dedicated knowledge management personnel to be in place; however, eighty-eight percent (88%) of the employees believed the same. Fifty-eight percent (58%) of the companies had access to knowledge management tools and databases. In contrast, ninety-six percent (96%) of the total G.C. employees had access to knowledge management tools and databases. Thirty-three percent (33%) of the companies and eighty-nine percent (89%) of the G.C. workforce were aware of a specific knowledge management program. These findings significantly support the previous perception analysis results regarding the knowledge management culture.

	% Of agreement - Company level	**% Of agreement - Employee level**
Dedicated knowledge manager	25%	88%
K.M. tools accessible	58%	96%
K.M. program	33%	89%

Table 3: Knowledge Management Program - Company vs. Employees - General Contractors

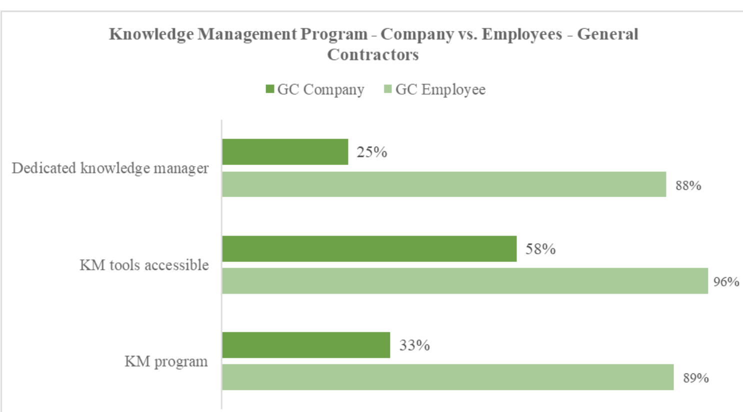

Figure 5:Knowledge Management Program - Company vs. Employees - General Contractors

Specialty Contractors

Knowledge Transfer Strategies

While sorting the survey responses, the data for trade partners were separated and analyzed to evaluate the perception, awareness, and implementation of the current knowledge transfer strategies. Similar to previous analyses, this data was also evaluated in two ways to understand the difference between the level of awareness amongst companies and the total number of employees. The total number of employees for each organization included the number of employees in management and field positions.

The total number of trade partner companies that responded to implementing knowledge transfer strategies within their respective organizations was four (4). Therefore, the sample size for analyzing the implementation of knowledge transfer strategies on a company level was four (4). Based on this analysis, the top three (3) knowledge transfer strategies currently implemented by respondent companies were observed to be: attending meetings as an observer, job shadowing, and web-based collaboration/communication in the descending order of their implementation. The three (3) least utilized knowledge transfer strategies were observed as a community of practice, facilitated learning session, and narrative database. Furthermore, the same data was analyzed to evaluate the actual number of employees who are aware of the knowledge transfer strategies. The implementation of knowledge transfer strategies was analyzed for the total number of management and field position employees within four (4) companies. Therefore, the sample size for the employee-level analysis was 952 (Figure 6).

Survey response for each organization utilizing various strategies was evaluated based on the number of employees to understand which strategies were known to most employees in the respondent organizations. Based on this evaluation, the top three (3) knowledge transfer strategies currently implemented by respondent companies were: attending meetings as an observer, job shadowing, and web-based collaboration/communication. The three (3) knowledge transfer strategies that demonstrated the least amount of awareness amongst the employees from respondent organizations were: a community of practice, facilitated learning session, and narrative database.

At this stage, the authors calculated the difference between the percentage of the surveyed S.C. organizations implementing knowledge transfer strategies (company level) and the percentage of the S.C. workforce aware of the knowledge transfer strategies (employee level). The strategies with the least amount of difference were: attending meetings as an observer, facilitated learning sessions, narrative database, and community of practice. All of the above-stated strategies showed a 0% difference. Similarly, the strategies with the most variation included lunchtime seminars, grooming assignments, peer group networks, young executive leadership, and standardized college programs/courses. All of the above-stated strategies showed a difference of 56%.

From the comparison between the analyses, it was observed that the knowledge transfer strategies that were perceived to be most prevalent in an overview of the survey results on the company level were the same as the ones that were popular amongst the majority of the S.C. workforce. However, this inference was only observed to be true in the case of the S.C. companies. In the case of the overall southeast region and G.C. companies, the knowledge transfer strategies notably differed in the most implemented to the least implemented strategies on both levels (company and employee). Community of practice was the only common strategy amongst the overall southeast region, G.C.s, and S.C.s with the least amount of % difference between company and employee levels. Similarly, the Executive young leadership program was the only common strategy amongst the overall southeast region, G.C.s, and S.C.s with the most amount of % difference between company and employee levels. This difference demonstrates the need to evaluate knowledge management on a deeper level.

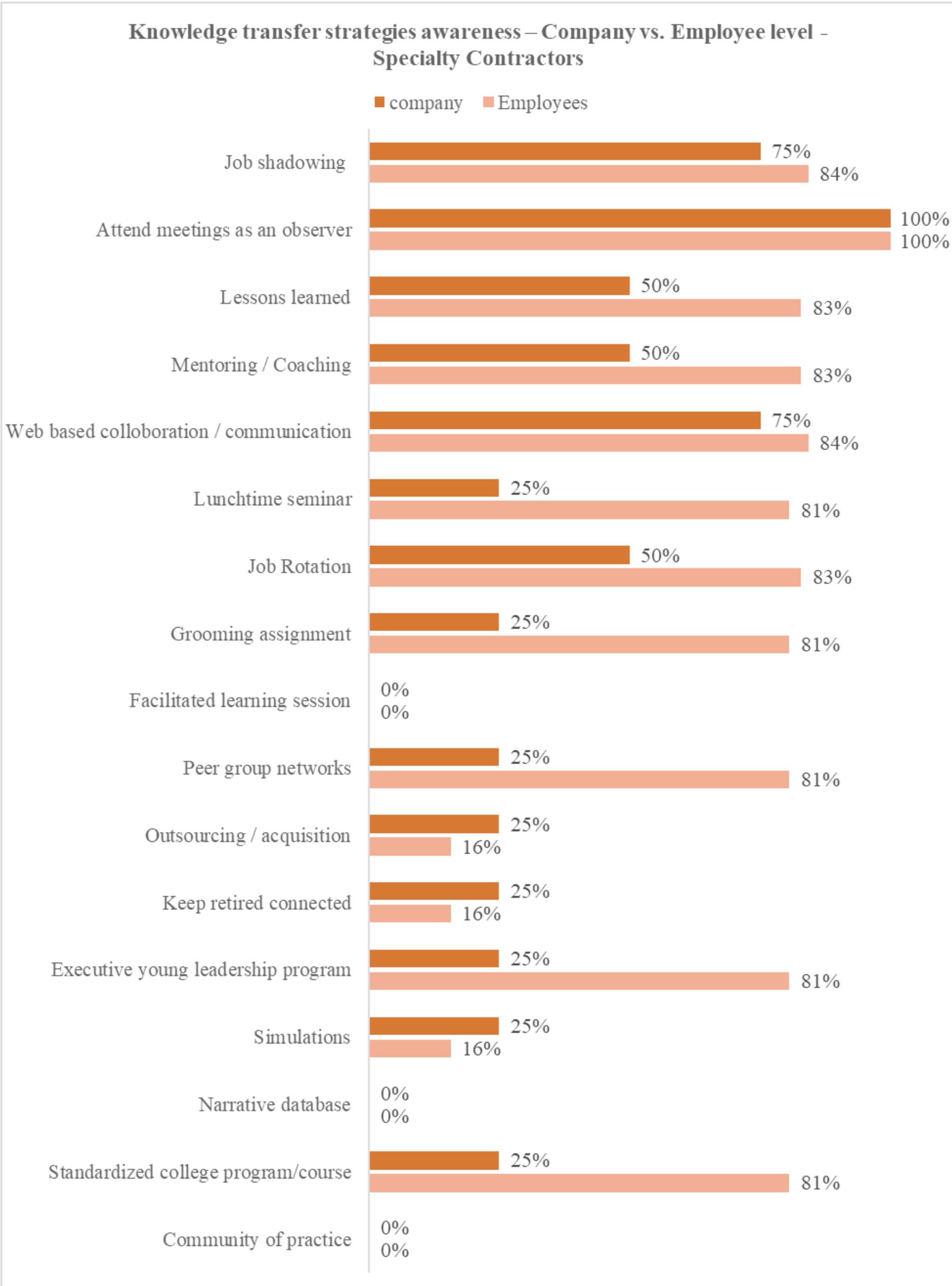

Figure 6: Knowledge transfer strategies awareness – Company vs. Employee level – Specialty Contractors

Knowledge Management Perception and Program

The evaluation of S.C. companies' perceptions concerning the knowledge management culture also took place in two sections. The survey responses were sorted out to separate the data collected from S.C. companies. In section one of the analysis, the perception of knowledge management was compared between the respondent companies that strongly agree with the concept versus other levels of agreement. The results of this analysis were compared on a company and employee level as well. The survey responses were analyzed for the percentage of the companies and the total workforce who lacked the belief that the different categories of knowledge management programs, as illustrated in Figure 7, were implemented in their respective organizations. When analyzed separately on a company level, all the categories of the knowledge management program weighed the same, similar to the analysis on an employee level. However, the percentage of S.C. companies that believed there to be a lack of knowledge management program, i.e., seventy-five percent (75%), varied from nineteen percent (19%) of the actual workforce who believed the same (Table 4).

	% Of strong agreement - Company level	**% Of strong agreement - Employee level**
Proactive K.M. plan	25%	81%
K.M. awareness	25%	81%
Strong support for K.M.	25%	81%
K.M. oriented culture	25%	81%

Table 4: Knowledge Management Perception – Company vs. Employees – Specialty Contractors

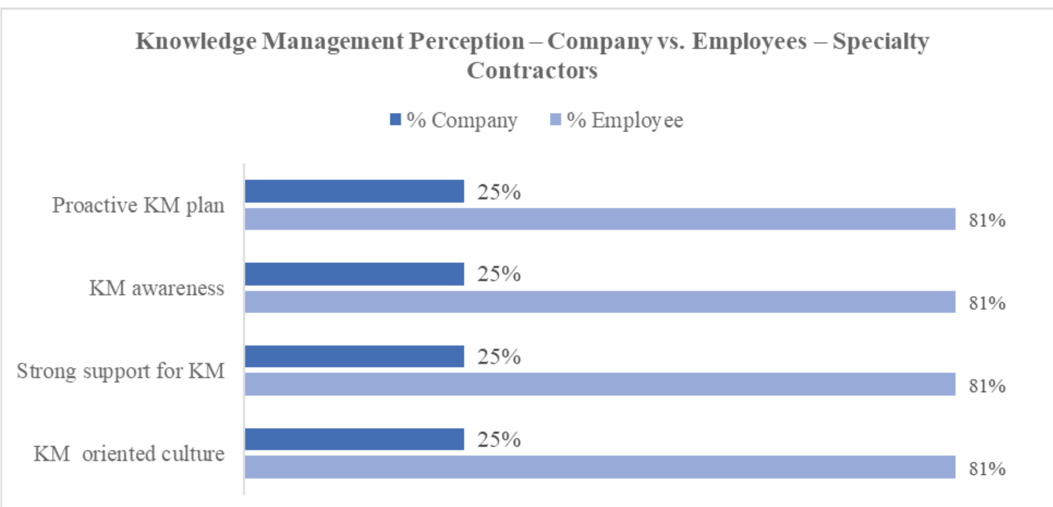

Figure 7: Knowledge Management Perception – Company vs. Employees – Specialty contractors

As a follow-up in section two, the survey instrument requested additional information on the accessibility of knowledge management tools and databases within each S.C. organization. The respondents were asked if their companies implemented an official knowledge management program or assigned specific knowledge management personnel within their companies. The results show that only twenty-five (25%) percent of the companies believe a dedicated knowledge management personnel to be in place; however, eighty-one percent (81%) of the employees believe a dedicated knowledge management personnel to be in place (Table 5). Seventy-five percent (75%) of the companies had access to knowledge management tools and databases. In contrast, ninety-eight percent (98%) of the total S.C. workforce had access to knowledge management tools and databases. Twenty-five percent (25%) of the companies and eighty-one percent (81%) of the actual S.C. workforce were aware of a specific knowledge management program (Figure 8). These findings significantly support the previous perception analysis results regarding the knowledge-management culture

	% Of agreement - Company level	% Of agreement - Employee level
Dedicated knowledge manager	25%	88%
K.M. tools accessible	58%	96%
K.M. program	33%	89%

Table 5: Knowledge Management Program - Company vs. Employees – Specialty Contractors

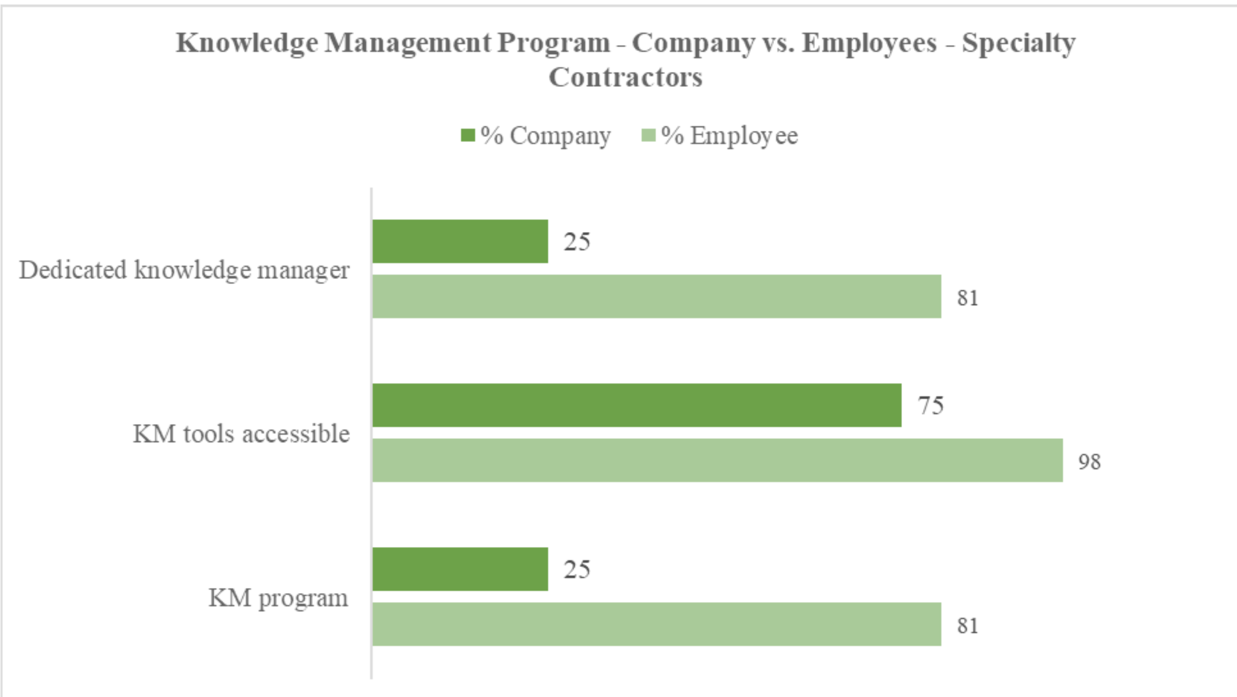

Figure 8: Knowledge Management Program - Company vs. Employees – Specialty Contractors

Comparative Analysis for General Contractors and Specialty Contractors

Knowledge Transfer Strategies

The authors conducted a comparative analysis between general contractors and specialty contractors post individual analyses of the difference between the percentage of surveyed organizations that implemented knowledge transfer strategies (company level) and the percentage of the existing workforce that is aware of the knowledge transfer strategies (employee level) (Figure 9). The comparison evaluated the implementation and awareness of knowledge transfer strategies, knowledge management perception, and implementation of the knowledge management program.

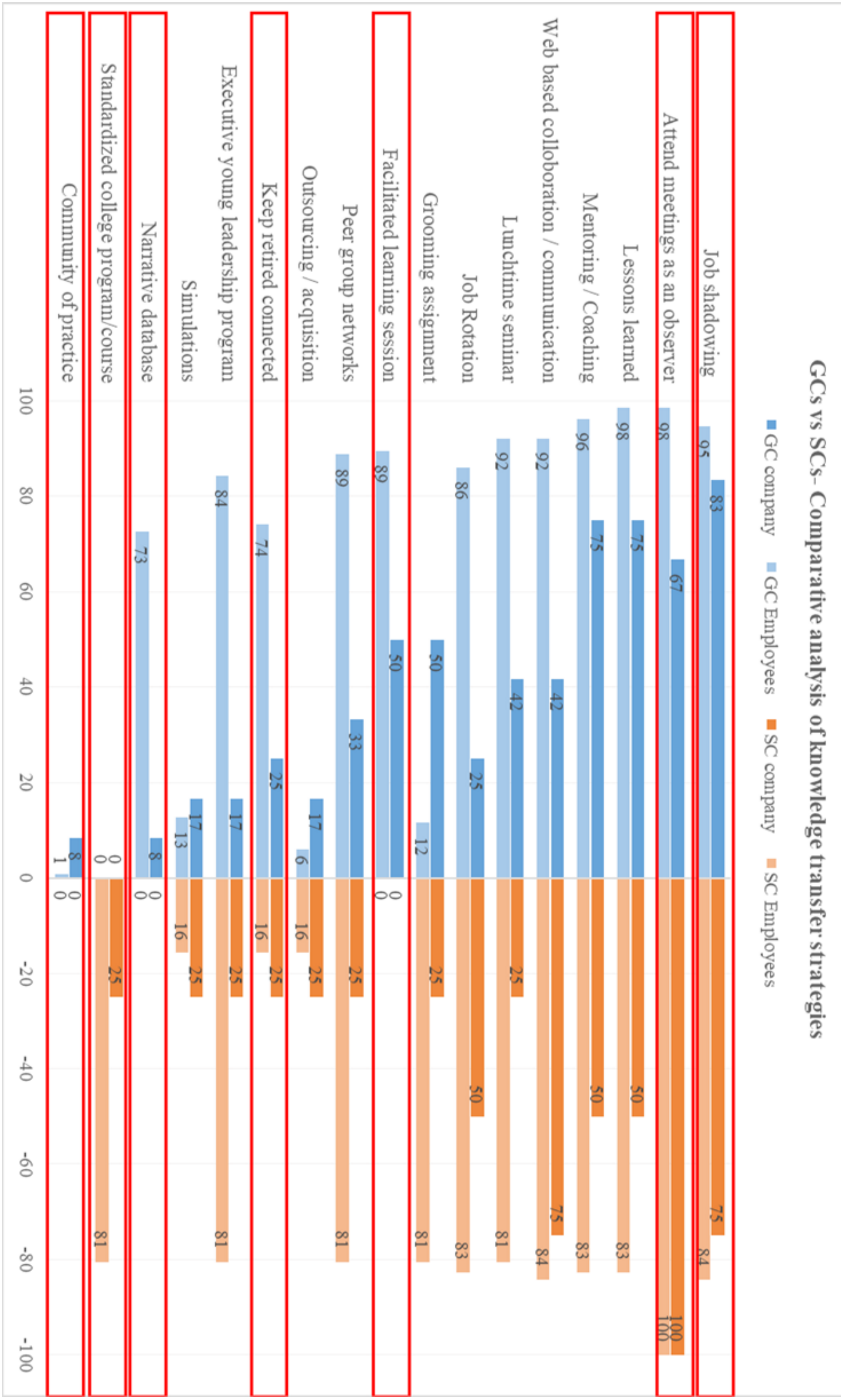

Figure 9: GCs vs SCs - Comparative analysis of knowledge transfer strategies

The findings of a comparison of the implementation and awareness of knowledge transfer strategies suggest that none of the strategies are implemented equally on both company and employee levels for both G.C.s and S.C.s. However, *keeping retired connected* is one strategy implemented by twenty-five percent (25%) of general contractors and S.C. companies. 83% of the G.C. companies implement job shadowing on a company level, making it the top-ranking knowledge transfer strategy for G.C. companies; however, only 75% of the S.C. companies employ *job shadowing* as a knowledge transfer strategy. Similarly, 100% of the S.C. companies implement *attending meetings as an observer*, making it the top-ranking knowledge transfer strategy for S.C. companies; however, only 67% of the G.C. companies implement it. The results also indicate that on a company level, G.C.s must pay more attention to implementing *standardized college programs/courses*. In comparison, S.C. companies need to focus more on implementing *facilitated learning sessions*, *a narrative database*, and a *community of practice* for a more effective knowledge transfer.

The findings of this analysis on an employee level indicate that a total of 98% of the G.C. workforce and 100% of the S.C. workforce are aware of *attending meetings as an observer* for knowledge transfer, making it the top-ranking strategy for both G.C.s and S.C.s with a minimal difference of 2% between their implementations. On the other hand, s*tandardized college programs* severely lack the attention required by the G.C. workforce, as 0% of the employees believe in this strategy's implementation. In contrast, 81% of S.C. employees are optimistic about implementing *standardized college programs/ courses* for knowledge transfer. A significant difference was observed between the implementation of f*acilitated learning sessions*(89%) and *the narrative database* (73%) amongst the G.C. and S.C. workforce. These knowledge transfer strategies need prioritized attention by the S.C. workforce, as 0% of the S.C. workforce is aware of these knowledge transfer strategies. Furthermore, regardless of the level at which the above-stated strategies were implemented (company or employee), a *community of practice* is the least implemented by G.C.s and S.C.s. Therefore, both G.C. and S.C. companies need to focus on implementing a *community of practice* and ensure that the majority of their workforces are equally aware of this strategy for knowledge transfer.

This finding indicates that the perception of knowledge transfer strategies on a company level differs from the actual conditions of their awareness amongst the workforce for G.C.s and S.C.s. Further support for this argument is provided from the analysis of the overall southeast region. Therefore, a deeper dive into the employee-level implementation is required.

Perception of Knowledge management culture

The study observed a significant difference in the perception of knowledge management programs between G.C.s and S.C.s on both company and employee levels (Figure 10). On a company level, 25% of both G.C.s and S.C.s believe that their company has a knowledge management culture; however, there is a notable difference of 65% in the perception of knowledge management culture amongst G.C. and S.C. workforces. These numbers suggest that G.C. companies must focus on actively ensuring awareness of the knowledge management culture amongst their employees. A slight difference of 17% was observed between the perception of support from the leadership amongst G.C. and S.C. companies; however, more than 50% of both G.C. and S.C. companies do not believe that their executive leadership has strong support for knowledge management culture. Therefore, both G.C. and S.C.s need to work on that.

On an employee level, both G.C. and S.C. workforces show a significantly positive awareness regarding knowledge management strategies, tools, and a proactive knowledge management plan available within their respective companies; however, the companies seem to have a significantly contradicting perception. This analysis indicated that companies need to work harder to be on the same page as their employees regarding the perception of knowledge management cultures to avoid misinterpretation.

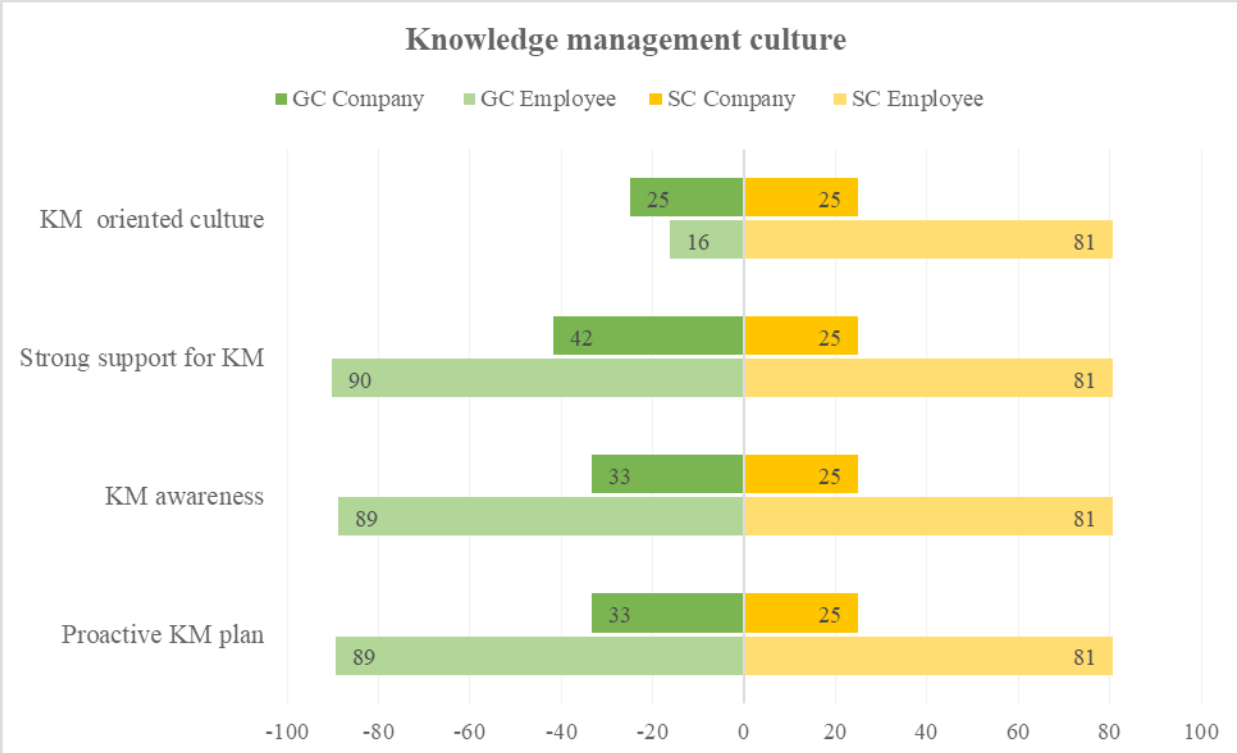

Figure 10: G.C.s vs. S.C.s - Comparative analysis of the perception of knowledge management culture

Knowledge management program

There is a significant difference between perceptions of G.C. and S.C. companies and perceptions of G.C. and S.C. employees. More than 80% of the G.C. and S.C. workforces believe that there are dedicated knowledge managers within their company, whereas only 25% of the G.C. and S.C. companies agree (Figure 11). On an employee level, both G.C. and S.C. workforces strongly believe that knowledge management databases and tools are easily accessible within their companies; however, neither G.C. nor S.C. companies believe that very strongly. The above-stated results show that the perceptions of knowledge management programs, accessibility of knowledge management tools, and the existence of dedicated knowledge managers significantly vary between G.C.s and S.C.s on both company and employee levels.

Conclusion

This paper aimed to study the correlation between workforce shortages and knowledge management. This study highlighted various concerns regarding knowledge loss to evaluate the perception of knowledge management amongst responding companies, such as the retiring workforce and the perception of workforce shortage for the past, present, and the near future. This overview laid the groundwork for understanding the current implementation and awareness of knowledge transfer strategies on two levels – Company and employees. Separate data analyses were conducted to determine which strategies were implemented the most on a company level compared to which strategies most employees were truly aware of. The analysis on an employee level helped the researchers better understand which knowledge transfer strategies are more widely adopted. In a comparative analysis between G.C.s and S.C.s, a significant difference was observed between the implementation and awareness of these strategies on both company and employee levels. The results of this study indicate that knowledge management should be studied on a deeper level, i.e., to understand how many employees genuinely are aware of knowledge management, in order to avoid a false perception of knowledge management within individual organizations.

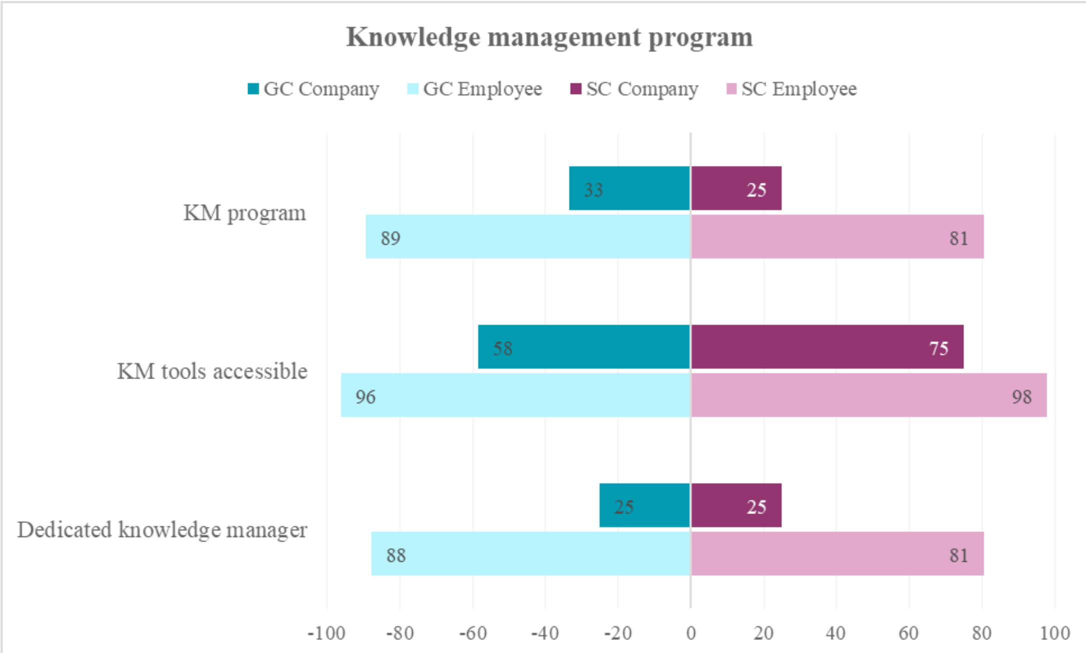

Figure 11: G.C.s vs S.C.s - Comparative analysis of knowledge management program

This paper also studied the perception of knowledge management culture within G.C. and S.C. organizations to support the above findings of knowledge loss. The results indicate that the majority of the surveyed employees had the necessary access to knowledge management tools and were also aware of knowledge management strategies; however, their implementation was not encouraged sufficiently. The results indicate that companies and the workforce do not share a similar understanding of the perception of knowledge management culture and programs within their organization. This perception is more positive amongst the workforce than the companies themselves. This means there is a lack of communication between the companies as an overall and the actual workforce. Promoting the knowledge management culture through formal knowledge transfer programs and assigning a knowledge management professional could help improve things in the future in terms of knowledge loss. Furthermore, embedding knowledge management into the company culture could improve the awareness and implementation of knowledge management strategies equally on both company and employee levels. A comparative analysis between G.C.s and S.C.s was conducted, and the results support the above-stated findings.

This paper is an extension of the previous study that focused on the distribution of employees concerning age, gender, and management or field/skilled labor positions. The previous study also evaluated the rate of retirement for the company's current employees and the impact of COVID-19 on workforce shortages. Based on previous results, this paper has further studied the correlation between the retiring workforce, workforce shortages, and knowledge management.

Based on the results of data analysis for knowledge management on an employee level, studying workforce challenges for individual employees of respondent companies should provide a better insight into the current state of workforce challenges. Post understanding the current state of workforce demographics, the supply and demand of the new talent need to be evaluated to develop proactive implementation plans for dealing with the workforce challenges. This includes attracting and keeping Gen Z and knowing how the retiring generation is distributed across leadership, management, and other roles. This follow-up study will enable knowledge management implementation techniques and the creation of company-specific indices. The implementation plans for knowledge management require training for H.R. professionals within individual companies. This study lays the groundwork for pursuing knowledge management on a deeper level through more opportunities for collaboration beneficial for the industry partners.

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Appendix A

No	Strategy	Definition
1	Job Shadowing	For job shadowing, a seasoned person is paired with a protégée. The idea is for the protégée to observe, absorb, and eventually work alongside the expert.
2	Attend meetings as an observer	This knowledge-transfer strategy includes a less experienced employee participating in meetings as an observer or a learner.
3	Lessons Learned	A lesson learned is knowledge gained from past experiences, whether successful or unsuccessful, to enhance performance in the future.
4	Mentoring/ Coaching	Mentoring demands an experienced person to support their mentee's professional growth by being accessible and approachable for sharing their knowledge and insight and assisting in developing their mentees' decision-making abilities.
5	Web-based collaboration/ communication	Web-based communication connects individuals and specialists by enhancing the capacity to network, connect, and correspond. Through online forums, conversations, networks, or other established communication infrastructure, users engage with one another and share knowledge.
6	Lunchtime Seminar	A lunchtime seminar is a short presentation to a group to share an idea or experience based on firsthand knowledge relevant to the audience's growth in wisdom, insight, or decision-making capacity.
7	Job rotation	Job rotation allows employees to develop a broader knowledge base regarding organizational operations and how their job contributes to it
8	Grooming assignment	As a part of the grooming assignment, an employee is put into place to enhance their skills to become an SME. Grooming strategies offer more exposure and an improved understanding of the job to employees.
9	Peer group networks	Desk-side reviews are a technique where a peer or supervisor shares knowledge and resources relevant to a worker's position in a casual context (i.e., at the worker's desk).
10	Outsourcing/ acquisition	When internal development is too costly or time-consuming, employers can acquire wisdom, insight, or sound judgment for a particular job through acquisitions or outsourcing.
11	Keep retired connected	Keeping retired connected involves using retired workers in a variety of roles. The purpose of keeping in touch with retirees is to continue to gain knowledge from their experience and to share their wisdom, insight, and excellent judgment.
12	Simulations	Simulations replicate the experience by presenting hypothetical situations during problem-solving sessions that require participants to execute critical thinking and make immediate judgments.
13	Narrative Database/Storytelling	In storytelling, professionals share their experiences that were important to the growth of their critical wisdom, insight, or capacity for decision-making.

No	Strategy	Definition
14	Standardized College Program/course	A standardized college program is a means to close the experiential knowledge gap within organizations by training students in a classroom environment before starting work.
15	Community of practice	A community of practice is a group of people with similar interests and experience levels. Collectively, they discuss, spread, and exchange knowledge; and foster an atmosphere of learning and sharing by promoting conversation and cultivating intuition based on the experiences of others.

Status of Drone Education in Construction Management Programs at 2-year Community Colleges

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ABSTRACT

Unmanned Aircraft Systems (UAS), commonly referred to as drones, are a tool that is rapidly being incorporated into the construction industry. Contractors use the technology for site logistics, improved documentation, and a wide range of other activities. UAS is a highly technical tool requiring national licensure and training. It is incumbent on institutions of higher education to train their students on emerging technologies. This paper aims to evaluate if 2-year community colleges in the southeast are providing adequate UAS education to support the construction industry. The study reviewed the course catalogs and program websites of 251 SACS-accredited 2-year schools in the Southeast and found that only three programs had a drone class associated with a construction management degree. The study surveyed more than 40 program coordinators and found that they understand the construction industry is using drones significantly and that they desire to add a UAS curriculum to their degree program. They identified that the lack of faculty with UAS experience and funding for equipment and professional development are the leading barriers to creating a drone curriculum. This study outlines several options for the schools to overcome these barriers, including funding through the NSF Advanced Technological Education program.

Keywords: Drone, UAS, Community College, Curriculum

Author Bios

Joseph Burgett is an associate professor at Clemson University's Nieri Department of Construction, Development and Planning. His area of research is unmanned aerial systems with specific applications to the built environment. He is also on the board of directors for the South Carolina Interagency Drone Users Consortium.

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INTRODUCTION

There are many examples of contractors using emerging technology to provide a better and more cost-effective product to their customers. One such technology that has grown significantly over the past decade is Unmanned Aircraft Systems (UAS), often referred to as drones. The FAA defined a small UAS as an aircraft weighing less than 55 pounds and operated without human intervention from within the aircraft (Small Unmanned Aircraft Systems 2021). Drones currently support industries including filmmaking, real estate, marketing, agriculture, and construction (Rao, Goutham & Maione 2016). Progress monitoring, marketing, stockpile calculations, and inspections are some of the more common applications in the construction industry (Gajjar & Burgett, 2020). More than 300,000 drones have been registered with the FAA for commercial activity (FAA n.d.-a). This is almost twice the number of registered fixed-wing general aviation aircraft in the U.S. (FAA n.d.-b). The three most common airframes include multirotor (helicopter style), fixed wing (similar to an airplane), and vertical take-off hybrids (Li & Liu 2019). Multirotor quadcopters are the most commonly used by contractors because of their ability to take off vertically in confined job sites, simple to fly, and their ability to inspect work in a hover.

Drones are technical tools that require training and licensure to operate effectively. The use of drones for commercial operations is primarily regulated by the FAA under CFR Title 14 Part 107 (Part 107). Commercial operations are widely defined and include any missions associated with activities that generate revenue, even if the pilot is uncompensated. Part 107 requires commercial pilots to pass a knowledge test and earn a remote pilot certificate. Those without a background in aviation typically attend a UAS ground school to learn applicable federal regulations, airspace classification, weather, UAS performance, loading factors, and general operational best practices. Although obtaining the FAA license is required, it does not comprehensively assess all the skills and knowledge needed to operate safely in the national airspace. For example, pilots need to know how to request air traffic control authorization using the FAA's Low Altitude Authorization and Notification (LAANC) system when flying in controlled airspace. They also need to be able to check for FAA notice to airmen (NOTAM), temporary flight restrictions (TFR), and UAS-specific weather forecasts for cloud heights. State and local regulations regarding topics such as privacy and insurance requirements are not addressed in the federal exam but are still critical for pilots to be aware of. Perhaps the most significant exclusion of the Part 107 exam is that it does not assess flight skills. The exam is a knowledge test and does not require the pilot to demonstrate flight proficiency or provide evidence that they have ever operated a drone before.

It is incumbent on institutes of higher education to support industry needs by infusing new technologies into their curriculum (Harper et al., 2022). There are many examples of 4-year institutions with construction management degrees successfully incorporating drones in their program (Sanson 2019; Williamson & Gage 2019; Irizarry 2019; Sanchez 2021; Pereira et al. 2018). However, there are nearly no scholarly articles addressing how 2-year community colleges with construction management degrees are incorporating drones into their program. This study aims to identify if 2-year community colleges are adequately supporting the construction industry with drone education. Additionally, this study identifies the top barriers to improving the UAS curriculum and the federal resources available to remove those barriers.

LITERATURE REVIEW

Drone Uses

The first use of drones dates back to 1839 when the Austrians used hot-air balloons to deliver explosives to the Venetians (Sanson 2019). Most UAS applications since that time have stayed in the military arena. However, in recent years, drones have been used to support a wide range of civilian activities, including the construction industry. Drones are most frequently used in construction for progress photos, marketing, video production, inspections, and 3-D modeling (Burgett 2021). However, drones have a wide range of other construction-related applications. Table 1 provides an overview of the literature showing how drone applications support the construction industry.

Table 1: Drone Uses in the Construction Industry

Drone Applications	Reference
Photography	1, 2, 3, 4, 6, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18
Monitoring	7, 8, 10, 12, 13, 14, 15, 17, 18
Surveys	1, 2, 3, 4, 5, 6, 7, 9, 11, 17
Inspection	1, 4, 5, 7, 8, 10, 14, 16, 17
Safety	1, 4, 6, 7, 8, 14, 16, 17
As-built	11, 12, 13, 15, 16, 17
BIM	3, 4, 7, 13, 15, 16, 18
Marketing	10, 17, 18
Thermal Imaging/Scanning	2, 5, 10, 11
Material Delivery	7, 10
Material Tracking	17, 18
Automated Assembly	1
Mapping	6
1) Tatum & Liu 2017; 2) Williamson & Gage 2019; 3) Irizarry 2019; 4) Zaychenko, Smirnova & Borremans 2018; 5) Agapious 2021; 6) Aiyetan & Das 2022; 7) Li & Liu 2019; 8) Howard, Murashov & Branche 2018; 9) Adjidjonu & Burgett 2021; 10) Cajzek & Klansek 2016; 11) Varbla, Puust & Ellmann 2021; 12) Bognot, Candido, Blanco & Montelibano 2018; 13) Anwar, Izhar & Najam 2018; 14) Martinez, Albeaino, Gheisari, Issa & Alarcon 2021; 15) Jacob-Loyola, Munoz-La Rivera, Herrera & Atencio 2020; 16) Alizadehsalehi, Yitmen, Celik & Arditi 2020; 17) Hubbard & Hubbard 2020 18) Dupont, Chua, Tashrif & Abbot 2017	

Contractors' Perception

The most comprehensive study conducted on the value that contractors find using drones was published by Burgett in 2021. Burgett surveyed more than 50 large general contractors and/or construction managers in the commercial market sector. The contractors were asked to score (0–100) how beneficial drones were to their company. Table 2 provides how the contractors responded. Improved job site documentation and positive perception by clients were the two highest-ranked drone benefits. Improved BIM modeling, reduced cost, improved safety, and increased job efficiency were the lowest-ranked benefits. These responses were used in this paper's survey to analyze how well construction management program coordinators understand drone use in construction.

The survey in the Burgett (2021) study asked the contractors what activities they had used drones for in the past three months. The 3-month time frame was given to collect data on drone activities contractors engaged in regularly. The authors did not want a positive response if a company had only experimented or infrequently used a drone for the given activity. Table 3 provides the contractors' responses. Job site progress photos and marketing were the most common uses. Safety and quantity take-offs were the activities least frequently conducted with drones. These responses were also used in this study's survey to determine if program coordinators had an accurate perception of how real-world contractors were commonly using drone technology.

Table 2: Benefit Drones Bring to Construction Companies (Burgett 2021)

Benefit	Points out of 100
Improved job site documentation	90.2
Positive perception by clients	80.4
Improved communication	54.9
Improved jobsite coordination	49.0
Improved logistics	49.0
Improved quality control	31.4
Reduced risk	9.8
Increased job efficiency	5.9
Improved safety	5.9
Reduced cost	3.9
Improved BIM modeling	3.9

Table 3: Contractors' Use of Drones (Burgett 2021)

Job site progress photos	90.2%
Marketing	80.4%
Video production	54.9%
Inspection	49.0%
Creating 3-D models (photogrammetry)	49.0%
Supporting BIM models	31.4%
Thermal photography	9.8%
Quantity take-offs	5.9%
Safety	3.9%

Drone Education at 4-year Construction Management Programs

The existing literature is peppered with case studies of how 4-year construction management programs have introduced their students to drone technology. Georgia Tech was one of the first universities to incorporate drone education into their construction management curriculum. Their graduate-level drone course incorporated a wide range of skills, including Part 107 regulations and flight skills (Irizarry 2019). UAS flight skills were taught using a combination of computer simulation and small drones flown in an indoor netted studio. Georgia Tech had some challenges because its campus is located in downtown Atlanta. This required special precautions and regulatory compliance issues not faced by universities in more rural locations.

Youngstown State University collaborated with a local contractor to stand up their UAS program (Sanson 2019). They introduce drone technology to their first- and second-year students as part of a construction surveying course. They enhanced the construction mapping and road layout sections with a drone-related curriculum. During the construction survey lab, students operated a drone and collected data later used with mapping software.

Like Youngstown State University, the University of Florida published a similar case study in which they integrated UAS modeling into an existing BIM course (Pereira et al. 2018). The course included an overview of Part 107 rules; however, they did not require students to take the FAA knowledge exam. An introduction to flight controls was provided by having the students fly small category one drones indoors. The primary focus was on providing an overview of photogrammetry using sample data provided by the instructor.

Texas A&M has one of the largest construction management programs in the U.S. They introduced drone technology by including it as part of an existing surveying course (Williamson & Gage 2019). The instructors took advantage of Texas A&M's access to an abandoned airfield to conduct surveying and mapping missions. In this course, students were exposed to Part 107 regulations, insurance requirements, and environmental considerations for conducting UAS missions. The core curriculum is related to collecting drone data to create 3-D maps and models to benefit construction workflows.

Drone Course Curriculum

The case studies in the literature focus on the barriers and successes of developing drone course(s) or module(s). They also provide an overview summary of the specific topics they included with their curriculum. The most comprehensive study addressing specific UAS curricula in construction management programs was by Harper et al. in 2022. In this study, 1,369 survey invitations were sent to programs that were members of the Associated Schools of Construction and/or the American Society for Engineering Education. A total of 92 survey responses were received. Only 22 schools of the 92 that responded provided a drone curriculum at any level. The topics most frequently taught were photogrammetry, measuring quantities, site mapping, layout and surveying, and BIM. The topics least frequently taught included inventory management, tracking resources, and positioning and navigating a UAV. The Harper et al. survey also asked about the primary barriers to implementing a UAS course or module. Table 4 lists the barriers identified in the survey and what percentage of the 22 schools that indicated it impacted their UAS curriculum development. The barriers identified in the Harper et al. survey significantly influenced the questions in this study's survey related to barriers to community colleges developing drone coursework.

Table 4: Barriers to Implementing UAV Curriculum (Harper et al. 2022)

Barrier	Percent of Sample
Limited time for hands-on learning	55%
Lack of funding for purchasing UAVs and associated equipment	36%
Lack of a safe location to fly UAVs / Cannot fly on campus	32%
Limited administrative support	32%
Training needed for faculty	27%
Difficulty creating the curricula	18%
Lack of funding for maintenance of UAVs and associated equipment	14%
Limited industry support	14%
No champion to move the implementation forward	9%

The literature is populated with several articles describing how drones have been used at 2-year community colleges. For example, some community colleges have found success with drones in smart manufacturing education (Tantawi et al. 2022), UAS maintenance programs (Nicklin 2022), geotechnology (Fombuena 2017), and cinematography (Hanssen 2016). However, currently, there are no articles published focusing on how 2-year community colleges support the construction industry with drone education. This paper will start to fill this gap and be the first to explore drone curricula in 2-year construction management programs.

METHODOLOGY

The primary objective of this study is to learn if community colleges are supporting the construction industry adequately with UAS education. Data were collected in two distinct phases. The first involved scraping the community colleges' course catalogs and the construction management departments' websites for drone-specific keywords (drone, UAS, UAV, and unmanned). Information related to the drone curriculum was recorded for further analysis. During this phase, the construction management departments' program coordinators' contact information was also recorded. If the program coordinators' information was not listed, the faculty director was searched, and if needed, the general administrator was contacted. The study's second phase involved sending the program coordinators an online survey and analyzing the results.

Geographic Boundary of the Study

The Southern Association of Colleges and Schools Commission on Colleges (SACS) is one of the six major accreditation bodies for higher education. SACS accredits all the major universities in the Southeast, including the University of Florida, Georgia Tech, Clemson University, and many others. In addition to 4-year schools with graduate programs, SACS also accredited community colleges. For this study, "community college" will be defined as SACS-accredited schools with a 2-year degree being the highest degree offered. The exceptions to this definition are schools located in Florida. Approximately ten years ago, Florida moved away from 2-year degree schools in favor of state colleges with both 2- and 4-year degrees. This study also included schools from Florida that have primarily 2-year degrees and were formerly called "junior" or "community" colleges. The sample for this included 251 SACS-accredited community colleges.

Knowledge, Attitude, and Practice (KAP) Survey

The second phase of this study was to send a knowledge, attitude, and practice (KAP) survey to the program coordinators. KAP is a low-cost survey methodology used to collect representative data from an easily accessible population (Andrade et al., 2020). It was developed in the 1950s for medical research but has since been adapted to a wide range of fields (Kaliyaperumal 2004), including social services (Preethy & Somasundaram 2020), finance (Mostafavi et al. 2014), climate change (Gadzekpo et al. 2018), and UAS (Aydin 2019; Reddy & DeLaurentis 2016). The KAP survey methodology asks specific questions related to a participant's knowledge, attitude, and practices about a particular subject. "Knowledge" refers to how much a person knows about a topic. Often, they are given factual statements and asked to indicate if they are true/false or right/wrong. The "attitude" questions are focused on the person's opinion. They gauge the respondents' feelings and can sometimes help identify a participant's bias. Attitude questions are most commonly opinion questions, often given in a Likert-scale format. The "practice" refers to what a person has done. These questions focus on specific activities, behaviors, or accomplishments that a person has performed. This methodology is often used to determine if the lack of knowledge or a person's feelings contribute to undesired action or inactivity.

A KAP survey of particular interest to this study was used by Aydin (2019), which was an extension of the work by Reddy and Delaurentis (2016). These two studies used a KAP-style survey to understand the public's perception of the newly released Part 107 regulations. Several of the knowledge questions from Aydin and Reddy and Delaurentis asked their participants true or false questions related to Part 107 rules. The survey conducted as part of this paper used nearly identical questions. Some questions from Aydin and Reddy and Delaurentis were modified to reflect changes in the Part 107 regulations. By using similar knowledge questions, the research team could compare the construction management project coordinators' UAS knowledge to the general public reported by Aydin and Reddy and Delaurentis.

Limitations of the Methodology

There are several known limitations to this study's methodology. The first phase of the data collection involves scraping the course catalog for drone-related keywords. For this to be an effective methodology, the course catalog must be updated with the latest courses, and the course descriptions must be accurate. When the research team conducted a similar study in a non-construction discipline, it was found that some programs would offer a drone class as an "independent study" course. These courses may have a detailed drone curriculum but would not be included in the course catalog. The research team was able to mitigate this source of error to a degree by searching the program's website for drone-related keywords. If a drone-specific independent course was described there, it was recorded for this study. Additionally, the researchers found that some courses may have been revised to include a UAS module(s); however, the course description was not updated in the community college's course catalog. The researchers limited this source of error by including questions related to this on the program coordinator survey.

RESULTS

Phase 1: Course Catalog and Department Website Review

The course catalogs and department websites of 251 SACS-accredited community colleges were reviewed. Of those, 148 schools (59%) had a construction management or engineering 2-year degree. A total of 54 schools (22%) had one or more courses where drones were addressed. Most of these were concentrated in North Carolina and Kentucky. Kentucky has 14 community colleges with drone courses, but the courses in 12 of those schools were specific to law enforcement. Only three SACS-accredited community colleges had drone courses associated with the construction management department. Two of these courses were in North Carolina, and one in Mississippi. These three courses were listed only on the construction management program's website and not in the course catalog, suggesting they were new or infrequently offered. The course descriptions indicated that all had a generic UAS curriculum that was not specific to construction. See Table 5 for a breakdown of the drone courses offered by state. The results from phase one suggest that UAS technology is not included in 2-year colleges in a meaningful way.

Table 5: Drone Courses at SACS Accredited 2-year Community Colleges

State	No. of Schools	Schools With CM/E Degree	Schools With UAS Course(s)	Schools With a CM/E Course
SC	21	9	1	0
GA	25	20	6	0
NC	61	40	14	2
FL	33	21	6	0
VA	27	8	6	0
AL	26	10	0	0
TN	15	8	4	0
MS	16	12	2	1
KY	16	16	14	0
LA	11	4	1	0
Total	251	148	54	3

Phase 2: Program Coordinator Survey

In the second phase of the study, a survey was sent to 142 program coordinators identified from their schools' websites. A total of 47 surveys were completed for a response rate of 33%. The responses were well distributed geographically and in the population density of the areas they served. One of the initial questions the survey asked was, "Are drones included in your construction management curriculum." The survey indicated that 87% of the programs did not teach UAS technology at any level. Only five schools (11%) indicated that drones were addressed as a small part of one or more classes. A single school responded that it includes a drone curriculum that is a significant part of one or more classes in its program. These responses are consistent with the absence of UAS curriculum shown in the first phase of the study.

Knowledge

In a KAP survey methodology, knowledge is often assessed with a series of questions that compare a person's survey responses to a set of known facts. As mentioned earlier, this study used the same method and questions as Aydin (2019) and Reddy and Delaurentis (2016) when it evaluated the general public's knowledge of UAS regulations. The program coordinators were asked eight UAS regulatory questions, as shown in Table 6. On average, the program coordinators answered 18% of them correctly. The general public participants from Aydin's (2019) study answered 19.8% of these same questions correctly. Because Aydin's and this study's sample had similar knowledge, it can be inferred the program coordinators have not had any significant training or professional development related to UAS technology.

Table 6. Regulatory Questions Included With Survey

Question	Percent Correct
Every drone greater than 0.55 lbs must be registered with the FAA.	26%
Drones can be operated at night without a waiver.	11%
A commercial drone pilot must be at least 16 years old.	26%
You can fly drones beyond the line of sight as long as the first-person-view camera is used.	26%
The maximum ground speed allowed for commercial drones is 80 mph.	15%
A drone may be flown 400 feet above a structure such as a building or cell tower.	9%
Operating a drone from a moving vehicle is prohibited unless the operation is over a sparsely populated area.	17%
Government agencies can only operate under Part 91 Certificates of Authorizations (COAs) and not Part 107 rules.	11%
Average	**18%**

Although the program coordinators did not have significant knowledge of UAS regulations, it is still possible that they understood how drones are being used to support the construction industry. This study began to address this by asking the program coordinators, "How well do you understand how contractors use drones?" Table 7 shows a relatively even distribution ranging from "not well at all" (21%) to "very well" (19%). Notably, only one participant (2%) indicated they understood how contractors use drones "extremely well."

Table 7: "How Well Do You Understand How Contractors Use Drones?"

	Not Well at All	Slightly Well	Moderately Well	Very Well	Extremely Well
Question Responses	21%	31%	26%	19%	2%

Self-assessments do not always yield accurate results, so additional testing was needed. Burgett (2021) identified that the contractors' most common use of drones was for progress photos and marketing. The least frequent uses were for safety and quantity take-offs. The project coordinators were asked to "click and drag the following activities contractors use drones for in order of most frequently (1) to least frequently (4)." For this study, if the project coordinator indicated that progress photos or marketing were either first or second, it was considered correct. Similarly, if they indicated that safety and quantity take-offs were either third or fourth, it was considered correct. Table 8 shows that, on average, the project coordinators ranked the activities correctly 68% of the time. An important takeaway from this data is that project coordinators do not appear to have a firm grasp of the technology's use in the construction industry. It appears that, on average, they understood contractors' UAS use cases slightly better than a 50/50 random chance.

Table 8: Program Ranking of How Contractors Use Drones

UAS Use Case	Correct
Job site progress photos	60%
Marketing	75%
Material quantity take-off	50%
Safety	85%
Average	**68%**

Attitude

The next portion of the survey addressed the respondents' attitudes about drones in construction. These questions are generally subjective and gauge opinions and feelings. Five-point Likert-style questions were used often for this section. The first of these questions provided the program coordinators with a list of potential benefits of UAS technology and asked them to rate how beneficial they were from 1 "not beneficial at all" to 5 "very beneficial." Table 9 sorts the data by the mean response. An important finding is that the program coordinators feel that drones benefit the construction industry. Even the lowest-ranked item, "reduce cost," had an average ranking of 3.42. The highest-ranked benefits included improved job site documentation, positive perception by clients, improved communication, and improved BIM modeling, all having near 4.0+ scores. It is interesting to note that in the Burgett (2021) study, contractors ranked "improve BIM modeling" as 11th of 11 benefits they gained from drones. This reinforces the position that there is a disconnect between industry drone use and the project coordinators' perceptions.

Table 9: Perceived Benefit of UAS Technology in Construction

Potential Benefit	Min	Max	Mean	SD
Improved job site documentation	3	5	4.46	0.67
Positive perception by clients	2	5	4.05	0.92
Improved communication	1	5	3.95	0.97
Improved BIM modeling	1	5	3.95	0.95
Improved jobsite coordination	2	5	3.93	0.84
Improved safety	1	5	3.83	0.92
Improved quality control	1	5	3.75	1.11
Improved logistics	2	5	3.7	0.9
Reduced risk	1	5	3.7	0.98
Increased job efficiency	1	5	3.67	1.03
Reduced cost	2	5	3.42	0.86

To further understand the program coordinators' attitudes about drones in construction, they were given four direct questions and asked to rank how strongly they agreed. The first statement asked if drone use will increase in the construction industry. The program coordinators strongly felt that it would, with a ranking of 4.29. This question was intended to address the potential that a UAS curriculum was not being developed because they felt the technology was a short-lived fad. This high score does not indicate that this is the case. The second question addressed whether drone use should be taught in 2-year construction education programs. Here again, the program coordinators largely felt that it should, ranking it at 3.93. The third and fourth questions addressed whether drones support profitability and safety in construction. An argument could be made that those two considerations are the lens through which any new technology adoption should be evaluated. The program coordinators strongly agreed with these statements, with scores of 3.85 and 3.93, respectively. See Table 10 for a summary of the statement responses.

Table 10: Statements Supporting Benefits of UAS Technology in Construction

Statement	Min	Max	Mean	SD
Drone use will increase in the construction industry.	1	5	4.29	1.04
Drone use should be taught in 2-year construction education programs.	1	5	3.93	1.24
Drones can increase the profitability of contractors.	2	5	3.85	0.61
Drones have the potential to reduce injuries on a job site.	1	5	3.93	0.95

In a follow-up to these statements, the program coordinators were asked, "if adequate resources were provided, would you personally be interested in developing new drone courses at your school?" Given the lack of the UAS curriculum developed, the researchers were surprised to see that 83% of the coordinators indicated they would personally be interested in developing drone course(s). The data show that program coordinators believe there is a benefit to UAS technology: the use of the technology will increase, it benefits contractors' profitability and safety, and it should be included in their curriculum. If this is their attitude, it implores the question, "What barriers are keeping UAS curriculum out of the construction management programs?" The program coordinators were asked to rank how challenging a list of barriers identified from the literature (Burgett 2021; Harper et al. 2022) was to developing drone course(s). Table 11 shows the results of the findings. The leading barrier is the "availability of faculty with drone experience." The next four leading barriers can be categorized as a general lack of resources. Specifically, the resources needed are funding for equipment and training or professional development. There are federal programs that address these barriers and they will be elaborated on in the conclusion section of this paper.

Table 11: Barriers to the Development of a Drone Course(s) at 2-Year Community Colleges

Barrier	Min	Max	Mean	SD
Availability of faculty with drone expertise	1	5	3.88	1.02
Lack of funding for purchasing drones and associated equipment	1	5	3.66	1.24
Training needed for faculty	1	5	3.55	1.09
Lack of resources for professional development	1	5	3.46	1.11
Overall lack of resources to develop new courses	1	5	3.33	1.25
Limited time for hands-on learning	1	5	3.27	1.15
Lack of a "champion" to move implementation forward	1	5	3.03	1.07
Lack of interest from current faculty	1	5	2.92	1.13
Lack of a safe location to fly	1	5	2.92	1.31
Lack of administrative support	1	5	2.74	1.19
Lack of interest from college administration	1	5	2.51	1.11
Lack of industry support	1	4	2.49	1.01
Lack of interest from students	1	5	2.4	1.02

Practice

The final section of the survey addresses the practice of UAS coordinators developing UAS curriculums. These questions focus on specific actions they have taken based on their knowledge and attitudes. These questions were selected based on anticipated barriers to UAS curriculum development. The first question asked if the project coordinator or their department requested resources from their school to develop or expand drone courses. Approximately a quarter of the respondents indicated that they had requested resources from their school. The second question asked if they had participated in a grant submission to receive funding for UAS curriculum development. Only 12% of the respondents indicated they had requested grant funding in the past. Finally, a question was asked if they had used any professional development resources already allocated to their department on UAS technology. Approximately 29% indicated that they had done this. Although the program coordinators identified trained faculty and lack of resources as the leading barriers, a relatively small percentage of the program coordinators had taken strides to overcome them. See Table 12 for a summary of the responses.

Table 12: Program Coordinator Actions Taken to Overcome Barriers

Question	Responded "Yes"
Have you or your department requested resources from your school to develop or expand drone courses?	26%
Have you or your department participated in a grant submission for funding to develop or expand drone courses in your program?	12%
Have you or your department dedicated any professional development funds or time to incorporate drone education into your program?	29%

CONCLUSIONS AND DISCUSSION

This study evaluated if 2-year community colleges were teaching UAS technology as part of their construction management or engineering programs. The study found that community colleges were not preparing their students to use this technology. The study then surveyed the project coordinators leading these programs. The program coordinators understood that contractors are using drones and that their use is likely to increase. They also indicated that they believed that UAS education should be included in their program and that they would be interested in developing the coursework in most cases. The two leading barriers to creating a drone program were the availability of faculty with drone experience and funding for equipment and professional development.

There are several effective ways to address the barrier of faculty without drone experience. The literature review described how Youngstown State University worked with a local contractor to develop its drone program (Sanson 2019). Additionally, program coordinators can hire UAS experts as adjunct instructors to teach a single drone class. Keeping the curriculum generic so the course is applicable to multiple disciplines at the community college will help ensure that the enrollment is high enough to justify the course financially. Clemson University's professional development program teaches Part 107 exam preparation, flight skills, and photogrammetry. Community colleges starting with a single generic UAS course should consider those topics as foundational and of interest to a wide range of industries.

The second leading barrier involves access to funds to purchase equipment and provide faculty professional development. The National Science Foundation (NSF) has specifically created the Advanced Technological Education (ATE) program to address this barrier. The ATE is targeted at 2-year institutions desiring to train the "technicians for the high-technology fields that drive our nation's economy" (NSF 2021). They have a history of funding UAS programs at multiple community colleges and specifically mention professional development and equipment as items eligible for funding. There are several tracks within the program, including a "New to ATE" designed for community colleges who have not participated in the program before. This track provides additional support and more flexibility for schools new to the program. Community colleges desiring to start a drone program are encouraged to participate in this federal funding source.

A limitation of this study is that it measured the UAS curriculum by whether the program had a dedicated drone course or not. It is possible that some programs addressed UAS technology less comprehensively by including individual modules in other classes. It is unlikely that the skills and knowledge to operate a UAS safely and in compliance with FAA regulations could be taught in less than a full 3-credit course. However, offering individual UAS modules related to the core curriculum of other courses can be an effective strategy. It also has the benefit of minimal initial investments in faculty resources to begin.

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Lean Construction and Design-Build Projects

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ABSTRACT

As projects increase in complexity, there is a growing need to explore more efficient construction and delivery processes. Approaches such as Lean Construction and Design-Build have independently shown potential in achieving higher efficiency in construction projects, but not much attention has been paid to their joint impact. This study explores how Lean Construction principles impact and complement Design-Build projects. This article performs a detailed review of a case study project, a new medical clinic and office building in California, along with interviews with nine industry professionals from the case study project and two other highly regarded firms. The results of the case study demonstrate the effective implementation of the Lean Construction practices in a Design-Build project. The case study review and the interviews highlighted that all parties involved were able to collaborate extensively, resulting in a better coordinated project and high end-user satisfaction levels. Additionally, the research uncovers that Lean Construction and Design-Build share many similar principles but under different terminologies. Based on the literature review, case study project, and the interviews, the study provides recommendations for effective implementation of Lean Construction principles in Design-Build projects.

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INTRODUCTION

As projects increase in complexity, there is a growing need to explore more efficient construction and delivery processes. Approaches such as Lean Construction and Design-Build have independently shown potential in achieving higher efficiency in construction projects, but not much attention has been paid to their joint impact. Studies of these two approaches also indicate that they share many of the similar principles but under different terminologies. This research explores how Lean Construction practices impact and complement Design-Build projects.

Design-Build

Design-Build is defined as a single organization responsible for both the design and the construction of a project. In a traditional "Design-Bid-Build or Design and then Construction" project delivery, the owner must manage two separate contracts, one with the designer and the other with the contractor, which often leads to an adversarial relationship between the designer and the contractor. Design-Build is meant to reduce costs and miscommunication between the design side and the construction side. Coined in 1993 by the Design-Build Institute of America (DBIA), Design-Build allows for a more streamlined design and construction process for a project. Building a project was divided into design and construction during the Industrial Revolution. As buildings became increasingly complex, a considerably higher overlap between design and construction started to occur. This overlap became the starting point for the birth of the Design-Build approach. Initially, DBIA termed it "Design-Construction," but the term "Design-Build" became more popular as it rolled off the tongue better. Figure 1 shows that the Design-Build method gives the owner a single point of contract and contact for project delivery and provides for a single point of contact for responsibility and communication with the entire project team. One important aspect of the Design-Build approach is the inherent culture of collaboration. This culture allows for effective problem-solving and innovative approaches to conflicts that may arise, allowing for a more efficient use of time and resources (Chan et al. 2002, DBIA 2021).

Design-Build is now the fastest growing method of project delivery. As per Korman (2021), the popularity of Design-Build delivery method in the U.S. is projected to grow to $400 billion or 47% of the overall construction work by 2025.

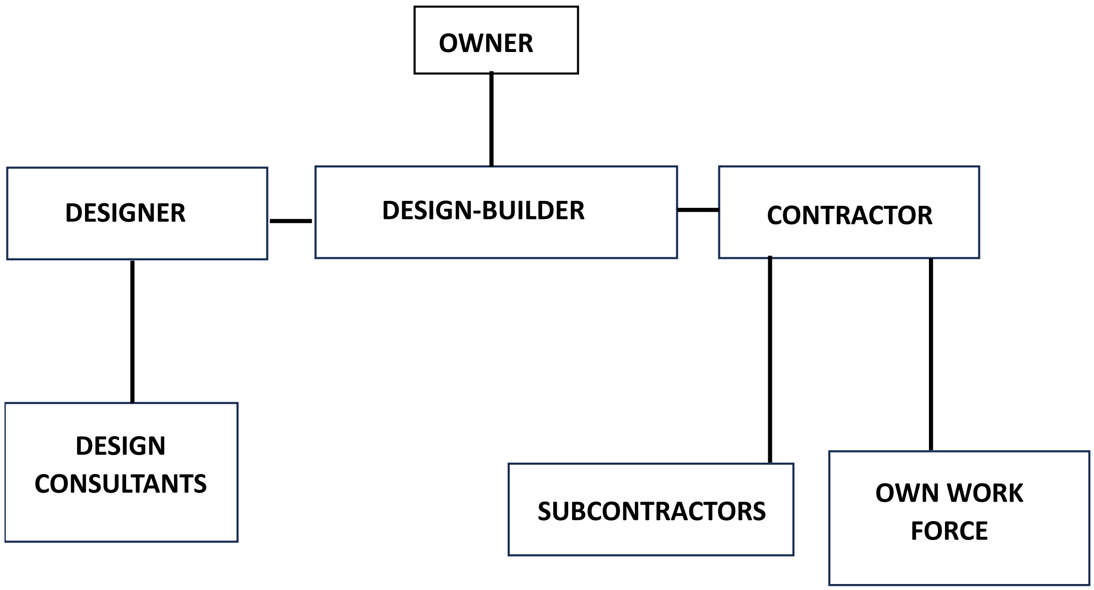

Figure 1: Design-Build Delivery System

Lean Construction

Lean Construction is defined as a respect-oriented production management approach to project delivery and a transformational way to design and build capital facilities that provide the means for efficient use of resources. This approach helps manage and improve construction processes with minimum waste and maximum value for customer needs (Koskela et al. 2002, LCI 2021, Pinch 2005). Lean Construction is based on lean manufacturing or lean production management, introduced in the car plants by Ford and Toyota motor companies. Lean Manufacturing refers to practices that allow manufacturers to cut costs, optimize processes, and reduce lead time. The main trait of lean manufacturing is to reduce waste in three key resources: materials, labor, and time (Lynn 2021).

Lean Construction is defined as "a way to design production systems to minimize waste of materials, time, and effort to generate the maximum possible amount of value." (Koskela et al. 2002). Lean Construction Institute (LCI) contends that projects with high Lean intensity are three times more likely to be completed ahead of schedule and two times more likely to be completed under budget. The core of the Lean Construction approach is "respect for participants" with a focus on the five areas as shown in Figure 2. It is based on the belief that in any organization, it is impossible to accomplish anything if team members don't respect and trust each other (LCI Tenets 2022).

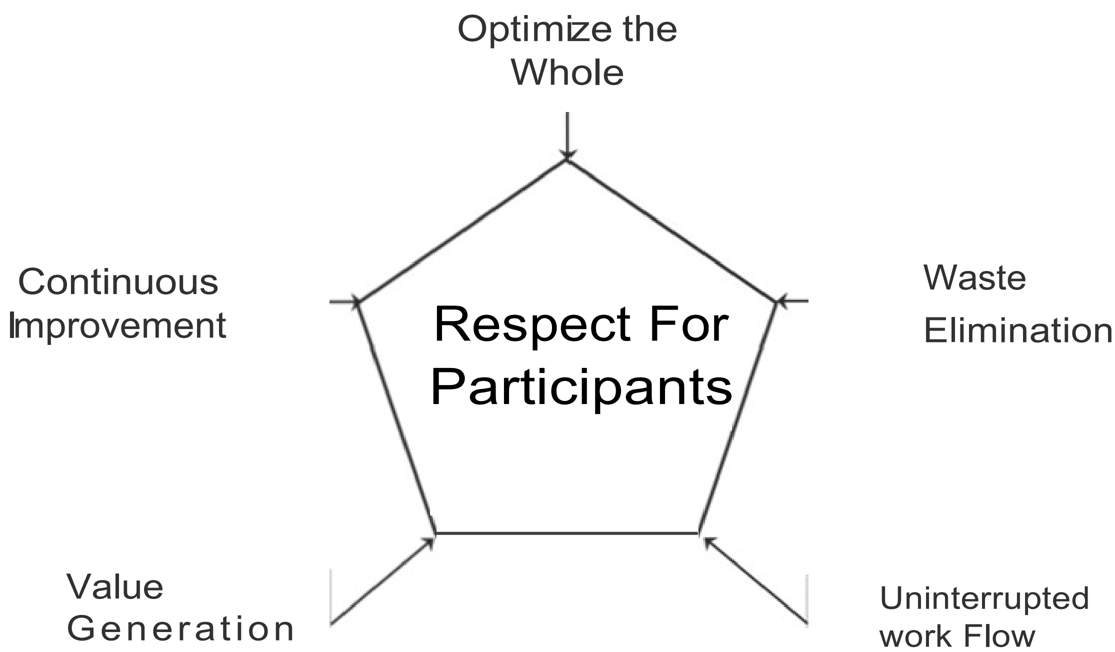

Figure 2: Tenets of Lean Construction (LCI Tenets 2022)

RESEARCH OBJECTIVES AND METHODOLOGY

This research aims to explore how the Lean Construction approach can impact the Design-Build process and how each method complements the other. Understanding how the two are intertwined may build a larger audience for both approaches. In addition, it will allow for a more efficient design and construction industry in the form of lower costs, faster completion dates, safer worksites, and higher satisfaction, among others. The objectives of this research are: understand Design-Build and Lean Construction processes, explore the impact of Lean practices in Design-Build projects, and develop recommendations for effective implementation of Lean Construction in Design-Build projects. The methodology to achieve the above-noted objectives consisted of the following aspects:

Literature review: the main sources of literature are the Design-Build Institute of America (DBIA) and the Lean Construction Institute (LCI) websites, where several case studies information and research studies are accessible. Several reports, articles, and case studies from the DBIA and LCI websites were reviewed to understand the individual and joint impacts of Lean Construction practices and Design-Build projects. Both websites were also reviewed to identify similarities between the LCI and the DBIA approaches and terminologies (DBIA 2021, LCI 2021). In addition, several studies that proposed tools that can facilitate joint implementation of these two approaches were reviewed (Luo et al. 2005, Darrington 2011, Becker et al. 2012, Aibinu & Papadonikolaki 2016, Khanzode et al. 2006, Tauriainen et al. 2016).

Detailed review of a case-study project and interviews with key professionals: during the 2021 Design-Build Conference in Denver, a case study was presented about a medical clinic and office building project in California, utilizing both the Lean Construction and the Design-Build practices. The lead researcher was able to connect with the architect and the superintendent of that project who agreed to provide full access to project details and to the key professionals. Five key individuals responsible for the case study project were interviewed to learn about their experiences and the lessons learned.

Interviews with industry experts with experience in both approaches: the authors were able to identify and interview four industry experts with backgrounds in both Lean Construction and Design-Build. These interviews allowed the researchers to better understand the current issues related to the two approaches and the implementation of Lean Construction in the Design-Build projects (Otto & Syal 2022).

LINK BETWEEN DESIGN-BUILD AND LEAN CONSTRUCTION

In order to complement the literature from the LCI and DBIA websites, the authors reviewed additional research studies that explored Lean Construction and/or Design-Build from different angles such as prefabrication (Luo et al. 2005), contract documents (Darrington 2011, Becker et al. 2012), and Building Information modeling and Virtual Design and Construction (Aibinu & Papadonikolaki 2016, Khanzode et al. 2006, Tauriainen et al. 2016). In addition, LCI and DBIA sources focusing on the link between the two were also reviewed (LCI Cross Mapping 2022, DBIA Hornbeck 2017). A review of these studies, as summarized below, helped explore the complementary aspects and the similarities between Design-Build and Lean Construction.

Lean principles for prefabrication in green Design-Build projects (Luo et al. 2005): this paper explores the implementation of Lean principles to reduce costs through improved productivity by integrating prefabrication in Green Design-Build (GDB) projects. This research examines the impact of prefabricated systems on green building goals through evaluating the interplay between multiple economic, environmental, and social variables. It provides guidance for the use of prefabrication in lean and green projects within design-build environments.

Design-Build and Lean Construction contracts (Darrington 2011): this study reviews the distinctions between Design-Build as a project delivery system and as a contract type. It contends that design-build contracts can be a useful vehicle for implementing Lean Integrated Project Delivery (IPD). IPD is a delivery approach, conceptually based on a collaborative culture, that uses a single contract for design and construction with a shared risk/reward model. It can be applied to a variety of contractual arrangements and usually includes members beyond the owner, designer, and general contractor from early design through project completion. The author suggests two major alternatives for implementing Lean IPD in design-build contracts. It can be set up as a relational design-build contract that allows for full implementation of Lean IPD, or it can be set up as a traditional transactional design-build contract but with implementation of Lean IPD within the supply chain, even without the owner's sponsorship or mandate. The first option will be Leaner, but the second approach will be more Lean than a traditional Design-Build project delivery. Another report from Becker et al. (2012) compares Lean Construction with Design-Build as a framework for contractual agreements. It contends that the language between the two processes is contractually very similar.

BIM implementation and project coordination in Design-Build (Aibinu & Papadonikolaki 2016): this research aims to explore and identify the relationship between design-build and Building Information Modeling (BIM). BIM has allowed project management and coordination between teams to be more concurrent and, therefore, more effective. Although this research focuses on BIM and Design-Build, it indicates that BIM has also allowed for a stronger emphasis on collaboration between the designer and the builder, attributes that are desirable in both Design-Build and Lean Construction approaches.

Effects of BIM and Lean Construction on design management (Tauriainen et al. 2016): the use of BIM and lean design management can lead to an increased value realization for the customer. In managing building design, the use of lean management tools can be seen as a driver to increasing value to the customer, improving operations, and removing activities that do not add value. In this study, typical structural and building services design management problems in the context of BIM implementation were identified, and improvement methods and tools were suggested. It recommends that Lean principles can be implemented in design management to generate value for the customer. For example, on large projects, collaboration between parties could be facilitated using ideas of the "Big Room." The basic idea of the big room is that different designers work side by side. This enables more effective information sharing between them. It has been found that using this approach leads to a shortening of overall design time due to face-to-face information sharing and, thus quicker decision making. One of the example areas that can benefit greatly from the big room approach is when there are conflicts between BIM models from different design disciplines. For not very large projects, a less involved version of the big room was suggested where designers meet at the same location at certain critical points of the project and then go back to their own offices.

Virtual Design and Construction (VDC) and Lean project delivery process (Khanzode et al. 2006): this paper introduces Virtual Design and Construction (VDC) and how these concepts can be applied to the Lean Project Delivery Process (LPDP). It found that VDC tools can be effectively applied to accomplish the objectives of the LPDP. For example, (1) product modeling tools such as 3D modeling can be effectively applied to the project definition, and the lean design and lean assembly phases; (2) product and process modeling tools such as 4D models can be applied during the lean supply and the lean assembly phases; and (3) product, organization, and process modeling tools can be used to analyze the tradeoffs during the lean design phase of LPDP.

Link between Design-Build and Lean Construction (LCI Cross-Mapping 2022, DBIA-Hornbeck 2017): in recent years, there have been few research efforts that have attempted to link Lean Construction and Design Build. One important effort is the cross-mapping matrix by the LCI. This matrix takes the "Design-Build Done Right" approach, as recommended by DBIA, and illustrates which Lean practices relate to various aspects of this approach. It expands the three main areas of the Design-Build Done Right approach into various practices and recommendations and then links them with corresponding lean practices. Table 1 shows the three main areas on the matrix and an example in each area of the link between the two approaches.

Along the similar thinking but from the DBIA side, a recent study discussed the collaboration between the two methods. It contends that the design-build and lean construction movements share many commonalities going back to their roots in the Total Quality Management (TQM) revolution of the 1950s. It further asserts that when used individually, both lean practices and the Design-Build Done Right increase the chance of overall project and team success, but when used together, however, opportunities for success, innovation, and creativity are even greater. In Table 2, the common goals of the two methods are highlighted. These include maximizing value to the client, increased productivity and owner satisfaction, overall team success, and appropriate risk management (DBIA-Hornbeck 2017).

Table 1: Cross-Mapping Between Design-Build and Lean Practices (LCI Cross-Mapping 2022)

Design-Build Done Right	Lean Practices
1. Procurement of Design-Build Services Owners should develop their design-build procurement with the goal of minimizing the prescriptive requirements and maximizing the use of performance-based requirements, which will allow the design-build team to meet or exceed the owner's needs through innovation and creativity.	Target Value Delivery (TVD) Set-based Design Prefabrication
2. Contracting for Design-Build Services Contracts should encourage, rather than hinder, communications among project stakeholders	Alignment Partnering Core group Transparency Collaboration
3. Execution of Delivery of Design-Build Projects Design-Builder should clearly, thoroughly, and expeditiously advise owner about any issues that might impact contract price or schedule to enable the owner to make an informed decision as to how to address such issues	Constraint log, Last Planner® Daily huddles

Table 2: Common Goals of Design-Build and Lean Practices (DBIA-Hornbeck 2017)

Design-Build Done Right + Lean Practices
1. Maximized value to the Client: First- and life-cycle costs, achieved through optimization of budgets
2. Increased productivity: Resulting in time savings and earlier project completion
3. Increased owner satisfaction: Better quality, fewer change orders, reduced conflict, and the greater return on investment
4. Increased likelihood of overall team success: Favorable profit margins and expanded team capacity for future projects
5. The appropriate management of risk: Reduction in uncertainty, as well as enhanced transparency and collaboration

UNIVERSITY MEDICAL BUILDING – CASE STUDY PROJECT

The case study project is a new medical clinic and office facility for a major university in California. It was designed and constructed to stay operational at a magnitude seven earthquake and withstand up to magnitude eight earthquake. This project had planned to incorporate both Lean and Design-Build approaches from the inception. In addition to reviewing details of the project, interviews were conducted with five individuals from three groups: the general contractor, the architect, and the owners' representatives (Table 3).

Table 3: Individuals Interviewed from the Case Study Project

Job Title	Organization	Role on the Project
Architect	Architect	BIM Architect
Project Manager	General Contractor	Lead Project Manager
Superintendent	General Contractor	Lead Superintendent
University Senior Project Engineer	Owners Representative	Owner's Subcontractor Coordinator
University Project Manager	Owners Representative	Owner's Project Manager

The project was designed as a clinic and an office facility with an overall area of 300,000 square feet. Around 200,000 square feet were for the clinic and the rest for the office space. On the clinic side, it was designed to be a complete eye and vision center with examination rooms, diagnostics space, testing areas, surgical procedures, wet and dry labs, a library, and a 100-seat auditorium. The office space consisted of an open floor plan with multiple conference rooms and offices.

In the interview, the following nine questions were asked with an option for additional comments. The interview results were synthesized in four sections as summarized after the questions:

1. What was your role in this project?
2. Can you give me a short summary of the project?
3. What was your understanding of Lean Construction practices before and after this project?
4. What was your understanding of Design-Build before and after this project?
5. At what point during the project did you decide to implement Lean practices?
6. During this project, what similarities did you notice between Lean Construction and Design-Build?
7. If you had not implemented some lean practices, what do you think would have

happened?

8. If you could go back, are there any practices you would not have implemented?
9. If you had the opportunity to do another project like this, would you?
10. Any additional comments?

Implementation of Lean Construciion and Design Build

Before this project, most of the individuals interviewed had some understanding of Lean Construction, mostly focused on limiting waste. However, the general contractor had utilized Lean Construction practices for more than a decade as a contractual requirement on past projects. This general contractor almost exclusively works with Design-Build projects, therefore, the project manager's and the superintendent's experience level with Design-Build was very high even before this project. In addition, the university project manager had completed two previous design-build projects.

The implementation of Lean Construction into this Design-Build project was contractually intended. Because of that, the kickoff meeting was a significant event, inviting all parties involved, including contractors, designers, owner's representatives, and the end-users/occupants.

Both the contractor's project manager and university project manager emphasized that many key aspects that were implemented included many Lean practices needed for a Design-Build project to succeed. One critical aspect that all parties agreed on was the reliance on collaboration, which is considered to be a key aspect of both approaches.

The design of the building was done in packages, where once one package of the project was designed, it was sent to the field to begin construction. Early in the design stage, the primary users, including doctors, nurses, and technicians, were invited to review the mockup of the finished rooms. It was done to help with finalizing the space with the most efficient layout. In addition, parts of the project were designed to be prefabricated, another aspect of Lean Construction. Waste minimizing was another crucial factor that was discussed by all. In addition, the responsible decision-making and action being correctly assigned to the person best suited were followed. For example, the contractors were expected to provide accurate costs and budgets throughout the design. At the same time, architects were expected to resolve code issues with an inspector, which would be beneficial in the long run to a project.

Overall, the interviewees highlighted the following aspects as outcomes of implementing both approaches:

- The owner's representatives felt that having the project be contractually built in a Lean and

Design-Build oriented model allowed the project to become a best-value proposal for the owner.

- All parties were required to share a trailer that allowed maximum collaboration, significantly improving project coordination, relationships, and morale. Although, some field personnel felt that there was too much collaboration. For instance, some felt that in the beginning, some meetings were too large to provide quick decision making and would have been more effective with a smaller audience.
- A cloud-based system for all documents via the Projects Solution Group allowed for real-time changes, reducing the number of RFIs.
- In the early design state, a multi-day input session with all parties, including end users, allowed everyone to understand the building design through the mockups and identify any possible problems. This led to a reduction in change orders and corresponding cost and time overruns.
- The project was designed and built as three separate packages that were combined at the end. Once the first package was designed and submitted, the contractor began constructing as the second package was simultaneously being designed. Dividing the project design into packages allowed for a leaner timeline and a higher level of focus on that specific package.
- Building Information Modeling was used extensively, and it allowed all parties, especially contractors and end users, to inform the designers of any possible conflicts or solve potential problems before they occurred.
- A positive collaborative relationship was developed with most external parties, and it helped mitigate many unforeseen issues. For example, a positive collaborative relationship was maintained with the Fire Marshall that helped mitigate many potential code-related issues emerging especially close to the project completion.
- Morale among the participants after the project was extremely high, resulting in all members interviewed stating that they would do another project like this again.

INTERVIEWS OF INDUSTRY EXPERTS

Additional data was collected through interviews with industry experts at two well-regarded companies. Company 1 is a European construction company established in 1887 and has a major office in Seattle, WA. Company 2 was established in 1906, with the global headquarters located in Canada, while the United States headquarters is in Denver, Colorado. These individuals bring in a total experience of 42 years with their respective companies. Table 4 lists the individuals interviewed with their job titles and company affiliations.

Table 4: Industry Experts Interviewed

Title	Company
Vice President of Operations	Company 1
National Director of Continuous Improvement	Company 1
Senior Manager of Continuous Improvement	Company 1
Lean Manager - National	Company 2

The interviewees were asked the following questions. Their comments can be summarized in three categories provided below.

1. What is your name, what company you work for, and your role?
2. In your own words, how would you describe Lean Construction
3. In your own words, how would you describe Design-Build
4. If Lean Construction is your focus, have you considered applying Design-Build practices into Lean projects?
5. In previous projects, have you implemented Lean principles in Design-Build projects?
6. When in a project do you decide to implement these principles?
7. In your opinion, do you see Lean Intertwined with Design-Build becoming more commonplace? If so, why? If not, why not?
8. Any additional comments?

Understanding of Lean Construction and Design-Build

Lean Construction: Both the Vice President and senior manager of company 1 shared the view that Lean Construction identifies processes that need improvement and helps devise a plan to address those areas and then spread the information to all those involved. They further stated that Lean Construction is a specific set of tools designed to maximize or leverage talent available to create the most value for clients/end users of the building and everyone involved in the entire process. On the other hand, the national director of company 1 and the lean manager of company 2 portrayed Lean Construction more holistically, stating that Lean Construction is more of a methodology or body of knowledge that focuses on developing respect for people. It can be summarized from the comments from all four experts that Lean Construction is a people-oriented process and it focuses on improving the construction process and value adding for all parties, including occupants, during the building life cycle.

Design-Build: All professionals at company 1 stated that Design-Build is bringing everyone in the project together under one roof, thus allowing for a higher level of collaboration to work towards a common goal rather than individual goals as in other contractual systems. The lean manager of company 2 stated that Design-Build is a procurement model that brings the two main parties, the designer and builder, under one roof. Bringing the builder in during the project's design phase to streamline the project's constructability provides more collaboration and, ultimately, more value.

While each person stated it differently, the main consensus on Design-Build was that it is about bringing all groups together to have more collaboration, efficient planning, and better results. These were found to be similar attributes of both Design-Build and Lean Construction.

Implementation of Lean Construction and Design-Build

The national director from Company 1 stated that Design-Build brings collaboration early in the project, allowing for troubleshooting to occur earlier, resulting in projects being even Leaner. The senior manager stated that Company 1 implemented the continuous improvement process ten years ago and that Lean is an essential part of that implementation plan. Their focus is more on Lean, but they believe that bringing the contractor into the design phase of a project allows for the highest level of collaboration. Therefore, their perspective is that Design-Build is closest to Lean Construction philosophy in terms of collaboration.

The vice president stated that while the two may be contractually different, both share the key quality of making informed decisions through collaboration. He provided an example of a hospital renovation project where a bathroom needed to be installed on a floor above an active operating floor. Since this was a Design-Build project, all parties collectively analyzed the situation and decided to go for the prefabricated bathrooms. Additionally, the VP stated that in such projects, the goal is to be quick and nimble while maintaining a high level of quality. They believe that Design-Build projects, along with Lean practices, make it easier to achieve this goal.

The national director stated that Design-Build really relies on Lean thinking. As a result, all parties know when things need to be established as early as possible, allowing for better use of all available resources for the project. He further stated that the main similarity between the two is precisely the goal of having all groups work together.

Specific to the question on how they implemented Lean into a project, the project timeline, and who was involved in that decision-making process, company 1 professionals spoke about the involvement of end users early in the design process. One key example for this question was the implementation of mockups, as they allow the end-user to understand better what the actual finished project will resemble. The National Lean Manager stated that the team would usually start implementing systems like Last Planner (LCI Last Planner 2022) during a project stage, especially when they need input from trades for project scheduling and progress.

When concluding the interview with the lean manager, it was stated that Lean, in essence, creates value for the client, and it all comes back to the people on the project. All stakeholders want these projects to be successful, therefore, it is paramount to increase communication/connections between people in the industry. Ideally, it is the owner who drives the idea of going Lean, but it is almost always in the interest of the Contractor to go Lean.

All those interviewed at Company 1 stated that continuous improvement is critical. For the company to understand how to build better through Lean and Design-Build has allowed them to grow. Also, it is hypothesized by those interviewed that if the client and the designers can get on board with a higher level of collaboration early on, many positive impacts can result and the Design-Build approach can be the vehicle for such collaboration. This collaboration spirit, coupled with technologies such as BIM and VDC, makes the future look bright for these two approaches.

During open discussions with the interviewees, some of the challenges or pitfalls were brought up. It was shared that there were some stressful and tedious points, especially when it came to Value Engineering (VE) processes. Additionally, there were instances in the project where some field personnel felt that too much collaboration was not helpful. For instance, it was mentioned that in the beginning, some meetings felt too large to provide proper value and would have been better with a smaller group. When discussing Design Build, it was brought up that lack of qualified and experienced personnel who can handle both design and construction is a challenge. Similarly, when discussing Lean, the architect and GC project manager stated that it is a buzzword that can rub some people the wrong way if not explained correctly.

When asked to speculate on the future, all parties were asked if they see Lean and Design-Build becoming further intertwined, and it was a resounding yes from all the interviewees. The Vice President stated that "if you are not using both practices together, the maximum potential is not being realized."

SUMMARY AND RECOMMENDATIONS

This research has attempted to present the positive impacts of Lean Construction principles in a Design-Build project. The goal was to explore how Lean Construction practices complement Design-Build projects. Although there is a fair amount of literature on the benefits of Lean Construction and Design-Build implementation individually, there is not much research done to investigate them jointly. This research performed a detailed review of a case study project, a new medical clinic and office building in California, along with interviews with nine industry professionals, five from the case study project, and four from two other highly regarded firms. The case study demonstrates effective implementations of Lean Construction practices in a Design-Build project. The case study review and the interviews highlighted that all parties involved were able to collaborate extensively, resulting in minimizing RFI requests and achieving high end-user satisfaction levels. Additionally, the research uncovered that Lean Construction and Design-Build share many of the similar principles but may have different terminologies.

Based on the literature review, the case study project, and industry interviews, the authors propose the following recommendations for effective implementation of both approaches.

Recommendation for the Design-Builder - All parties should work together in a common physical space: having all design and construction groups working in the same facility / trailer allows for a much higher level of collaboration between these groups. It also leads to higher level of morale and a lower level of conflicts and RFIs. Future research should be conducted in this area to better understand the various impacts of having all parties in the same facility in addition to those mentioned above.

Recommendation for all parties - Involving all parties including end users in design: input of all parties, especially end users, must be incorporated from the beginning of the design. All interviewees stated this was a key factor in everyone taking ownership in the project. Having the end-users/occupants of the project present during the Big Room Planner meeting and allowing for mockups to be finalized based on user inputs allows for a higher level of satisfaction from the occupants. Therefore, it increases the value of the building, which is in alignment with Lean and Design-Build approaches. Further research is needed in the area of occupant satisfaction and its correlation with their participation in the design and construction phases for a deeper understanding of its impact on the project success.

Recommendation for the Owner - Dividing projects into multi-step design-construction packages: First of all, owners should be made aware of the benefits of going for Design-Build and Lean Construction, so more owners require them on their projects. A specific recommendation involves dividing the overarching project into multi-step design-construction packages. As was seen in the case study project, it allowed the project to better utilize the limited time and resources on the project. The commencement of construction of the first phase, while the design of the second phase is underway, can significantly reduce the project's overall timeline and create a higher level of efficiency.

This research gives a glimpse into the advantages of Lean Construction and Design-Build approaches, individually and jointly. The authors found that every professional interviewed and those involved in the case study project expressed that both approaches complement each other and bring about positive impacts for the project. They all believed that joint implementation of these two approaches, especially with advanced technologies such as prefabrication, BIM, and VDC, has a bright future in the AEC industry.

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Benchmarking Residential Carpentry Contractors’ Perspective on Safety in the South Eastern U.S.

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Abstract

Improved safety practices and a company safety culture that promotes safe work practices impact a company’s economic health. In order to address improved safety with smaller companies, it is important to understand their current views and practices. With a higher rate of injury and fatalities for smaller residential firms and a lack of research exploring company-level safety practices for these smaller firms, a better understanding of safety practices is needed. This paper discusses an extensive literature analysis to identify company-level safety factors. The identified factors were then utilized to develop a survey to benchmark company-level safety-related practices of small residential carpentry firms. The respondents were grouped by actual safety performance (Experience Modification Rate: EMR), age of firm, growth, and company volume to identify potential drivers that more greatly affect the safety performance of this demographic of the firm. Finally, the paper presents areas where small carpentry firms are performing well in terms of safety culture and discusses areas where some improvements can be made.

Keywords: Residential Construction, Safety, Carpentry, Safety Performance

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Introduction

The dynamic nature of construction job sites creates a challenging work environment that exposes employees to significant amounts of risk and safety hazards (Bigelow et al., 2012). The construction industry accounts for 21.4% of all private industry worker fatalities (Anderson, 2018). Improving safety in construction can generate a significant financial impact on the global industry. Safe project outcomes increase project value as they relate to the success of the project and savings in project management and human resources costs (Mohammadi et al., 2018). Despite recent improvements in construction safety, the construction industry accident rate is still higher than most other industries (Mohammadi et al., 2018, Amiri and Ardeshir, 2017).

Specific to the residential construction sector, non-fatal rates were 3.8 per 100 full-time workers with 11% of all construction-related fatalities in the residential sector; 58% of those fatalities were due to falls (Marin and Roelofs, 2018). For residential carpentry workers, most fatalities and non-fatal loss of workday injuries were related to falling to a lower level (Kaskutas et al., 2009) and ladder falls (Evanoff et al., 2016) which have led to research in fall prevention intervention methods for residential construction. Carpenters have accounted for the third greatest number of fatalities related to falls behind roofers and general laborers from 2011-2015 as well as the second most (behind general labor) nonfatal injuries and days away from work for 2015 (CPRW, 2018). Smaller companies (those with 10 or fewer employees on the payroll) have accounted for the majority of fatalities, even though these companies collectively employ only about 30% of the overall construction workforce (CPWR, 2018). Additionally, inexperienced workers, as well as temporary workers, non-fluent speakers, and employees of smaller firms, are especially vulnerable to workplace falls and injury (CPWR, 2018). Smaller companies have limited resources to put towards safety and improvement of practices when compared to larger companies. Furthermore, the company's size and financial growth factor into its ability to realize the value of accident investigation and inspections as drivers for improving safety performance (Mohammadi et al., 2018), so it is often not done.

Most studies pertaining to safety culture have been done with larger construction companies. This study examined factors of the safety culture of residential carpentry firms to benchmark different company-level processes that are utilized in terms of creating a better safety culture. The focus is on carpentry as they are one of the trades with a higher level of risk and are responsible for a significant portion of the work. The first objective of the research was to understand, to what extent, smaller companies were employing safety measures within their company. The second was to examine which may influence the company's overall safety performance when comparing those with a stronger performance against those with a weaker performance. This paper discusses the company-level safety practices that were identified through an extensive literature review, the survey development and administration process, and the data analysis.

Literature Review

The perception of safety by workers can impact the overall safety climate and culture of the organization. The "safety culture" of an organization is defined by Frazier et al. (2013) as the values, behaviors, attitudes, beliefs, perceptions, and competencies related to safety. The "safety climate" of a company is defined by workers' perception of the role of safety within the workplace (Mohamed, 2003). The safety climate of an organization has been linked to injury and illness rates, an organization's strategic decision-making, and an organization's employees' perception of safety strategies (Bigelow et al. 2012; Mohammadi et al. 2018; Rowlinson et al. 2016). There is no universal agreement on the definition of safety culture and climate or if the terms are interchangeable (Jin and Chen, 2013), however for this research, safety culture will be used as an indication of the company-level processes used to promote safety within an organization and safety climate deals with the perceptions of an individual. The company-level processes, or "safety culture", are the focus of this study.

Choudry et al. (2007) stated that safety culture is a top-down organizational approach determined by the firm's management. It is the organizational safety that is supported by project management (Choudhry et al., 2007) which serves as the root cause of good or poor safety performance (Newaz, et al., 2018). Some of the factors that go into an organizations safety culture include management commitment, appropriateness of safety procedures (Choudhry et al., 2007), management concern, personal responsibility, peer support for safety, safety management systems (Frazier et al., 2013), worker involvement, safety training, safety attitudes, appraisal for safety risk and hazards, safety resources, competence, and risk-taking behavior (Newaz et al, 2018).

Several studies have concluded that the presence of safety personnel on-site helped manage safety issues and reduce injuries and accidents (Hallowell & Calhoun, 2011). Employment of a safety manager has been found to be one of the commonly adopted safety initiatives for larger companies (Esmaeli & Hallowell, 2012) and having a safety manager on site is one of the most central elements to an effective safety program (Hallowell & Calhoun, 2011). The employment of a safety manager for smaller companies working on smaller projects is often cost-prohibitive so the responsibility for on-site safety often falls on someone else. Other studies have indicated the importance of where the message of safety comes from within the organization as to how effective it is in promoting a safety culture. Advanced leadership skills among front-line supervisors, such as field supervisors and foremen, have been identified as having an impact on a company's ability to establish a good safety culture (Ringen et al., 2018).

Company Level Safety Practices

A literature analysis was conducted by utilizing keyword searches of scholarly databases. During the comprehensive search, a total of one-hundred and fifty-five (155) relevant publications on safety performance were reviewed. Approximately 71% of the publications were published since 2012. These publications were reviewed for key safety drivers. Depending on the study these drivers were often identified as key safety best practices, safety factors and sub-factors, or leading indicators of safety.

Each study was evaluated and factors that were not relevant to company-level safety performance were eliminated. Additionally, other publications were eliminated if key drivers were duplicate efforts of similar papers by the same authors, lacked a rigorous methodology of how the drivers were identified, focused on construction activities primarily outside of the United States, or if the study focused on project specific safety rather than an examination of project results based on company safety culture. Factors from different studies that had similar definitions but were labeled differently were grouped together and in total thirty-nine (39) references were included in the study that discussed key company-level safety drivers (Appendix A).

In total, from these references, eleven (11) unique categories were identified. Each category defined was noted in more than one reference (Table 2) however the source identified in the Table 3 is associated with the definition.

In total, 223 key safety factors were identified from the literature (see Appendix A). Similar factors were organized into sets which were then placed within the ten (10) identified categories. As part of the process to support this research, each of the factors was then reviewed to identify company or organization-level factors. These were sorted out from factors that were at the worker and/or project level. In all, 119 company or organizational-level safety factors were isolated. The isolated factors were reviewed by safety professionals within the construction industry to validate their importance and ensure that they would be related to the company, not project, level procedures. These company-level factors were then utilized to develop the survey.

Table 2: Categories of Key Safety Categories

Reference	Categories of Key Safety Practices										
	Incentive Programs	Safety Training and Orientation	Financial Aspects of Safety	Safety Resources and Equipment	On-site Safety Manager	Provision of Safety Equipment	Work Condition and Pressure	Job-Hazard Analyses	Safety Culture and Climate	Accident/Incident Investigation	Written Safety Policy/Plan
(Mohammadi, et.al, 2018)	X	X	X	X	X	X	X	X	X	X	X
(Hinze, et.al,, 2013)	X	X	X	X	X	X	X	X	X	X	X
(Guo & Yiu, 2016)	X	X		X		X	X	X		X	X
(Swacha, et.al,, 1999)		X			X	X			X		X
(Gambatese & Hinze, 2003)	X	X						X		X	
(Hallowell & Calhoun, 2011)		X			X			X	X	X	X
(Wehle, et.al, 2013)	X	X						X	X	X	
(Findley, et.al, 2004)	X	X			X				X	X	X
(Cheng, et.al, 2015)		X							X	X	X
(Hallowell & Gambatese, 2009)		X			X			X	X	X	X
(Russell, et.al, 1996)		X			X				X	X	
(Choudhry, et.al, 2008)	X	X		X		X		X	X		X
(Karakhan, et.al, 2018)	X	X	X		X			X	X		
(Cheng, et.al, 2012)		X			X				X	X	X
(Hallowell, 2011)		X	X		X			X	X	X	X
(Hallowell, 2010)		X	X		X			X	X	X	X
(Esmaeili & Hallowell, 2012)		X			X			X	X	X	X
Total number of studies per topic area:	8	17	5	4	12	5	3	12	15	14	13

Table 3: Definitions of Categories

Category	Definition (Key Reference)
Incentives Programs	Motivators, such as reward programs, wage, job satisfaction programs, peer mentor programs, rewards and penalties used to motive safer work performance (Mohammadi et al., 2018)
Training and Orientation	Orientation of safety requirements for a company or project and formal training programs (Hallowell, 2011). Includes recording of hazard awareness, training, and education (Mohammadi et al., 2018)
Financial Aspects	Safety programs should account for a program budget and investment in safety. Investments should be cost-effective such as creating subcontractor and management selection criteria (Hallowell, 2010).
Safety Resources and Equipment	The focus of providing/requiring the appropriate personal protective equipment, safety equipment, equipment selection, and incorporation of equipment (Mohammadi et al., 2018)
On-site Safety Manager	Organizational requirement, or motivation to have a dedicated safety manager on site is one of the central elements of an effective safety program (Hallowell & Calhoun, 2011). In smaller organizations, it is important to have someone identified as being the one responsible for safety on that site.
Provision of Safety Equipment	The effects of a company providing safety equipment to properly do the job (Guo & Yiu, 2016). Also, having the right tool for the right job.
Work Condition and Pressure	The conditions and pressure that workers are put under by the organization, including time constraints, work hours, and other stresses that affect safe worker behavior on site (Chi et al., 2013)
Job-Hazard Analysis	As part of the company culture, hazards are appropriately identifying on the jobsite allows for preparing to adequate complete the task (Guo & Yiu, 2016). This can include the selection and availability of the right equipment for the conditions.
Safety Culture and Climate	Concepts recognized by the construction industry to enhance safety performance (Choudry et al., 2007).
Accident/Incident Investigation	Identification of root cause with intention of reviewing/revising protocol for future improvement (Mohammadi et al., 2018).
Written Safety Policy	Documented plan that identifies project-specific safety objectives, hazards, and practices for risk mitigation. Serves as the foundation required for a good safety program (Hallowell, 2010).

Methodology

The study was completed in two phases (Figure 1). The first phase was a review of safety data. A comprehensive literature review was completed to isolate company-level safety factors. Additionally, insurance company data was reviewed to better understand the safety performance data available. Within this phase, a potential response pool of organizations doing primarily carpentry work within North and South Carolina was identified. The potential response pool was identified based on the amount of companies available within one segment of the industry, the inherent risk associated with carpentry workers in residential construction, and the availability of needed data for initial analysis. A survey was developed in the second phase based on the identified factors and categories from the literature review.

The survey was disseminated to the identified response pool of 150 companies utilizing Qualtrics. Once the data was collected it was analyzed to benchmark current safety practices of smaller carpentry firms as well as analyze which factors may influence overall safety performance.

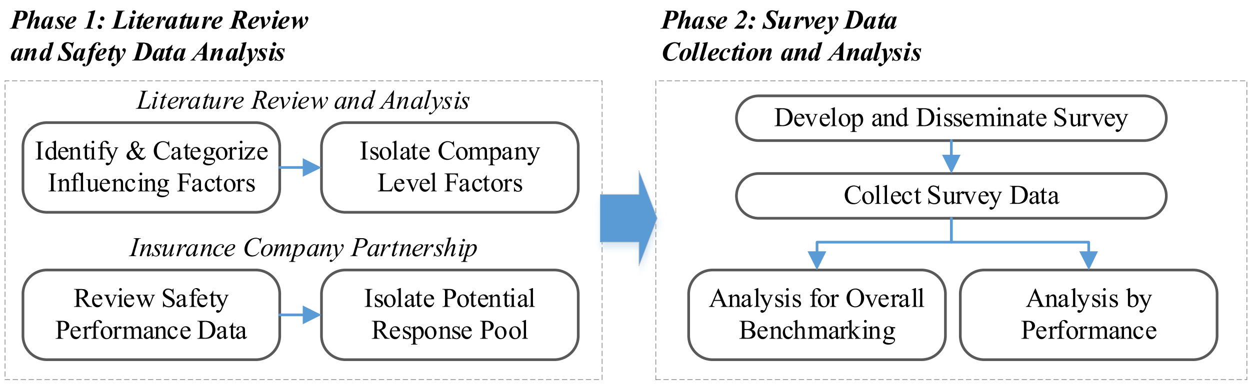

Figure 1: Research Steps

Survey Administration

The study aimed to identify perceptions and practices of safety within smaller companies in the residential construction industry. Through a partnership with an insurance company, safety data was examined for smaller firms that worked in various trades. Carpentry firms (NCCI Governing Class Code 5645), based on data reflecting overall safety and incident report, was chosen as the group that would be further examined. This group had the greatest number of potential respondents with a degree of disparity in terms of EMR which suggested firms with a variety of safety records and practices.

The survey was designed specifically for residential carpentry firms and has three sections. One for demographics, the second for benchmarking certain safety practices as found in literature, and the third to document the survey respondent's perception of safety. In total, 150 different firms were identified within North and South Carolina for the potential pool of participants based on the limiting criteria of a minimum of 5 years of available data and a minimum of $100,000 reported payroll. The decision to utilize one class of companies was to eliminate the inherent danger of work experienced by crews that do different types of work from influencing the results of the study. Besides the availability of potential participants, residential carpentry, especially for those working on exterior framing, is inherently dangerous. The survey was administered through Qualtrics and an initial invitation by email blast. Follow-up emails were sent at 2 and 4 weeks with a paper survey and invitation mailed at week 4. With multiple undeliverable emails and other forms returned to the sender, a total of 24 complete and usable survey responses were received. The demographics for those respondents are included in Table 4.

Table 4: Respondent Demographics

Demographic	**Mean (µ)**	**Range**
Age of Firm	18.46	2-34
Approximate Volume of Work	$5.2 Million	$675,000 - $20 Million
EMR	0.98	0.77-1.51
Estimated Payroll	$394,356.50	$102,187 - $1,535,000
Residential Work	88%	66% - 100%
2 Stories or Less	69%	0% - 100%
Interior Carpentry	35%	0% - 100%

Benchmarked Safety Practices

From the literature, there are several key safety features that help contribute to a company's safety culture. These include hiring practices, safety training and orientations, formalized safety programs, and the use of safety incentives. To get a better understanding of the industry practices, responses were also sorted by Age of Firm, Safety Record, and Volume. With a range of years of existence for responding firms being from 5 – 34, younger firms are identified as those who had 15 years of experience or less. In terms of volume, a $3 Million mark was used to distinguish between the two groups. Lastly, lower EMR firms had a mean EMR of 0.83 with a range of 0.92 or less. Higher EMR firms had a mean EMR of 1.11 with a range of 0.94 and greater.

Hiring Practices

The key safety factor of "Hiring Practices" within the context of the literature contains different variables that are taken into consideration when looking to hire employees. The factors that were explored as part of this study included drug testing, experience requirements, employment verification, background checks, reference checks, and if task-specific certifications/credentials were required as a consideration for employment. Table 5 shows the summary of findings for hiring practices.

Table 5: Summary of Hiring Practices

Activity	*Position*	*All Firms*	*Low EMR*	*High EMR*	*% Change*
Drug Test	Worker	41.67%	36.36%	46.15%	9.79%
	Supervisor	45.83%	27.27%	61.54 %	34.27%
Experience Requirements	Worker	79.17%	81.82%	76.92%	4.90%
	Supervisor	79.17%	72.73%	84.62%	11.89%
Employment Verification (I-9, Green card etc.)	Worker	75.00%	72.73%	76.92%	4.20%
	Supervisor	62.50%	54.55%	69.23%	14.69%
Background Check (criminal record)	Worker	41.67%	45.45%	38.46%	6.99%
	Supervisor	37.50%	36.36%	38.46%	2.10%
Reference Checks	Worker	62.50%	54.55%	69.23%	14.69%
	Supervisor	62.50%	54.55%	69.23%	14.69%
Task-Specific Certification/ Credentials	Worker	33.33%	36.36%	30.77%	5.59%
	Supervisor	45.83%	36.36%	53.85%	17.48%

The findings were reviewed and also sorted based on different variables. The only variable that showed any differences was sorting the firms by EMR. Worth of note, experience was ranked high for both worker and supervisor from all firms, however when looking at those with a lower EMR the worker experience was higher but for higher EMR firms the supervisor experience was higher.

When sorting the survey data by age of firm between younger firms and older firms, younger firms all identified Experience Requirements as an important aspect of the hiring process whereas only 58% of the older firms noted experience requirements as important. Younger firms were also more likely to do Employment Verification, Background Checks, and Reference Checks. 58% of the younger firms looked for task-specific credentials of workers while only 8% of the older firms did. The younger companies' hiring practices were clearly different than the older firms. The reasoning for this difference could not be identified with the survey responses and will be explored more during follow-up interviews, but may be explained based on risk mitigations. Younger firms do not have a proven history, so ensuring the hiring of safe workers may have a larger overall impact than older organizations.

Safety Training Programs

All the safety studies discussed the importance of safety training and orientation and its influence on construction safety performance. Hinze, Baud, & Hallowell (2013) considers safety orientation and training as a key practice to improve construction safety performance. Safety training involves the communication of project-specific goals on safety, safety hazards, safe work behavior, and safety policies to ensure all workers and employees know health and safety goals (Hallowell & Gambatese, 2009). Other studies found that safety orientation and training helped workers to identify hazards that reduced injuries and incidents (Wehle, et al., 2013). Additionally, safety training is identified as an essential element for an effective safety program to reduce construction injuries and incidents (Findley et al., 2004).

Table 6 lists the types and frequency of training offered by the respondents.

Table 6: Frequency of Safety Training

Type of Training	***When Hired***	***Beginning of Project***	***Periodic***	***Pre-Task***	***Never***
On-Site Supervisor Training	41.66%	25.00%	58.33%	25.00%	4.16%
PPE Training for Workers	50.00%	29.16%	16.66%	16.66%	8.33%
General Task Training	37.50%	29.16%	20.83%	29.16%	0.00%
Site Specific Safety Training	20.83%	45.83%	16.66%	29.16%	8.33%

When sorting the data by "Age of firm," older firms do more training when hired and pre-task. Sorting by "Growth," those with lower growth performed more training. When the data is sorted by "Volume of Work," 83% of companies with larger volume of work indicated periodic training for on-site supervision, and only 33% of the companies with less volume of work. Overall, companies with larger volume of work indicated utilizing more types of training and offering training more often.

In addition to the type and frequency of safety training, the person responsible for providing the training can impact the effectiveness of the overall training program. Leadership and communication skills have been identified as having an impact on a company's ability to establish a good safety culture (Ringen et al., 2018). 9% identified as using a safety coordinator, 29% of the companies surveyed identified the company owner as the responsible party, 53% identified the project manager or field supervisor, and the remaining company identified an outside consultant. On average, companies indicated that about 9% of the responsible person's time is dedicated to safety (including training and other safety-related activities).

Also related to safety programs was the review of OSHA 10, OSHA 30, and other safety credentials. Only one company indicated an OSHA 10 training as a requirement for workers after being hired and three required it for supervisors and project managers. None of the respondents indicated the requirement for OSHA 30 certification.

Within some firms, third-party resources are available to provide safety advice and guidance to project supervision and the workers. These third-party resources have reference and training materials and consist of written content as well as other forms of multimedia. Some common parties that offer these support training materials are consultants, insurance companies, trade organizations, as well as OSHA. Nearly 50% utilized resources from their insurance company, while less than 25% utilized consultants, trade organizations, or OSHA-developed resources.

Lastly, related to safety practices within an organization was the utilization of a third-party site inspection or safety consultation. Of the options of Beginning of Job, Pre-task, Periodic/As-Needed, and Never, 30% of the companies indicated "Periodic/As-Needed" and the remaining firms indicated never.

Incentive Programs

Safety incentive programs are often used for correcting worker behavior and reducing incidents and injuries. These are especially useful when connected to organizational policies and programs (Sparer et al., 2015). However, Hinze (2002) noted that there was not always a correlation between companies who had established safety incentive programs and safe work performance. This lack of correlation was also found in the results of the survey. More companies with higher EMRs offered safety incentives than those firms with lower EMRs. Overall there was a lack of incentive programs used, with the most common being tied to raises (21%) and on-site celebrations for the project team after a successfully safe project (16%). Only two (2) companies offered monetary bonuses or gift cards as rewards for safety incentive programs.

Perception of Safety

The respondents were asked a group of questions about their views of safety and its importance in different aspects of the industry. Perception of safety and safe practices helps to indicate the safety climate of a company (Mohamed, 2003). The results were sorted based on various demographic variables. The results based on the safety of the company, age of the company, and company volume are included in the analysis.

Safety's Influence on Company Performance

Likert scale questions were used to document respondent perception of safety's influence on Company Performance. As shown in Figure 2, the highest importance was listed as Company Reputation, followed by Profitability and Worker Productivity, which were equally ranked. Worker motivation was the lowest, with a rating of 3.7. Profitability was the only factor that did not receive a rating of 1, or "Does not Influence".

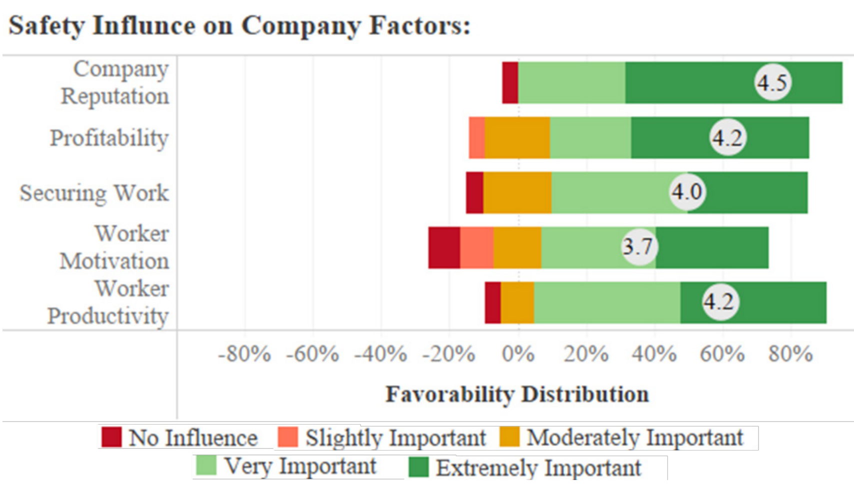

Figure 2: Perception of Safety Influence on Company Factors

When looking at how firms perceived the influence of safety based on safety performance, Lower EMR firms rated all aspects higher than Higher EMR firms except for profitability (Fig. 3). The largest difference was with "Worker Motivation".

Older firms also indicated a significant increase in the effect of safety on company reputation and profitability and to a lesser extent on worker productivity (Fig. 4).

Larger firms had a slightly less positive view of the influence of the identified factors when compared to smaller firms. The larger difference is the effect of safety on worker motivation where smaller firms indicated a 4.2 and larger firms a 3.2.

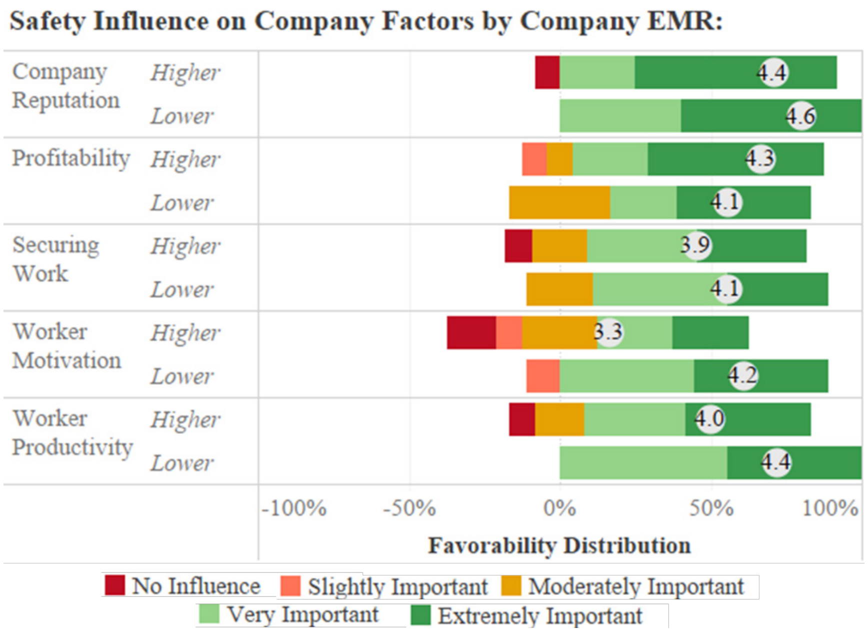

Figure 3: Perception of Safety Influence on Company Factors based on Company EMR

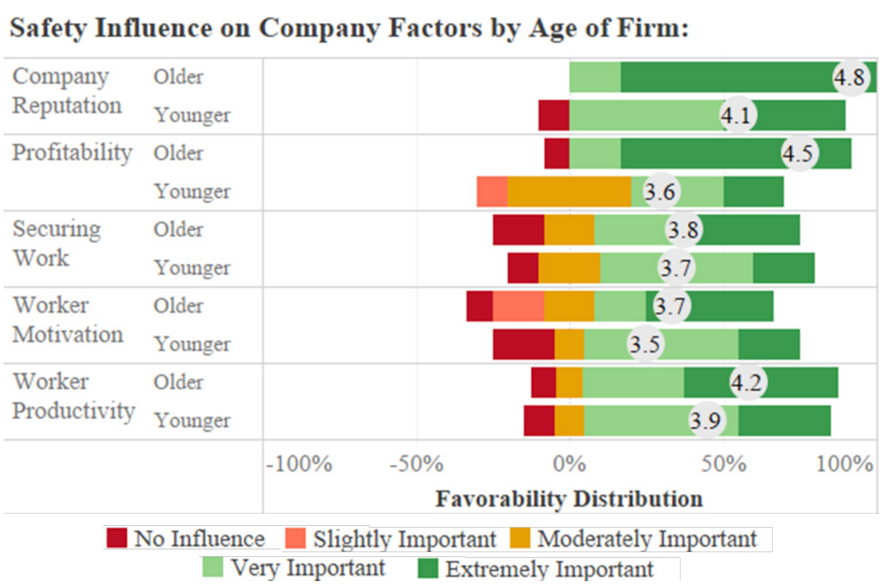

Figure 4: Perception on Safety Influence on Company Factors by Age of Firm

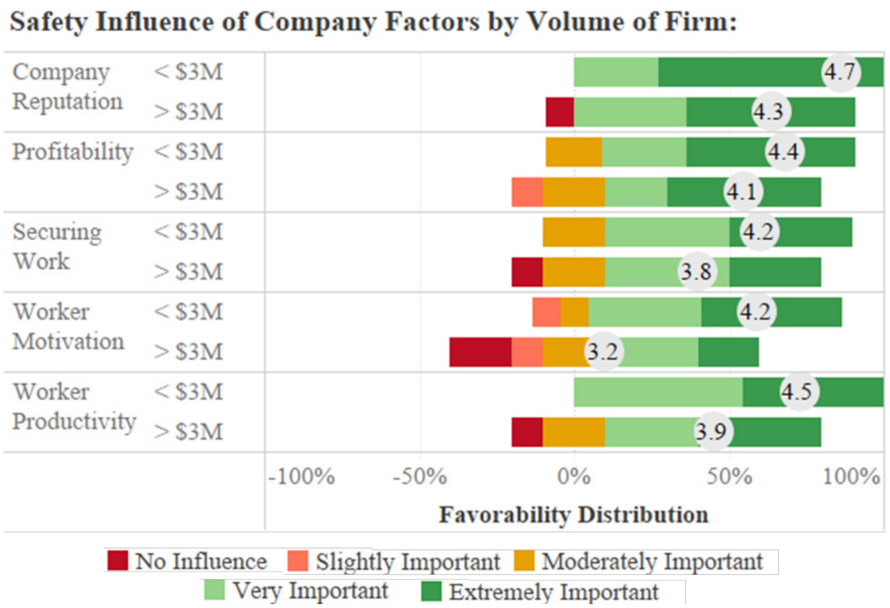

Figure 5: Perception of Safety Influence on Company Factors by Size of Firm

Factors for Selecting Subcontractors

The respondents were asked a group of questions as to what influences their selection of subcontractors (Fig. 6). The factors included: Bond Capacity, EMR, Financial Stability, References, and Work Experience. Bond Capacity and EMR were extremely low on their importance and influence when choosing a subcontractor, with 1.9 and 2.3 out of 5 mean ratings. Work experience was the highest rated with a 4.5. In addition, there were no ratings for work experience in the “Does not Influence” or “Slightly Influence” choices.

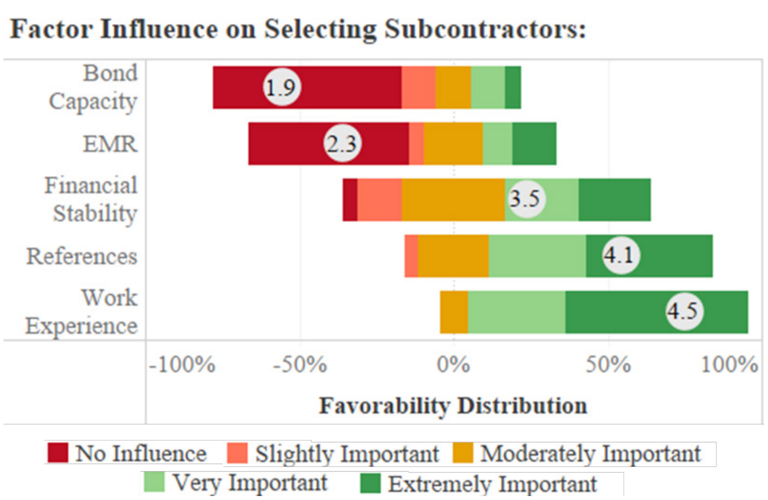

Figure 6: Factors for Selecting Subcontractors

When looking at separated responses based on the EMR of a company, those firms with a higher EMR (less safe) have a more negative outlook in terms of the influence of a subcontractor’s bonding capacity and EMR rating than those with a lower EMR Figure 6.

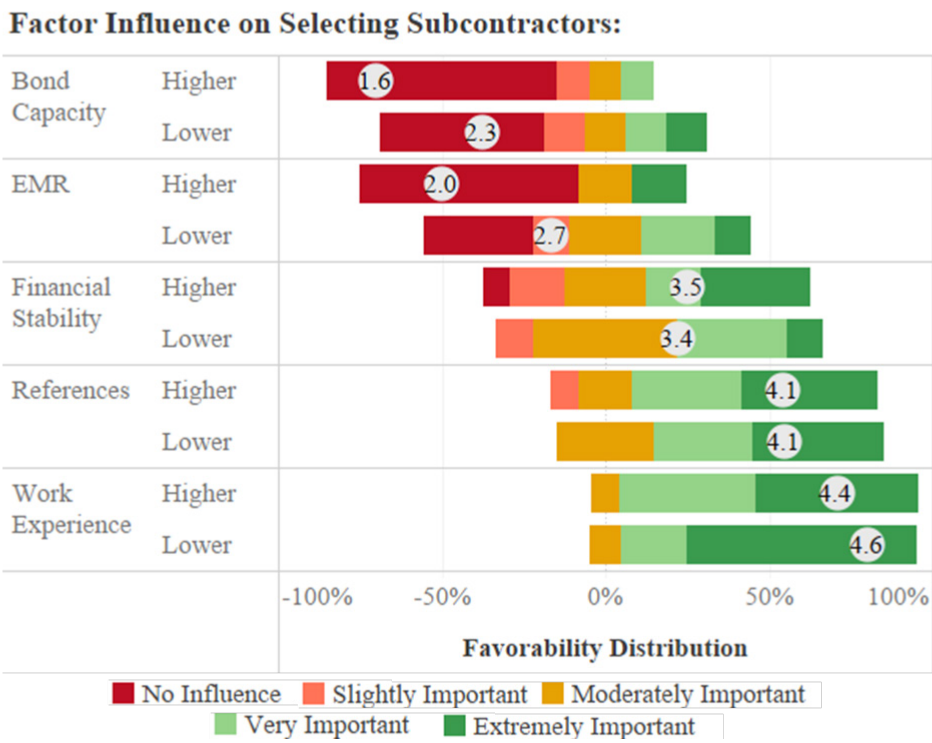

Figure 7: Factors for Selecting Subcontractor by Company Safety Record

When grouping the firms by volume were no significant differences. However, when reviewing the factors based on company age, younger firms indicated all factors were more significant in their selecting subcontractors than firms that have been around for a longer period of time (Fig. 8).

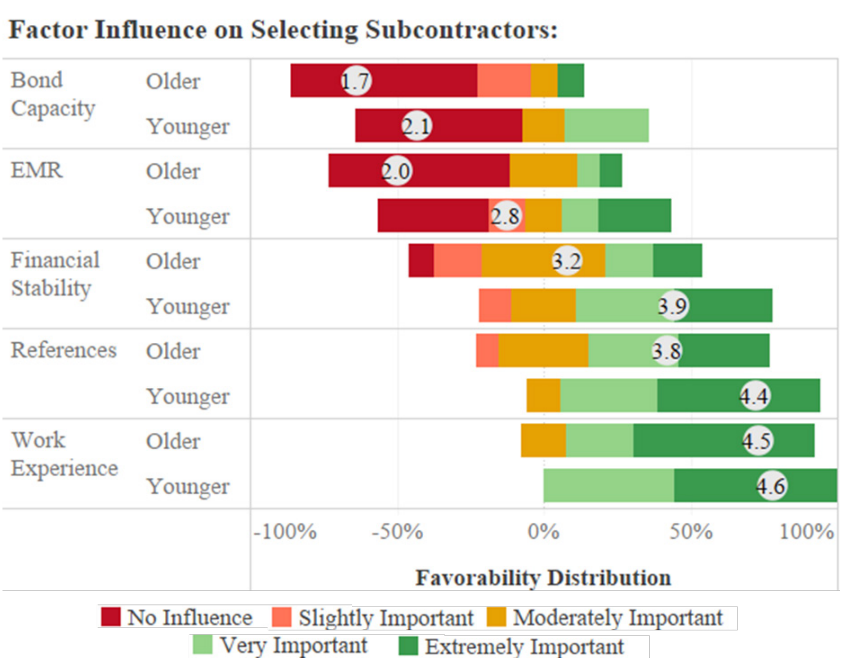

Figure 8: Selecting Subcontractors Separated by Age of Firm

Worker Safety Performance

The final part of the survey asked firms about how various aspects of an employee's job are influenced by the worker's individual safety record. Overall, on average, all factors were rated as moderately important or no influence (Fig. 9).

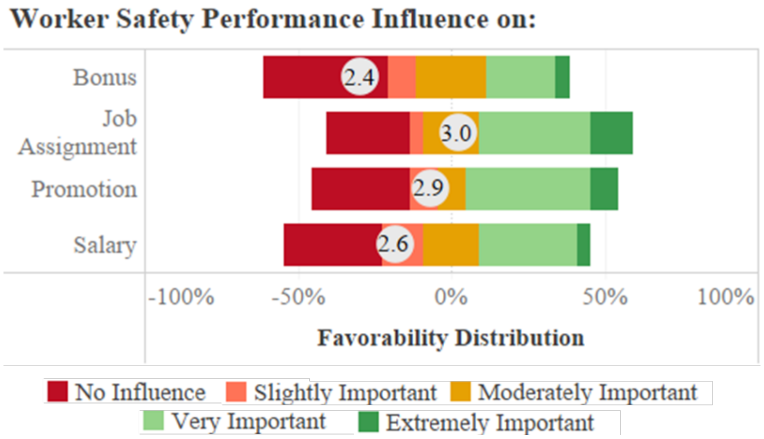

Figure 9: Worker Safety Influence

When looking at what the worker's safety performance influenced based on the safety of the company, those companies with a lower EMR indicated less influence of the worker's safety on assigning a bonus, promotion, and salary and considered job assignment to be about the same level of influence as the companies with a higher EMR (Fig. 10).

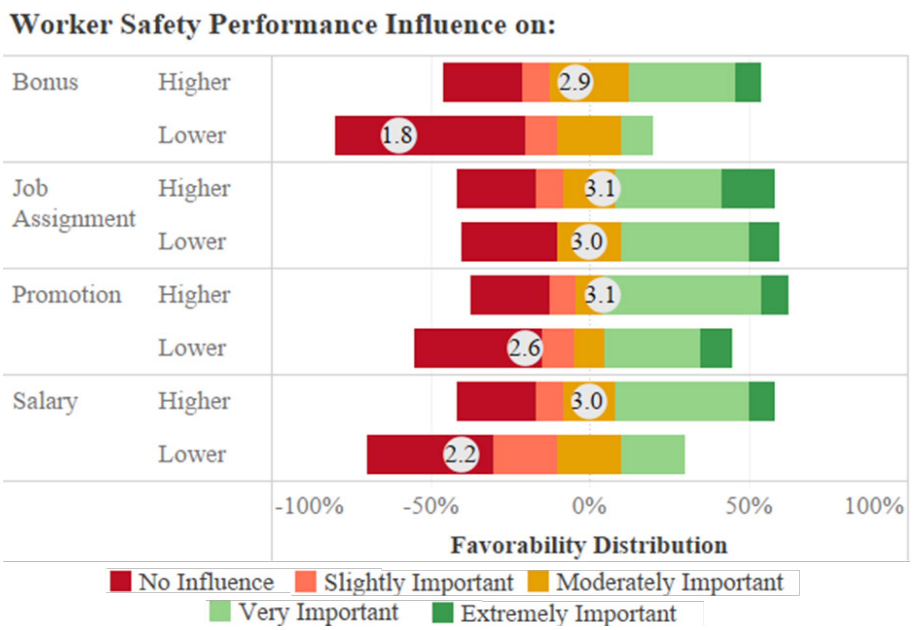

Figure 10: Worker Safety Influence against Company Safety

The disparity between firms when sorted by volume is more noticeable (Figure 11). Smaller rated all aspects as less important than larger firms.

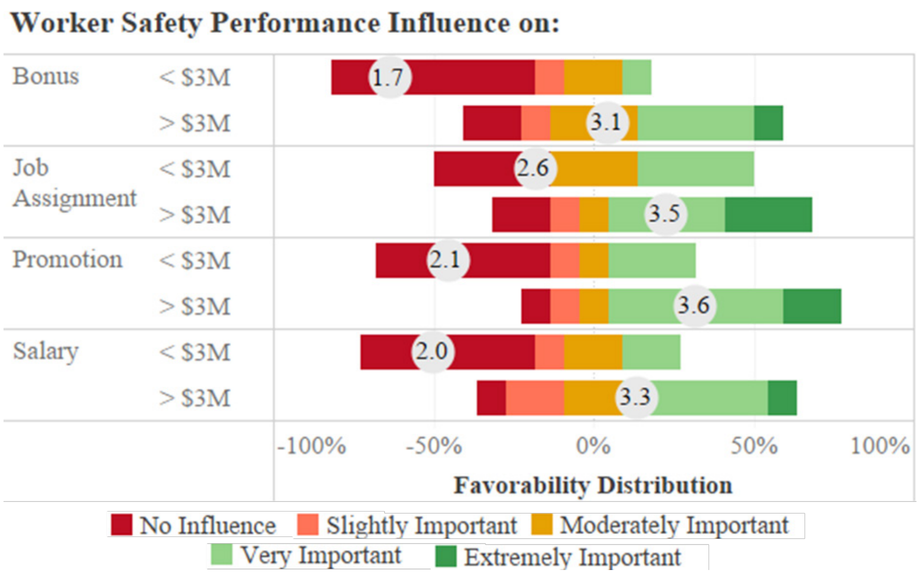

Figure 11: Worker Safety Influence against Company Size

There was no correlation when looking at the size of the firm and the age of the firm so data was again examined by looking at the age of the firm. The younger firms identified that individual worker safety had more of an influence on Bonus, Job Assignment, Promotion, and Salary of that worker. Whereas, older forms did not take the worker's safety into consideration when looking at these areas (Fig. 12).

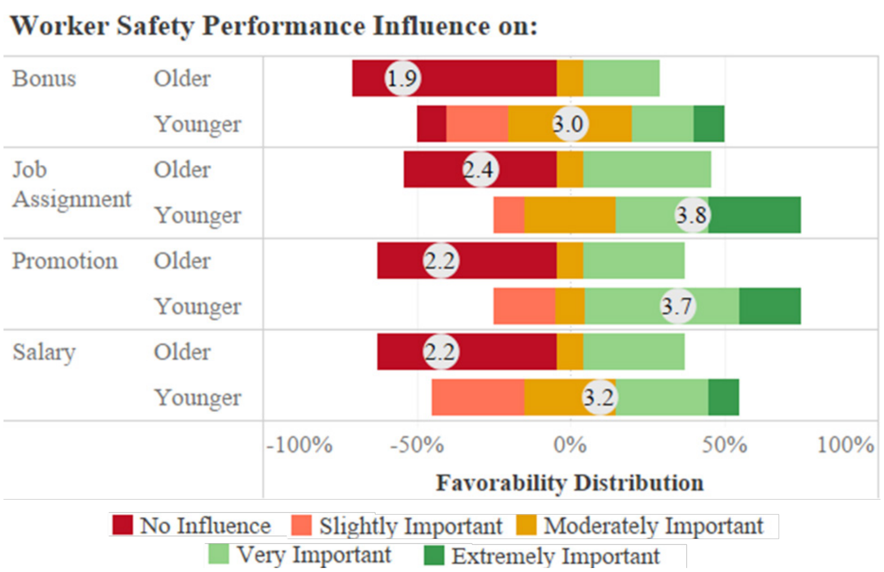

Figure 12: Worker Safety Influence against Age of Firm

Results

As noted earlier in the literature, safety resources and provisions for safety equipment enhanced the site personnel's ability to manage safety issues, equipment assessment, and protection leading to a reduction in injuries and incidents (Mohammadi et al., 2018). Several studies have concluded that the presence of safety personnel on-site helped manage safety issues and reduce injuries and accidents. (Hallowell & Calhoun, 2011) In their study found that a safety manager on site is one of the most central elements of an effective safety program, and (Esmaeili & Hallowell, 2012) claimed that the employment of a safety manager was one of the commonly adopted safety initiatives. Due to the size of the type of firms participating in this research, it is likely that participating companies would have an employee functioning in multiple roles, including that of a safety coordinator because of limited resources to have one safety manager on site. It was not surprising to find very few safety coordinators listed as responsible for safety due to the size of the firms. According to the survey, companies with better EMRs utilize OSHA support resources more. Whereas companies with poorer safety performance utilize insurance company resources more. When sorting companies by Volume of Work, companies who perform a larger volume of work took advantage of more support resources.

Another area that very few firms took advantage of is the recording and evaluation of safety incident information beyond what was required by OSHA and insurance companies if a safety event happened. Mohammadi et al. (2018) discuss that a company's size and financial growth factor into their ability to realize the value of accident investigation and inspection as drivers for improved safety performance. This can explain why only the largest companies noted any type of use of safety investigation data. Interestingly, companies that identified more "Growth" over the last 5 years had also tracked more data related to safety than those who were more stagnant in size. Those that have more than 10% growth over the last 5 years compared to those with less than 10% of growth reported tracking reportable accidents 84.6% to 54.5%. Companies with higher growth also tracked days away from work at a rate (53.8% to 18.2%, restricted work requirements (23.0% to 18.2%), and costs associated with accidents (23.1% to 18.2% for direct costs and 23.1% to 9.1% for indirect costs of accidents).

The use of safety incentives was relatively low across the board. The use of incentives was slightly higher when looking at the company safety record. Those with a higher EMR used incentives more. This could be reactionary as a motivation to help improve safety performance as Mohammadi et al. (2018) suggested that an effective incentive program was found to improve construction safety performance by rewarding appropriate safety behavior. Yet, safety programs can also be viewed as controversial since safety should be the morally right thing to do as part of the worker's job (Gambatese & Hinze, 2003). Overall, the survey aligns with the findings of Hinze (2002) where companies with a poorer record on safety were more likely to have an incentive program. Commonly in larger industry sectors the promotion, bonuses, and raises of job site supervisors are directly tied to measures of safety on the jobsite. This study showed that this is not happening in the residential carpentry sector of the industry. By tying promotions and bonuses to jobsite safety performance and jobsite safety practices (ex: workers participating in training, use of procedures checklist, etc.) it may help create a more positive safety culture and support better safety performance.

Site-specific safety orientation for all employees has also been documented as beneficial to overall company safety performance (Hinze et al., 2013). Ensuring that the training is project-specific helps to support better safety performance as workers are aware of current risks on site (Esmaeili and Hallowell, 2012; Findley et al., 2004). There was a slightly higher rate of job-site specific safety training in the lower EMR group indicated at the beginning of the job and a significant increase of job-site specific safety training "pre-task". This suggests that only job-site safety analysis and training are integrated into the work processes for starting a job but are reviewed periodically throughout the job as site conditions and hazards change.

An area needing further investigation is within the hiring practices. Follow-up interviews with respondents will be used to further explore what companies are looking for in terms of workers, specifics on training types, and how involved higher-end leadership is with safety training and hiring. Another area that was difficult to explore in a mostly quantitative survey is the extent a safety program is written, formalized, and developed. This will be examined further as well.

Limitations

Because of the focus on one type of work, the number of potential respondents was limited, and future research would need to repeat the study with other groups to check the generalizability of the findings outside of small residential carpentry firms.

One limitation of the research is the response group size when dividing it into groups based on safety performance. Because of the limited responses, breaking them into groups limited the types of statistical analysis that could be performed with any level of confidence. This did not limit the value of the data collected or the trends that were otherwise identified through descriptive analysis.

Another limitation is the use of EMR as an indicator of safety. EMR was considered the best indicator for safety based on the quantitative nature of how it is calculated. However, as Jazayeri and Dadi (2017) have identified, a firm's size can greatly influence the EMR because the value is heavily counted on the frequency of injury and not the severity of the injury. Some of the companies may have several smaller incidents that influence the calculation of the EMR in a smaller company that otherwise would not be seen in a larger company that had fewer but more significant claims.

An alternative method for sorting safety performance could have been examining the number of claims over a period of time. Claims data and workers' compensation premiums were examined as potential metrics of safety performance with insurance industry partners. This was limited since those firms that were a higher risk with significant claims data would typically be dropped from coverage. Also, claims could be registered against a company's policy when someone else was at fault. In this case, the claim could eventually be covered by the responsible party's policy but be contraindicative of poor safety performance. Additionally, workers' compensation premiums are highly influenced by the EMR of the company and the type of work being performed. Since the companies perform the same type of work, the indicator of workers' compensation premiums as a measure of safety showed no noticeable difference than just using the EMR.

Another limitation of utilizing EMR is that it is a lagging indicator of safety performance. EMR is calculated by looking at data from the first three years of the past five years. Therefore, significant changes in personnel and company policy can potentially take place to drastically improve a company's actual safety performance, but the EMR would still indicate a less safe company. Consequently, the reverse is also possible where the EMR would indicate a safer firm even if, in the most recent two years of work, the firm exhibited a growing history of claims and accidents. The change in safety performance would not be fully reflected by the EMR in real-time and the EMR would suggest the firm is safer than their most recent performance is.

Despite the noted limitations of utilizing EMR, it was the most appropriate quantitative indicator of safety available. Other qualitative means that require exploring the safety history of firms in more depth could help identify characteristics based on the literature of a safe firm. Some of these characteristics will be explored by discussing the history of a firm's safety performance in the next phase of the research. The use of these qualitative means would require a subjective ranking and not necessarily be transferable from literature due to the nature of work and size of firms participating in this study versus those in the literature. The hope of using a quantitative measure was to provide a direct delineation of safety performance.

Conclusions

This study examined the key drivers related to improving company-level safety performance in small residential carpentry firms. Two objectives were targeted as part of this study. The first was to benchmark the findings of this effort against previous research that was conducted related to the safety culture and safety practices of larger construction firms. Due to the difference in resources available and methods for managing different-size firms, it is possible that certain policies and programs used by larger firms that have shown an increased improvement in safety performance might not be as effective for smaller firms. Additionally, the intent was to isolate key best practices for small residential carpentry firms that can be linked to improved safety performance.

An in-depth literature review was performed that isolated eleven (11) key drivers related to improving the safety culture and climate of a company. These key drivers consisted of multiple related factors that were then categorized as either company-level, project-level, or worker-level factors. The company-level factors were then used as a basis for the next steps of the research. The survey was used to gather higher-level data and the interviews were conducted to clarify details of practices as indicated in the survey.

For purposes of comparative analysis, the EMR was utilized as a quantitative measure of safety performance at the company level. Though this measure may be a lagging indicator and some argue it is not the best indicator of a company's safety for smaller firms, it was the most appropriate quantitative measure available. Additionally, practices were benchmarked by the size of the firm by volume of work completed annually, and the age of the firm.

The findings of this research are utilized in the next phase of the research, where interviews are conducted to develop specific case studies of safety practices within smaller carpentry companies. Topics that could not be fully understood within the quantitative analysis will be explored. Ultimately, this future stage of research. Additionally, future research would include expanding the study area to identify if the findings are consistent throughout the country as well as other classes of work.

Acknowledgments

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Appendix A: Reviewed Studies

Study Reference	Context of Study
Hinze, et.al (2013)	Lists construction-safety strategies implemented by industry-leading companies.
Mohammadi et. al (2018)	Reviews and extracts the factors of safety performance on construction projects.
Guo & Yiu (2016)	Developing leading safety indicators for the construction industry.
Swacha et.al (1999)	Discusses factors that influence safety on construction sites.
Gambatese & Hinze (2003)	Identified factors that influence the safety performance of specialty contractors.
Hallowell & Calhoun (2011)	Quantifies the interrelationships of implemented injury prevention strategies.
Wehle, et. al (2013)	Defines elements of safety management process for the construction phase.
Findley, et.al (2004)	Identified commonly used safety programs, plans, and process.
Cheng, et.al (2015)	Tests the effects of safety management practices on project performance.
Hallowell & Gambatese (2009)	Studies the relative effectiveness of safety program elements by quantifying their individual ability to mitigate construction safety and health risks.
Russell, et.al (1996)	Provides construction safety performance improvement through analysis of numerical profiles of companies and projects.
Choudhry, et.al (2008)	An exploratory study of site safety management in construction sites' environment.
Hallowell (2011)	Utilizes a risk-based framework to identify the incremental return on investment of a series of investments in highly effective injury prevention strategies.
Hallowell (2010)	Examines the cost of safety funding of safety programs.
Esmaeili & Hallowell (2012)	Examines the adoption highly effective safety innovations in the construction.
Karakhan, et.al (2018)	Decision-making framework to evaluate the safety maturity of contractors.
Cheng, et.al (2012)	Rates the level of importance of 15 safety management practices and criteria.
Rajendran & Gambatese (2009)	Examines the use of sustainable construction safety and health rating system for projects based on the importance and implementation of safety and health elements.
Feng (2013)	Examines effects of contractors' safety investment on safety performance.
Guo, et.al (2015)	Explores the dynamic complexity of construction safety management.
Sparer, et.al (2015)	Develops a leading-indicator-based safety program to incentivize safe work.
Hinze (2002)	Reports on the result of a study in which information is obtained on incentives.
Feng, et.al (2014)	Explores the interactive effects of safety investments, culture, and project hazard.
Feng, et.al (2015)	Investigates workplace accident costs and factors influencing workplace accident.
Feng (2015)	Investigates the minimum voluntary safety investment for projects in construction.
Han, et.al (2014)	Examines how production pressure relates to safety performance.
Frazier, et.al (2013)	Determine the core factors that make up a safety culture.
Choudhry, et.al (2007)	Presents a robust conceptual model analyze construction safety culture.
Newaz, et.al (2018)	Proposes a five-factor model to diagnose and measure safety climate.
Fang & Wu (2013)	Aims to propose a safety culture interaction model demonstrating of safety culture.
Choudhry, et.al (2009)	Determines factors that positively impact perceived safety performance.
Jin & Chen (2013)	Examined a multilevel safety culture and climate to assess a safety programs.
Rowlinson, et.al (2016)	Systematic review of studies on safety climate and culture measures.
Mohamed (2003)	Promotes adopting the balanced scorecard tool to benchmark organizational safety.
Feng, et.al (2018)	Discusses the concept of resilient safety culture and how it is applied.
Wu, et.al (2017)	Examines supervisor behaviors impact on safety climate and workers' performance.
Bigelow et.al (2012)	Investigates the measures of safety culture and risk perception.
Marks, et.al (2014)	Identifies best practices associated with near-miss reporting.
Chi, et.al (2013)	Explores the relationships between behavior and working condition and how these factors impact accidents and injuries in construction.

Using Takt Time to Increase Scheduling Reliability: A Case Study

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ABSTRACT

Increasing reliability of construction planning is key to reduce schedule delays and improve project performances. While construction practitioners have attempted to increase the reliability, major focus has been on the development of tools. Last Planner System, a technique of Lean Construction has been found to improve the work flow reliability in the construction projects. A case study was conducted on a healthcare project to examine the effect of Takt time planning in conjunction with Last Planner System on the planning reliability. Reliability of the planning process was measured through four metrics. The metrics demonstrated an alignment of long-term planning with the short-term planning for the case study project. Additionally, the metrics indicated focus on critical tasks, collaboration among the core group members, and creation of sound assignment that contributed to the increased reliability of the planning process. While maintaining the reliability of the planning required strict adherence to the implementation of Last Planner System and Takt time planning, the members showed improved understanding of the process even with increasing number of tasks and complexity of the project. This paper represents a case-study aimed at investigating the impact of TTP on the reliability of construction schedules.

Keywords: construction planning, planning reliability, takt time planning, lean construction

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INTRODUCTION

No matter how small or large the project, schedule is a major tool for construction planning and has major impact on the outcome of any project. The schedule is used to plan and manage different aspects of the project, such as adjusting labor requirement at various stages, identifying equipment need and managing material deliveries, estimating time needed to complete various tasks – all of which have profound effect on the success of any project. Due to its effect on the outcome of any project, efforts have been expended towards improvement of the planning process and development of scheduling tools. However, the major focus has been on developing scheduling tools rather than advancing the theoretical issues promoting the planning process (Gardarsson et al. 2019, Laufer et al. 1994). This result in poor management of the projects and unsatisfactory outcomes (Frandson, 2019; Koskela, 2000).

Planning and scheduling of construction projects depend on a variety of factors and involves managing the inherent variability of the projects. The variabilities can be in the form of varying labor production rates, inconsistent deliveries if materials, and others resulting in schedule delays. In simple terms, delay means the inability of the project team to complete a project within the planned duration (as agreed in the contract). Delays in construction projects have become common occurrences across the world, irrespective of the complexity of the projects. These are always counter profitable for all the parties involved and may result in clash, claims, and litigations. According to a study conducted by Beaty et al. (2016), even small projects can incur costs of almost $100,000 per month due to delays in schedule. Delays in construction projects suggest that the schedules lack reliability. Theoretically, ‘reliability’ can be defined as the probability of success. In context of construction planning and scheduling, reliability is defined as the execution of the activities occurring as planned. One reason traditional construction planning and scheduling struggle being reliable as they do not embrace the dynamic and interdependent nature of the construction activities and assume them as static (Gardarsson et al. 2019, Tommelein et al. 1999). To overcome this issue, Lean construction proposes the use of the Last Planner System (LPS), which is a Lean based production planning and control system.

LPS for planning and project controls within the paradigm of Lean Construction has been found to improve the reliability of the planning process at the operational level by aligning the resources available to the need of the participants. This is done by a collaborative process in LPS where overall project scope that should be accomplished is broken down into specific tasks that will be executed with identifying and eliminating constraints for a steady workflow thus increasing the reliability of the planning process. Ballard and Howell (1998) proposed measuring the reliability of the planning by comparing the variation at a weekly level. They proposed that, through LPS, right amount of work should be performed in the correct sequence, and that only work that can be executed is committed. Right amount of work is defined based on the resource available to the participants and the need of the schedule. LPS focuses on increasing the reliability of the planning process by reducing the variation in the workflow though collaborative planning, creating sound assignments, tracking commitments, and continuous learning process. Creating sound assignments in LPS involves gathering information on production rates of the crews and utilizing them in the planning process. However, hiring trade contractors who are non-collaborative and are not well versed with LPS process can be a challenge to achieve planning reliability (Maturana et al. 2007). To improve the reliability of construction planning and scheduling, this paper proposes the use of Takt Time Planning (TTP) in addition to LPS. From the German word for ‘beat’ or ‘rhythm,’ the ‘Takt’ time is the rhythm/beat that sets the pace of production. While LPS focuses on increasing the reliability of the planning process by creating sound assignments, TTP can facilitate continuous flow by matching the assignments with production rates of the crews. Using estimated labor production rates in place of intuition and matching the size of assignment for continuous and steady production increase the reliability of the schedule. Using TTP can be the next level of improvement to LPS to increase the reliability of construction schedule.

TTP is a fairly new concept in the realm of construction planning and scheduling. Only a handful of studies have been conducted till date outlining the process of TTP (Frandson et al. 2013) and capturing anecdotal evidences of the benefits from using TTP (Linnik et al. 2013, Frandson and Tommelein, 2014). The study presented in this paper is the first case-study based research to explore the effect of TTP on reliability of construction schedule. This paper presents detailed documentation of the use of TTP in a healthcare project and exploring its effect on the reliability of the planning process thus contributing to the body of knowledge of construction management. The case-study design is ideal for this research to capture the qualitative information in addition to quantitative data. In this paper, four metrics have been used to measure reliability of the planning process: (i) Commitment Level (CL), (ii) Percent Planned Complete (PPC), (iii) Percent Required Complete or Ongoing (PRCO), and (iv) Percent Planned Complete of Ongoing (PPCO). The metrics are discussed in detail within the case study. Analyses showed alignment of long-term planning with short-term planning by adhering to TTP. Additionally, focus on critical tasks to meet target milestones, collaborating to create sound assignments, and being able to keep commitments facilitated to increase the reliability of the planning process.

Background of Takt Time Planning

Takt time can be simply defined as “a design parameter used in production settings, be it manufacturing or construction, tuning the rate of work output to the customer’s rate of demand” (Frandson and Tommelein, 2014). It is the calculated time within which a product (or parts of a product) must be produced to meet the rate at which the product (or the parts) is needed. Takt time became a topic for interest in both manufacturing and construction industry, as a design parameter used in production settings, controlling the rate of work output to the rate of customers’ demand. The concept of pacing activities to meet end demand is not new in construction. Similar concept of using four activities (steel erection, concrete flooring, exterior metal trim, and exterior lime stone) as ‘pacemakers’ were used in the construction of the Empire State Building (Willis and Friedman, 1998). Balancing the labor production for continuous utilization using line of balance has been done in horizontal construction (pavement) is another (Arditi and Albulak 1986, Seppanen and Aalto 2005, Kemmer et al. 2008). The US homebuilding industry has been using the ‘even flow production,’ which is a demand management technique to facilitate continuous utilization of resources and reduce lead times (Bashford et al. 2004, Yu et al. 2009). While the concept has been in existence, TTP in construction is fairly new and only appearing recently with homebuilding in the United States (Wardell 2003 and Velarde et al. 2009) and highway construction in Ecuador (Fiallo and Howell 2012). Typically, TTP is limited to repetitive projects such as highways, pipe-line installation, high rise building, or, single family homes; however, Linnik et al. (2013) and Frandson et al. (2013) described the use of TTP in the planning of non-repetitive works at a healthcare project in California. While Linnik et al. (2013) documented the benefits of using TTP in exterior framing, Frandson et al. (2013) captured the benefits of using TTP in the exterior cladding installation process that was reduced to half of the original duration. Linnik et al. (2013), in their case study observed improved commitment level at the lookahead stage that facilitated deliveries to site with less risk of increasing on-site inventories. Improvement in labor and equipment productivity was noticed when TTP was applied to the homebuilding industry in Brazil (Mariz et al. 2013).

TTP can be combined with LPS to achieve time saving, money saving, and quality improvement (Frandson and Tommelein, 2014). Frandson et al. (2013) defined a six steps process for the implementation of TTP that comprised of: (1) gathering information of productivity and quantity, (2) defining work areas or spaces, (3) understanding the sequence of the activities (flow), (4) understanding the duration of individual activities, (5) balancing the workflow, and (6) creating the production plan. The implementation of TTP is not a simple conversion of the above steps, but rather an iterative and collaborative process. The planner must be involved in exchanges with the various trade contractors to extract information related to preferred sequence, desired workflow, durations, production rate, etc. The planner should be aware of any assumptions made by the trade contractors in their initial planning and possible alternatives to how each trade can perform their work.

Ballard (2003) first mentioned the use of TTP in a precast concrete fabrication shop, showing that productivity was improved by more than double in the plant while Takt time scheduling and control were used. Since then, a handful of case studies have described the implementation process of TTP while highlighting the critical role played by the collaboration between the contractor and the trade contractors in optimizing the project's Takt time (Linnik et al. 2013, Frandson et al. 2013). Instances of using TTP in conjunction with the LPS was found in the case study conducted by Frandson and Tommelein (2014). Benefits of TTP identified by the researchers were providing clear daily goals of activities, increasing the productivity and solving problems promptly. Overall, the case study concludes that balancing and managing the production of all trades by assigning work spaces on a short interval, though challenging, offered overall benefit to the project. A separate study conducted by Frandson et al. (2013) demonstrated how TTP improved the last planner's abilities to reduce variability.

In the LPS, the first level of planning to develop the master schedule (to identify the project milestones) is the broadest. As shown below in Figure 1, each subsequent level goes into greater detail. Once the milestones are identified, the planning team is then tasked with turning this work that 'should' be done into work the 'can' be done through the look-ahead planning. Work that 'can' be done is dependent upon the completion of the preexisting conditions. Koskela (1999) identified seven pre-conditions for successful completion of any construction activity: (1) design, (2) components, (3) materials, (4) workers, (5) space, (6) connecting work, and (7) external conditions. These seven pre-conditions are the constraints the planning team must consider when identifying work that 'can' be done. Once this work is analyzed and designated as 'can' be done, each trade contractor will review the assignment and provide commitments to finishing the work in the allotted time. This work then becomes 'will' do (Figure 1). According to Frandson et al. (2014), sound assignments should be well defined, properly sized based on production rates and resource availability, sequenced based on lookahead planning, and informed by lessons learned. As depicted in Figure 1, LPS through collaborative planning identifies what work 'should' and 'can' be done, then tracks the commitments for what 'will' be done and what 'was' done (did).

TTP with LPS (LPS was used in the case study project to develop the master schedule and phase schedule) seeks to stabilize the planning process through a predictable rhythm, which meets the schedule demand. Description of the planning process adopted in the case study will explain the use of TTP to facilitate the lookahead planning process by clearly communicating the task dependencies, task durations, spaces of tasks, constraints, and commitments of the trade contractors.

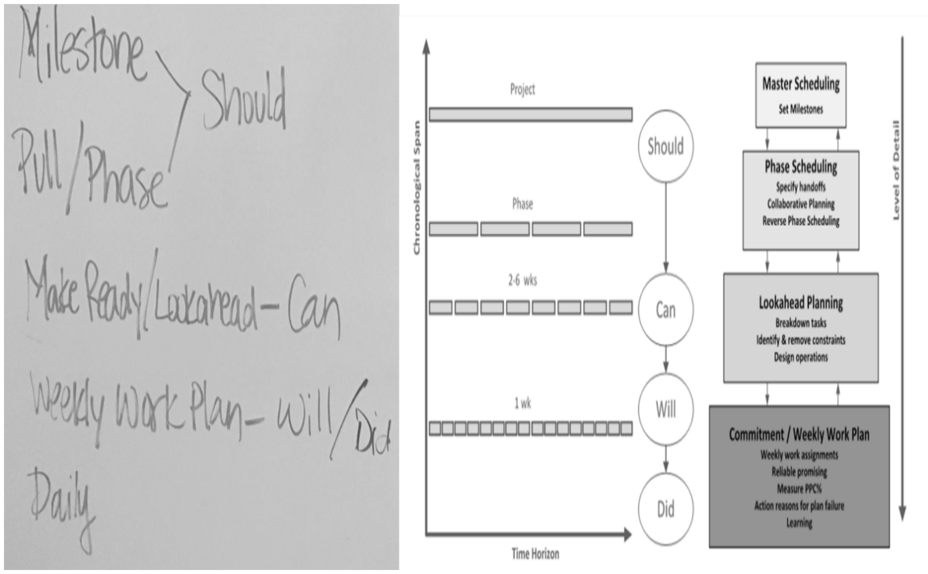


Figure 1: Overview of the Last Planner System® (Ballard 2000)

CASE STUDY

To explore the effect of TTP on construction schedule reliability, this paper aims to capture empirical evidence in the context of planning and scheduling for a healthcare project. It aims to address the following key questions: (i) How was TTP implemented in the project? (ii) Did implementation of TTP increase the reliability of the schedule? Case study research method was deemed as the most suitable approach to answer the question (Yin, 2009). While surveys and interviews would have elicited responses from large number of respondents, they would not have resulted in detailed understanding of the TTP process as in this in-depth single case study. Thus, an in-depth single case study was preferred in place of multiple case studies. Moreover, no other method would have enabled the study of the TTP implementation process and extract quantitative data from the schedules for a prolonged period.

The selection of the case study project was done from the first author's network of industry contacts based on convenience of data collection. The project was an addition to an existing healthcare facility in the Mountain States Region of the US. The addition involved a new four-story building with 168,000 SF for approximately 71 million USD to be structurally tied to the existing building. Concrete foundation with precast service blocks and structural steel structure were selected for the new building. The building skin was comprised of brick, stucco, metal panels, and curtain walls. The new addition had four floors: the first floor being the emergency department with emergency rooms, the second floor housed few operation theatres and shell space, the third floor was the Neonatal Intensive Care Unit (NICU), and the fourth floor was planned for utilities.

Data about the planning process of the cases study project was collected through attending the pull planning sessions, interviewing the superintendent and project manager, and review of project documents. The authors did the data triangulation (collecting data from multiple sources) to enhance the rigor of the case study and establish validity of the data. The plan for the case study project was to have a phased occupancy of the NICU in the new building, renovate the NICU of the existing facility, and subsequently occupy both the NICUs. This required the planning team to adopt a top down approach. The NICU would be completed with interior rough-in and finishes before the first and second floors. The top down sequence allowed the first and second floors to be completed while the hospital moved patients and staff into the new NICU space. This way the NICU in the existing building would be ready for renovation right after the project team had completed the first and second floors of the new building. This strategy was adopted to reduce the baseline schedule (of 22 months) by two months to earn a time incentive as part of the contract.

Description of the Planning Process

Figure 2 below shows the master schedule for the project that was developed as a collaborative effort of the core group members. The core group consisted of the general contractor, designers, owner, and trade partners for the case study project. Compiling and coordinating the inputs of the core group members helped to strategize the overall sequence. The team scrutinized availability of resources, site conditions, and constructability, which eliminated some constraints at the very beginning.

The master schedule helped set the milestones based on a backward calculation from the contractual finish date, and essentially identified the work that 'should' be done. The master schedule at this point was very broad with the timeline marked in months and the durations of the milestones in weeks.

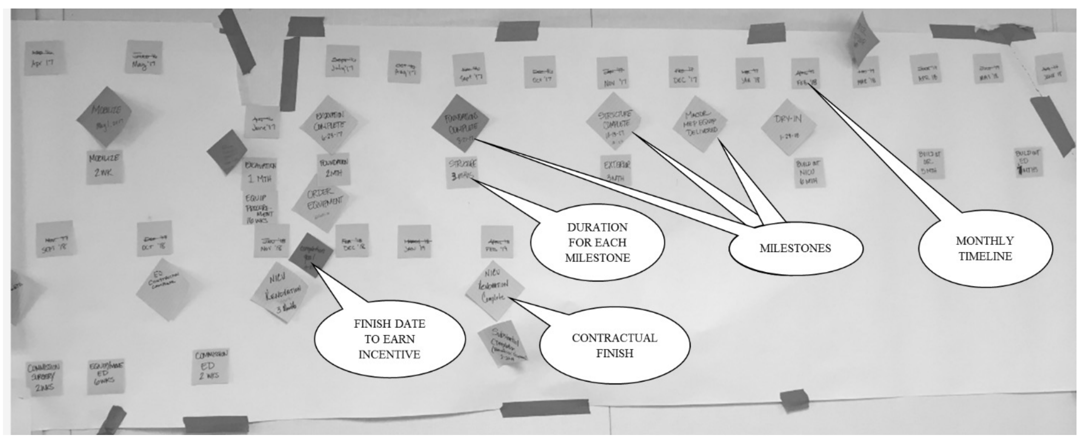


Figure 2 – The master schedule (setting milestones) of the case study project

When compared with the stages of the LPS suggested by Ballard (2000), the project team could follow the recommended steps very closely (Figure 3). While the master schedule and phase schedule identified the tasks that should be done at a broader level, the subsequent steps would break down the master schedule into a lookahead schedule for a shorter window of time (4 weeks) to present more detail. This process again involved the participation of the core group and the foremen of the trade contractors involved. The foremen then communicated what tasks could be done in the next four weeks that were included in the lookahead schedule.

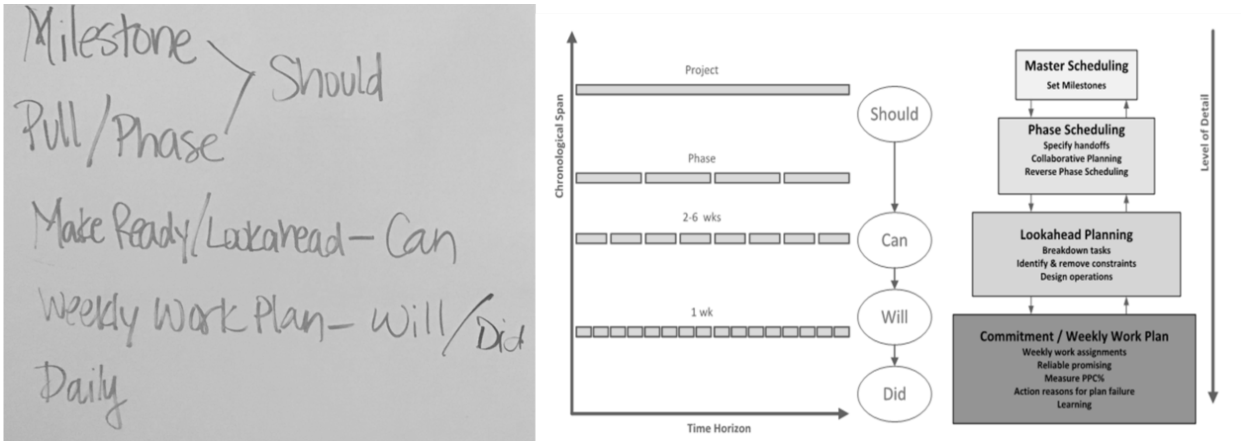


Figure 3 – The LPS process followed by the project team (left) matched that of Ballard (2000) (right)

The schedule for the case study project was prepared and saved on an online server which was accessible by all the members of the core group. Each member had selective editing capabilities of the schedule that restricted their abilities to alter another trades' schedule. An example of a typical lookahead schedule from the case project is shown in Figure 4. The lookahead schedule was divided into distinct swim lanes for different trades (also marked by different colors) for the ease of visualization. With the lookahead schedule meant to scrutinize each task before pulling in based on the milestones in the master schedule, detailed information of the tasks was captured. Figure 3 shows the typical information captured for each task by the core group members such as duration, assigned contractor, person making the commitment, location, and similar. The project team utilized TTP in preparing the lookahead schedule to facilitate continuous workflow for tasks and create a stable production system.

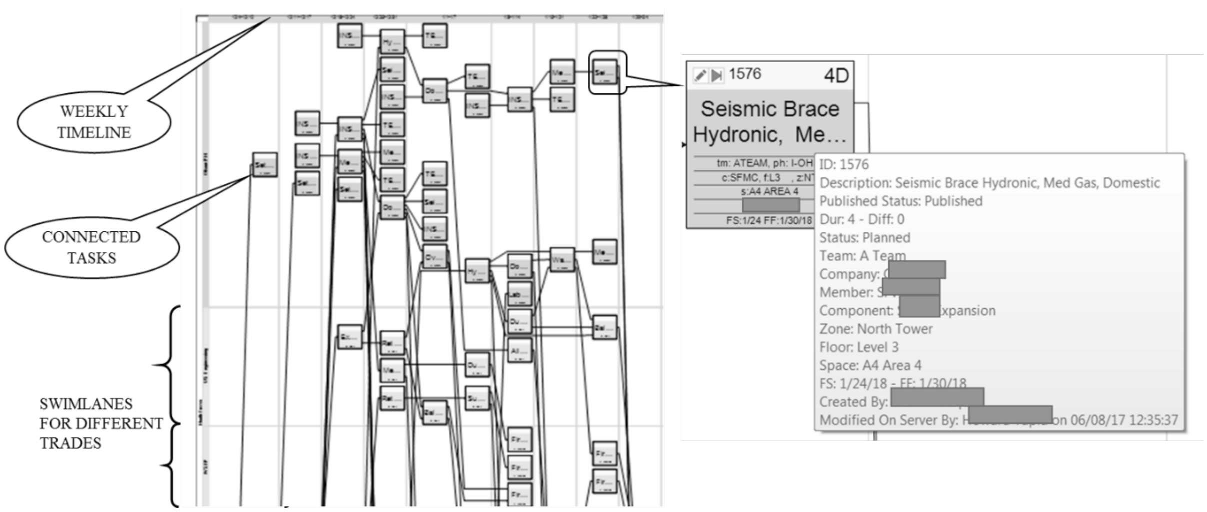
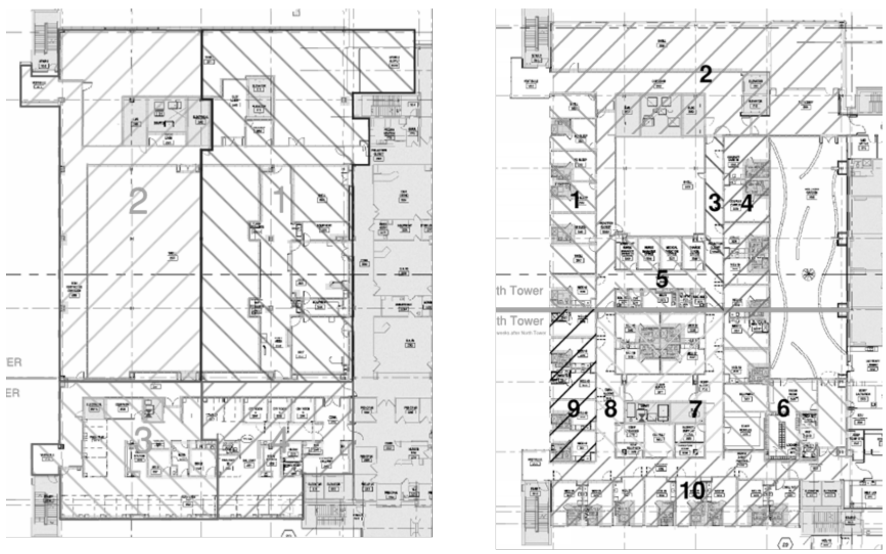


Figure 4 –Lookahead schedule for the interior overhead rough-ins with typical information captured for each task (right)

Use of Takt Time Planning

For the case study project, the sequence of work was faming, mechanical rough-in, electrical rough-in, medical gas rough-in, fire sprinkler rough-in, insulation and fire stopping, drywall, and finishes. The core group divided each floor into multiple spaces based on the amount of work associated with the respective spaces and whether that could be finished in the adopted Takt time for the project. As seen in Figure 5, each floor required a unique space plan, similarly each space within the floor varied by area and shape. Next, information about the crew composition and crew productivity were collected and found that the framing crew need one week to frame the walls for the each of the spaces across all the floors. Adjustments to the spaces were made where needed to maintain the takt time of one week by the framers. The other trade contractors adjusted their crew to match the takt time of one week so that they can follow the framers in all the spaces. Moreover, four-days work-week was adopted for the project, which gave an extra day every week to be used as makeup day if needed.



Floor 2 Floor 3

Figure 5 – Spaces for creating the schedule for the interior overhead rough-ins

Next, the core group completed the 'task make ready' exercise to pull tasks from the lookahead schedule over to the weekly work plan. Constraint analyses of the tasks appearing on the lookahead schedule were performed to make the tasks ready to be accomplished. Only those tasks free from constraints and meeting all the pre-conditions could pass through this process to become assignments to be completed. Those tasks were committed to, and were identified as 'will do' tasks. Figure 6 is an example of such a weekly production plan with the tasks that were only committed to be finished. For the tasks that could not be moved to the weekly work plan, constraints were integrated in the overall network and plan was reviewed to ensure that it still aligned with the milestones.

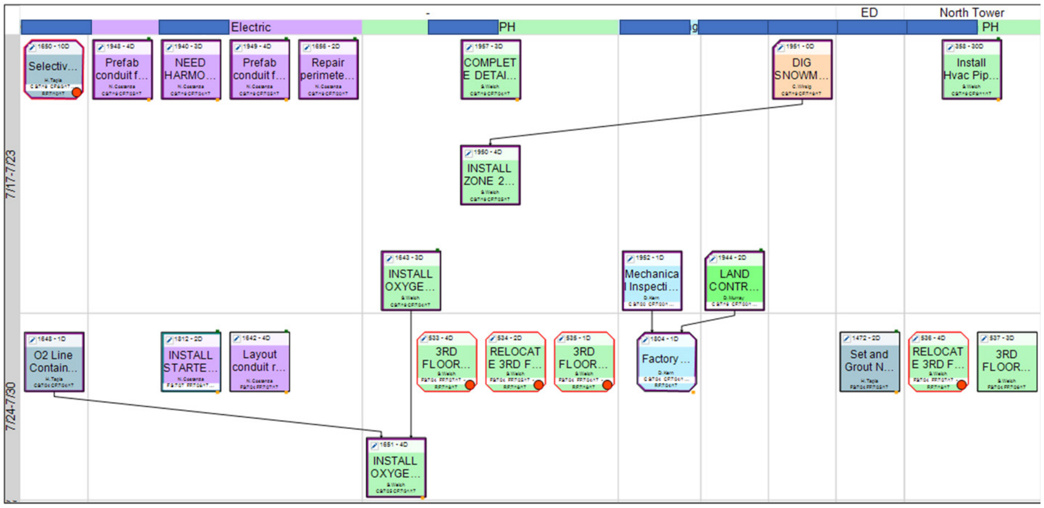


Figure 6– Example of a weekly production plan developed by the project team

Metrics to Track the Reliability of the Planning Process

For the case study project, the reliability of the of the planning process was measured by four metrics: (i) Commitment Level (CL), (ii) Percent Planned Complete (PPC), (iii) Percent Required Complete or Ongoing (PRCO), and (iv) Percent Planned Complete of Ongoing (PPCO).

The CL is a ratio of the total committed required tasks to total required tasks for any given weekly work plan expressed as a percentage. In this regard, a task was considered required when the late start of the same fell within the window of time for the weekly planning. The tasks were pulled based on the milestones from the master and phase schedules and controlled by the Takt time and planned spaces to improve the workflow. The numerator of this ratio refers to the critical tasks of the weekly work plan and the denominator refers to the tasks pulled from the phase schedule. Based on how CL was calculated, it demonstrated the reliability of the long-term planning of the project team.

$$Commitment\ Level\ (CL) = Required\ Will \div Should$$

PPC, which is the ratio of the committed tasks completed to the total number of commitments in any given week expressed as a percentage. However, all the committed tasks might not be required based on the pull from the master or phase schedule. No distinction was made between the critical tasks and the backlog tasks while calculating the ratio. PPC is regarded as an indicator of how well the planning process is performing at a weekly level, which was the planning cycle for this project.

$$Percent\ Planned\ Complete\ (PPC) = Did \div Will$$

PRCO is the percentage of the required tasks that were completed on/before the committed dates including the ongoing tasks. Ongoing tasks are ones that do not require intermediate handoff, start when promised, and span more than one planning cycle (which is one work week in this case). The ongoing tasks were included in this metric as they came up based on the core group members' updates on the remaining durations of the tasks. The duration of the ongoing task could then be reduced, and it would count towards PPC if its remaining duration still fitted within its promised date. The PRCO helped to capture the level of reliability for short-term planning of the project team. In conjunction with CL, PRCO provided a comparison of short-term planning reliability with that of long-term planning reliability.

$$PRCO = (Required\ to\ be\ Done + Ongoing\ on\ Track) \div Required\ Will$$

PPCO is the percentage of completed commitments and ongoing commitments against the total number of committed tasks. While calculating the PPCO, no distinction was made between critical tasks and backlog tasks. Like PRCO, this ratio is also an indicator of the reliability of short-term planning. In conjunction with PPC, PPCO provided a measure of the conversion rate of commitments to execution.

$$PPCO = (Commitments + Ongoing\ on\ Track) \div Will$$

The means and standard deviations of the four metrics are presented below (Table 1) from the case study project. The data presented has been collected on a weekly basis for a total of 78 weeks. The average number of activities in the lookahead schedule was 250 with approximately 30 activities consistently added or completed on a weekly basis Among the four metrics, CL showed the lowest value with the highest standard deviation.

Table 1: Means and SD of the metrics

Metrics	Mean	SD
CL	0.63	0.19
PPC	0.77	0.15
PRCO	0.78	0.10
PPCO	0.70	0.18

A cross tabulation was conducted to measure the correlation among the four metrics. Positive correlations are observed among all the metrics with strong correlations among PPCO/PPC, PPCO/CL, and PPC/CL. Statistically significant correlations are only observed among PPCO/PPC and PPC/CL.

Table 2: Correlation among the metrics

	CL	PPC	PPCO	PRCO
CL	1			
PPC	0.757*	1		
PPCO	0.846	0.939*	1	
PRCO	0.687	0.611	0.621	1
** indicates significant relationship p<0.05*				

DISCUSSIONS

LPS in conjunction with TTP was implemented in the case study project to achieve a stable workflow and increase the reliability of the planning process. The core group members realized the dynamic nature of the construction tasks and their interrelationships. They preferred the collaborative approach through LPS to manage the constraints arising due to variability and uncertainties. TTP helped the core members to balance the production rate based on the resource availability and target milestones. The CL, an indicator of the long-term planning reliability, if increases consistently implies successful collaboration among the group members. In case of groups that fail to collaborate on a regular basis and constantly focus on the remaining tasks will show a decrease in the CL value. The CL value of the case study project for the period of observation has shown an upward trend (Figure 7). It is clear from the trend that the core group members struggled with the process in the beginning, but managed to improve the process as the project progressed. The upward trend is indicative that critical tasks appearing in the weekly planning cycles were closely following the master and phase schedules prepared to meet the target milestones at the beginning of the planning process.

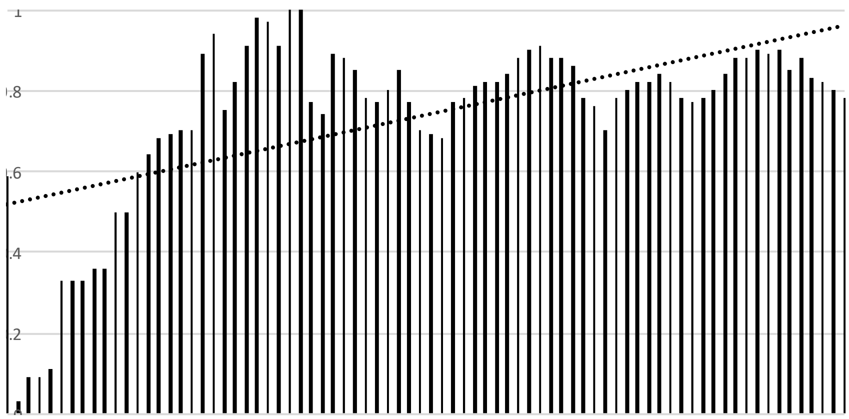


Figure 7 – Trend of the Commitment Level (CL) for the case study project during the observation period

CL in conjunction with PPC and PRCO provides an indication of both the long-term planning and short-term planning reliabilities. Comparable/similar values of the three metrics indicate the group members were successfully completing their tasks to meet the target milestones. Considering the core group members were trying to reduce their baseline schedule to earn incentives per the contract, it was important they meet the target milestones. Comparable/similar PPC and PRCO, as in the case of the case study project, indicate the group members were not overcommitting and meeting their targets with proper pre-planning. They were focused on completing the critical tasks (tasks required to be done) and did not fill out the weekly work plan with more backlog tasks than required tasks. If the group was not focused on critical tasks and had wrong priorities, the PPC would have been higher in comparison to PRCO.

The CL and PPC are complementary metrics that provide a snapshot of how the group's short-term planning was aligned with the overall planning for meeting project targets. A significant positive relationship between CL and PPC indicates that group members kept their commitments, they could create sound assignments, and were able to maintain alignment between the tasks that 'should' be done and 'will' be done. Using TTP had a major role in the group members being able to make sound assignments. They focused on sizing the spaces in each floor based on the task requirements and resource availability and re-planned whenever necessary that maximized the workflow. A steady increase in the PPC value was also observed. While the PPC (of 0.74) was just below the recommended percentage of 75%, it showed a significant positive correlation with PPCO. The positive correlation demonstrated the group members focused on completing the committed tasks thus increasing the reliability of the planning process. Additionally, a lower PPCO value than that of the PRCO indicated the completion of higher number of critical tasks by the group members.

CONCLUSIONS

The objective of the case study was to answer two questions: (i) How was TTP implemented in the case study project? (ii) Did implementation of TTP increase the reliability of the schedule? The project selected for the in-depth single case study was a 168,000 SF addition to an existing health care facility. The core group of the case study project consisting of the general contractor, designers, owner, and trade partners adopted TTP in conjunction with LPS for the planning process. The paper presented an overview of the planning process and attempted to measure the reliability of planning through four metrics: CL, PPC, PPCO, and PRCO. While CL indicated long term planning reliability, PPC focused more on short term reliability. In conjunction with CL and PPC, PPCO and PRCO provided added information regarding the planning reliability.

The values of CL, PPC, and PRCO demonstrated consistent long-term planning aligned with short-term planning. The standard deviations of the metrics serve as indicator of the planning reliability. The standard deviation of the CL was higher than that of PRCO indicating higher planning reliability in short-term planning than that of long-term planning. This can be explained due to the intentional lack of detail in the master schedule. Following the steps of LPS, the core group identified the 'should' be done work for the master schedule, which was very broad (Figure 2). The case study project showed similar values of PPC and PRCO indicating frequent collaboration with the group members focusing on required tasks to meet the target milestones. As the activities were pulled in the lookahead window, the core group worked out the detail and that improved the reliability of the short-term planning than that of the long-term planning. In theory, perfect matching between the load (calculated by dividing the floors to different spaces) and the capacity (calculated based on labor productivity) should imply planned activities equal to the executed activities, or 100% reliability. However, threat to the schedule reliability arise from variation in labor productivity from area-to-area and variation in duration between trade contractors. The trade contractors could successfully adopt TTP to drive both utilization and output rates. In the case study project, when the trade contractors could meet the takt time, the predictability of the hand-off between trade increased, that facilitated matching capacity to load, explained by better planning reliability. This improved the overall productivity that enabled the project team to reduce the overall schedule by two months to earn the incentive from the owner. This achievement of the project team resonates with the findings of Linnik et al. (2013) and Frandson et al. (2013). Linnik et al. (2013), in their case study, found an increase in the commitment level among the project participants. In absence of any such process where the trade contractors are encouraged to prepare detailed schedule balancing load and the capacity, durations of planned activities are mostly overestimated. The resulting reduction in project duration the team realized using TTP in addition to LPS helped the project team save money on general condition costs.

Completing tasks to meet the target milestones required the core group members to adhere to the process of LPS and TTP in creating the lookahead schedule and weekly work plans from the master and phase schedules. This required a systematic approach to the implementation of the techniques and sincere commitment from the core group members for successful implementation. There was the burden of spending long hours and additional effort on the members at the beginning of the planning process. The number of tasks committed in each planning cycle also increased as the project progressed and the group members became more adept at the process. Additionally, the time spent by the members to review and update a previous work plan, analyze the reasons for variance, and plan next week was reduced as they gained more experience in the process.

This case study based research was an ideal approach to learn the adoption of TTP during planning and scheduling of a healthcare project and measure the effect of TTP on the schedule reliability. The positive effect of TTP on the schedule reliability that was observed in this single case study will benefit from the future multiple case study based approach. The limited generalizability of the findings of this study can be overcome by future studies adopting rigorous sampling strategy and multiple cases. This research contributes to the construction management body of knowledge by advancing the concept of TTP to improve the schedule reliability. When the construction industry is striving to improve its efficiency and productivity, lack of schedule reliability leading to delays is a major impediment. TTP in conjunction with LPS can be the tool project participants can use to increase the commitment levels and reliability of construction schedules.

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Alec Kalogeropoulos
Roger Williams University

Second Place
Thomas Welch
Purdue University

Third Place
Nathan Keilholz
East Carolina University

Climate Change Impacts on and Actions from the Construction Industry: Past, Present and Future

Author: Alec Kalogeropoulos

Faculty Advisor: Dr. Amine Ghanem

Abstract

In the movement towards reduced emissions and sustainability, climate change policies have and will continue to influence actions taken in the construction industry. These policies can be seen on the local, national, and international level. This includes the banning of fossil fuel systems and sustainable building requirements to limit carbon emissions. In response, the construction industry has begun transitioning to electric equipment and vehicles, selecting renewable materials, and practicing value engineering for sustainable alternatives. AGC's role in this will be lobbying, educating the industry on new trends, and proposing new means and methods that promote green construction.

Climate Change Policies Effect on the Construction Industry

In the movement towards reduced emissions and sustainability, climate change policies have and will continue to influence actions taken in the construction industry. These policies can be seen on the local, national, and international level.

On the local level, ordinances have been put in place that require green certifications for public buildings, ban the use of certain building materials, and incentivize tax credits. Since the early 2000's, major cities around the United States have begun requiring public buildings to achieve various levels of LEED certification or face fines. A prime example of this is the city of Washington, DC, which beginning in 2012, required "that public schools shall aspire to meet LEED for Schools at the Gold level or higher" or face "fines on private commercial buildings that do not provide proof that the project is LEED certifiable within 2 years of receipt of occupancy" (*LEED Legislation by City: See Where LEED Certification Is Required*, 2015). In my home state of Massachusetts, many local communities have fought the attorney general over banning the implementation of fossil fuel infrastructure in new buildings and renovations. In 2019, the town of Brookline, MA "by an overwhelming majority," passed "a bylaw prohibiting fossil fuel infrastructure in new construction or gut renovations. It was the first such municipal measure passed outside of California. Inspired by the idea, other towns began preparing similar measures" (Shemkus, 2021). This was all in the effort to meet Massachusetts' goal of becoming carbon-neutral by the year 2050. The bylaw was ultimately reversed by Massachusetts Attorney General, Maura Healey, who deemed that it was unlawful for municipalities to supersede state building codes (Shemkus, 2021).

However, not all policy initiatives have been in an effort to limit or force certain actions upon the construction industry. One of the main climate change policies that incentivize green construction has been tax credits. As a part of the 2022 Inflation Reduction Act, there are "expanded tax credits for energy efficient commercial buildings, new energy efficient homes, and electric vehicle (EV) charging infrastructure" (The White House, 2022).

The 2022 Inflation Reduction Act not only saw the incentivization of tax credits, but also increased funding for many renewable new construction projects around the United States. Specifically, the act provides "$9 billion in home energy rebate programs to help people electrify their home appliances and for energy-efficient retrofits", introduces a "$1 billion grant program to make affordable housing more energy efficient", and "includes more than $60 billion to support "on-shore clean energy manufacturing in the U.S.,"" (*What the Inflation Reduction Act Does for Green Energy*, 2022).

On the international level, many countries have pledged to the Paris Agreement in an effort to "limit greenhouse gas emissions to levels that would prevent global temperatures from increasing more than 2 °C (3.6 °F) above the temperature benchmark set before the beginning of the Industrial Revolution" (The Editors of Encyclopaedia Britannica, 2019). As a part of this agreement, countries around the world have pledged to reduce their emissions in various industries, such as construction, to meet the world emission goals.

Actions from the Construction Industry

Within the construction industry, much has been done in recent years by companies large and small in an effort to reduce emissions. These efforts include the transition to electric equipment and vehicles, selection of renewable materials, and value engineering of sustainable alternatives.

Similar to the move of passenger vehicles towards electric and hybrid, the construction industry is also seeing a movement towards adopting electric equipment. One of the companies at the forefront of implementing green initiatives has been the Swedish-based construction company, Skanska. Specifically, Skanska UK "with its new EV First initiative, the company will no longer offer pure petrol or diesel vehicles as a benefit to eligible employees. Instead, fully electric vehicles (EVs) will be the preferred option, with petrol-electric hybrids (PHEVs) as an alternative, if more practical for the individual" (Sketchley, 2020). But the electric vehicle moment is not limited to just cars and trucks, as equipment ranging from site lights to excavators have also begun to go all electric. One of the most common applications of electric equipment has been in the use of portable solar site light stations. Primarily used for night work on heavy civil projects, solar light stations are a renewable source of light which provide many benefits over the traditional gas or diesel-powered light stations. Some of these benefits include off-grid power, no electricity bills or running costs, and little to no maintenance compared to fossil fuel powered engines (SOLAR CONSTRUCTION SITE LIGHTING | CONSTRUCTION WORK, n.d.).

Additionally, heavy equipment companies such as Komatsu and Caterpillar have also invested in electric technology. "In 2017, Komatsu unveiled a massive electric dump truck called the e-Dumper, which featured a gigantic 600-kWh battery pack. Caterpillar has also invested in Fisker, which is developing solid-state batteries designed to outperform the lithium-ion batteries used in all current electric vehicles" (Edelstein, n.d.).

On the topic of materials in the construction industry, a lot of efforts have been implemented to encourage renewable materials, and materials manufactured locally. Not only does the sourcing of local materials reduce emissions because of shipping, but also greatly benefits local businesses. Currently, transportation of material accounts for 2-3% of carbon emissions generated by the construction industry (Sizirici et al., 2021). One of the main construction materials trying to take the place of structural steel in the construction of commercial buildings has been cross laminated timber or also known as CLT. "Developed in Germany and Austria in the early 1990s… It is a subtype of engineered wood paneling, made of layers of solid-sawn lumber glued together, that has been widely used for the construction of both public and private buildings. Due to its versatility and reliability, as well as its eco-friendly nature, CLT is steadily growing as one of the preferred construction materials for load-bearing structures, as well as interior and exterior visual structures of modern, sustainable buildings" (CLT Construction: A Modern Building Material | WIGO Group, n.d.). Unlike steel, which is a limited resource, CLT is a renewable building material as it is primarily made of wood, which can be sustainably sourced from trees. For every tree cut down to produce CLT, another can be planted, thus ensuring the longevity of the resource.

One of the other major actions of the construction industry has been the increase in value engineering services from the contractor to promote more sustainable alternatives. The construction industry is starting to move away from the traditional design-bid-build delivery method and is shifting towards alternative delivery methods such as design-build, CM as agency, CM at risk, and P3. According to the Design-Build Institute of America, "design-build is anticipated to account for as much as 47% of construction spending in the assessed segments (nonresidential, highway/street, transportation and water/wastewater) by 2025" (kwright@dbia.org, 2021). All of these methods encourage the construction management firm or contractors to get involved in the project early during the design phase to provide constructability reviews and value engineering alternatives to the design team and owner. During the design phase, the contractor can help to identify alternatives that not only provide more utility to the owner but can also be more sustainable and efficient in terms of operation. Examples include the implementation of energy efficient lighting systems, energy efficient HVAC systems, and improvements to the exterior shell that can lead to improved thermal capabilities and lower heating and cooling costs.

Addressing Climate Change in the Construction Industry

In my opinion, there are many feasible actions that can take place in the construction industry to reduce emissions and combat climate change. Some of these actions include changing materials and types of equipment used and altering methods of construction.

One of the main causes of emissions in the construction industry comes from the production of materials. According to the United Nations Environment Programme, in 2019, "When adding emissions from the building construction industry on top of operational emissions, the sector accounted for 38% of total global energy-related CO2 emissions" (Neill, 2020). Of that, a majority of the emissions are the result of iron and steel production, which account for roughly 7.2% of overall global emissions (Ritchie & Roser, 2020). In order to lower these statistics, the construction industry must move away from the use of limited resources and move towards the use of more sustainable building materials. As mentioned before, the adoption of CLT in large commercial buildings must become more commonplace. On the infrastructure side, alternatives must be found to replace the use of concrete and asphalt on our bridges and roadways. While asphalt is one of the most recycled materials in construction, it is only used to make more asphalt, which the process itself releases vast amounts of emissions.

In terms of construction equipment, the United States must catch up to its European counterparts with the adoption of renewable equipment such as electric trucks, electric excavators, and electric light sources. At the very least, if this is not attainable, the construction industry must place regulations on the practice of machine idling and on the use of high emissions emitting equipment to lower the overall carbon emissions.

The most important of all the actions that can be taken by the construction industry, means and methods of construction must be changed to promote a more sustainable jobsite.

This can include actions that take place in the preconstruction phase to procure local materials, minimize the movement of equipment, and reuse or recycle materials on-site. Not only will this lead to a more sustainable project but could also lead to increased productivity and decreased project costs.

AGC's Role on Climate Change

The Associated General Contractors of America has the opportunity to be a major player when it comes to advocating for reduced emissions and sustainability in the construction industry. Primarily, AGC's role in the battle against climate change will be to advocate for green policies that benefit contractors, lobby for federal bills that increase spending for sustainable projects, and to educate AGC members and their companies on new methods and technologies.

The first key role that AGC will have on climate change is to advocate and lobby for green policies that benefit contractors. In particular, AGC Chapters at the state level should lobby for particular questions during election time that involve increasing funding for green construction projects. On the federal level, the national AGC could help to lobby for larger bills that see an increase in funding for green construction projects, or that provide incentives for contractors to reduce emissions. Some of these incentives could include tax reductions for companies that stay under a certain emissions threshold, tax write-offs/subsidies for purchasing electric equipment, and grants for construction projects.

The main area that AGC could have the most impact on combating climate change in the construction industry comes from their outreach and ability to educate. With the outreach that AGC has, their main tool could be to educate their members and member companies on new techniques and technologies. This could be in the form of promoting the use of electric equipment, incorporating more sustainable means and methods, recycling and adoption of more sustainable materials, etc.

Overall, AGC has the opportunity to make a significant contribution in the movement towards reduced emissions and creating a more sustainable construction industry. The construction industry has come a long way from past years with the adoption of more sustainable construction materials, equipment, and methods, but there is still a long way to go. If the United States and the world is able to meet many goals of reaching net-zero by 2050 and staying below the benchmark of 2 °C of warming, the construction industry has to be a leader in that effort. AGC, with its long history and widespan of influence in the construction industry is in the right position to be able to make change happen.

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CLIMATE CHANGE IMPACTS ON AND ACTIONS FROM THE CONSTRUCTION INDUSTRY: PAST, PRESENT AND FUTURE

Thomas Welch

Abstract

Over the past 100 years, global temperatures have risen steadily. The construction industry contributes to global emissions immensely. New policies aim to curtail emissions to limit the continued global warming. The construction industry will need to change to adhere to stricter emissions standards. Changes to construction materials, modifications to construction machinery, and the installation of greener building components and systems can reduce total emissions. Contractors' who embrace these changes will allow the construction industry to transition from a primary offender to a force for change, and the AGC has the opportunity to spearhead this evolution of the industry.

Introduction

The construction industry accounts for 13.2% of global GDP (Roman 2022), yet the industry accounts for 38% of total emissions (Neill 2020). The construction market is expected to continue to grow year over year, however recent international agreements have put sustainability initiatives in place that are, frankly, unattainable with the current construction practices. While action has been taken to make the construction industry more sustainable, there is still significant change needed. It is going to take a collaborative effort between construction contractors, material production companies, and the contractor's clients to institute meaningful change that reduces the emissions, pollutants, and waste associated with construction projects. A building's construction can also be altered to increase the sustainability of the structures themselves over their lifespans.

At the turn of the 20th century, the construction methods in use today began to gain popularity. By this point, early reinforced concrete was already in use, and structural steel use grew rapidly in the beginning of the century (A Brief History of Steel Construction, 2018). Many of the heavy construction machines used in modern construction were invented around this time as well (The History of Heavy Construction Equipment, 2021). As the construction industry grew over the past 100 years, so did the use of these building materials and equipment, contributing to the rising carbon emissions over this time period.

The graph in Figure 1 illustrates atmospheric carbon dioxide, measured at Mauna Loa Observatory from 1960-2020. The graph illustrates a steady rise in atmospheric carbon dioxide which has increased by nearly 25% over the last 50 years. This rise in carbon dioxide in the atmosphere is a major driver of climate change. The potential consequences of a continued rise have been recognized, and attendees of the UN Climate Change Conference have acknowledged the need to curb emissions in order to minimize future impacts to both the environment and society (UNFCCC, 2016). The Paris Agreement, entered into force on 4 November 2016, aims to limit the warming of the planet, primarily through a focus on the implementation on low- and zero-carbon solutions to numerous emissions sources (UNFCCC, 2016).

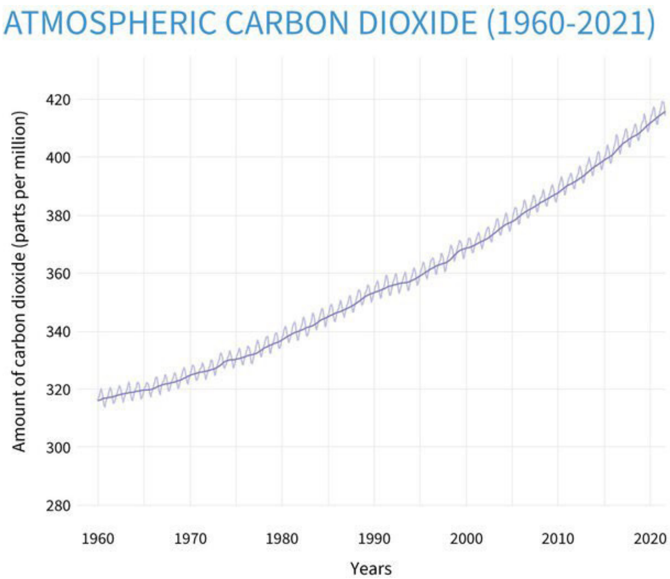

Figure 1: Record of atmospheric carbon dioxide levels recorded at Mauna Loa Observatory (Lindsey, 2022)

The construction industry, like every market sector, is not immune to the need to implement such changes. The reduction of carbon emissions can be achieved through the implementation of newer, more sustainable construction materials, lower net carbon methods of producing current construction materials, and more efficient construction methods and machinery.

One of the most exciting prospects in the construction industry is the adoption of mass timber as a design choice in high-rise buildings. Research into mass timber has solidified its validity as a construction method, and research from Germany's Institute for Climate Impact Research suggests that mass timber can reduce the carbon footprint of urban areas as a whole. In a paper published in *Nature Sustainability*, an increase in the percentage of new buildings constructed with mass timber provides a carbon sink in urban areas. If 50% of new building construction worldwide utilizes mass timber, it is estimated that between 1 and 11 billion tons of carbon dioxide would be stored within the mass timber structures over 30 years, which is the time remaining for the industry to achieve net-zero emissions. With annual emissions currently totaling 35 billion tons of carbon dioxide (Lindsey, 2022), mass timber construction could counteract 1% of these emissions. Mass timber buildings also reduce the total carbon emissions associated with material production. 50% of new building construction being comprised of mass timber results in roughly a 26% reduction in total carbon emissions of all material manufacturing for buildings over the same time period (Churkina et al., 2020). This reduction in emissions is due to both the lower emissions of mass-timber production and the reduction in transportation demands and foundation size associated with a smaller total weight of building materials.

The comparative emissions of the current material usage and a 50% mass timber usage, as well as 10% and 90% mass timber usages, are shown below.

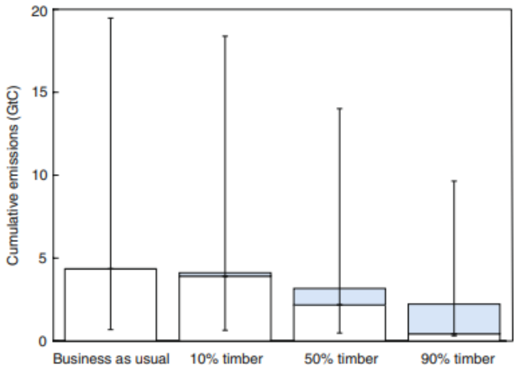

Figure 2: Total Carbon Emissions of material manufacturing with mass timber at various percentages of total construction (Churkina et al., 2020)

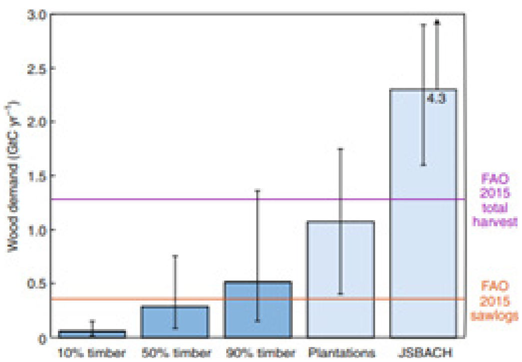

Figure 3: Comparison of wood demand at different percentages of total construction and available wood supply (Churkina et al., 2020)

While there are numerous benefits to mass timber from a net carbon perspective, the material demand must not exceed the supply of wood in the forests of the world.

Managing the demand ensures that forest areas can be replenished at a sustainable rate while maintaining tremendous carbon sink these forests provide. As shown above, if 50% of new construction utilizes mass timber, the existing annual harvest of wood is sufficient to supply the material demand, assuming current allocations for fuel wood are redistributed into building material production as more sustainable heating practices are enacted (Churkina et al., 2020). While this forecast is on the global level, the United States has both the forest area and wood processing facilities to make mass timber a substantial portion of new building construction.

The reduction in carbon footprint of mass timber can help offset the emissions of conventional building materials as production methods are updated to be more sustainable.

Mass timber provides a sustainable alternative to steel and concrete construction for buildings, but there are many other areas of the construction industry that will still necessitate the need for these conventional materials. Even with a reduction in total demand, existing production methods have extremely high emissions. Cement, a crucial component in concrete, is the single largest contributor to carbon emissions, accounting for 8% of total global emissions (Ramsden, 2020). There are several ideas that have been proposed to reduce the net output of cement production. Some of these ideas are carbon valorization, which is the process of converting waste CO_2 into valuable products, or the sequestration of the CO_2 into solid forms to keep it out of the atmosphere (Ramsden, 2020). One of the most interesting developments in concrete is the invention of greener alternatives to traditional cement. Solidia, a New Jersey based company, has made significant innovations in cement and concrete. Solidia has patented a method of cement and concrete production that utilizes a more efficient cement formula with a smaller energy demand, which cuts greenhouse gas emissions by roughly a third. This cement is then mixed with aggregate, but is cured using CO_2 in under 24 hours, rather than water curing which takes nearly a month. This curing method sequesters CO_2 in the concrete and drastically reduces the water demand of concrete curing (Solidia, 2020). Below is a graphic illustrating the difference in Solidia's proprietary method vs the traditional method of curing concrete, as well as the numerous benefits this new method provides.

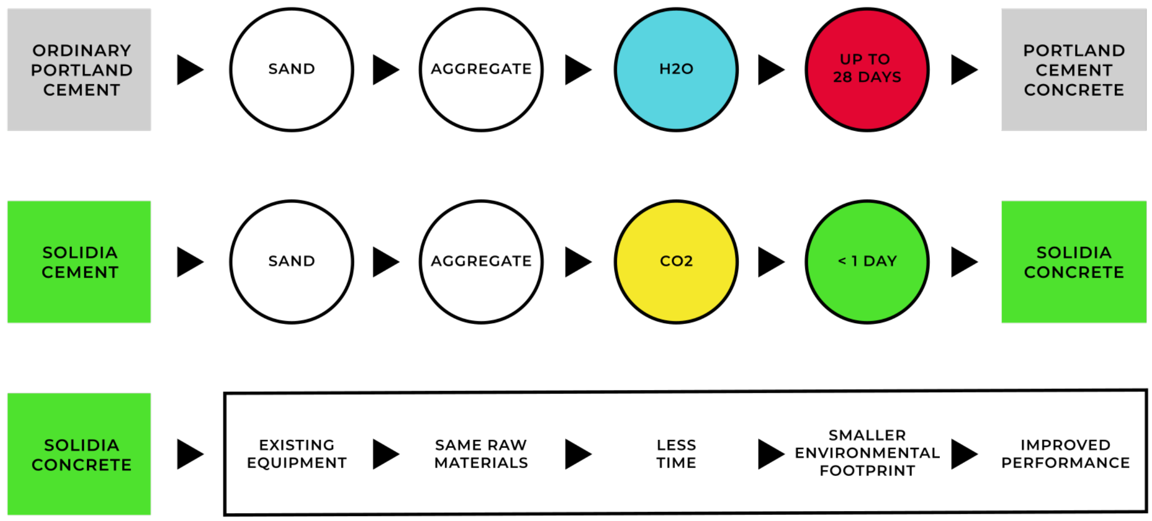

Figure 4: Comparison of Concrete Production Methods and the Benefits of Solidia Concrete (Solidia, 2020)

In addition to changes to the construction materials, construction machinery can be retrofitted to reduce emissions associated with the construction process. Clean Construction USA, a program launched by the EPA, was formed to advocate for such retrofitting and other changes that could reduce emissions from these machines. The program encourages the installation of Diesel Particulate Filters and Diesel Oxidation Catalysts on construction machinery to reduce the emissions from their engines. Other recommended practices include reducing idling, switching to cleaner fuels (i.e. biodiesel, natural gas), and the replacement of older engines with newer ones that are cleaner and more efficient. The EPA, as well as state and local governmental bodies, offer grants or tax incentives to motivate contractors to implement these changes (Environmental Protection Agency, 2022).

The materials and machinery used during construction account for the emissions associated with the construction industry. While the construction process is a contractor's primary concern, there are additional decisions contractors can make to increase the sustainability of the structures they work on. LEED is a grading system that evaluates the sustainability of buildings, from environmental, social, and economic perspectives, based on the installation of various features. There have been numerous innovations in various building components to reduce emissions and increase the efficiency of buildings. Most high-rise buildings have facades composed mostly of windows, and newer windows offer numerous advantages in energy efficiency. When constructing building layouts, the size and location of windows can be arranged to maximize this natural light which reduces the total energy need for internal lighting. Modern window panels can be double glazed and/or double paned, which reduces heat loss and limits additional heating from solar radiation, without compromising this natural light (Zhigulina and Ponomarenko, 2018).

Some construction projects are replacing traditional building systems with more innovative designs that maximize efficiency. A high-rise in Guangzhou China replaced the majority of air conditioning ventilation ductworks with a system integrating into the floor which circulates chilled liquid, cooling the building more efficiently. The building also has an integrated heating system and dehumidifier within ventilation shafts that run between panes of glass on the building façade (Zhigulina and Ponomarenko, 2018).

These integrated shafts increase efficiency without the need for additional costly machinery.

If a contractor lacks the specialized knowledge needed to implement new and innovative systems such as the ones discussed above, traditional building systems can be modified to increase efficiency. When rainfall drainage is installed, the inclusion of a rainfall collection and filtration system creates an auxiliary water supply for a buildings cooling system, reducing the total municipal water demands of the structure. Automated light dimming systems and shading systems can balance the reducing of lighting and cooling demands with the maximizing of natural light. Additionally, renewable energy systems can be installed on a building to reduce the overall energy demand on the power grid without actually increasing the efficiency of traditional systems (Al-Kohmany, 2022).

The most significant obstacle to the widespread adoption of any of these changes is increased cost. It is hard to expect contractors to include more sustainable components and practices when these alterations raise the overall construction cost. While the plethora of changes necessary to adhere to climate change policies is a daunting and expensive undertaking, changes can be made incrementally, spreading the additional cost over years, if not decades. Addressing climate change is also more than a strictly financial issue. A more holistic, long-term perspective can reduce a contractor's aversion to implementing change. Taking a greener approach to construction results in a net benefit for the entire community, and contractors can take pride in the progress they are making to foster a more sustainable and environmentally conscious society. Contractors can also convey this focus on sustainability to the owner, and clients are more likely to approve a more expensive budget so long as the benefits to the community and the environment are well explained.

In addition, federal climate change policies will continue to get stricter as we approach the Paris Agreement's goal of net-zero carbon emissions by 2050. An early adoption of sustainable materials and practices will allow contractors to familiarize themselves with this new style of construction, creating an advantage in the industry if competitors are slower to adopt.

While some contractors may have a conscious aversion to change, ignorance can pose a similarly significant obstacle to addressing climate change. The AGC has the means and access to inform a myriad of contractors of the effect climate change policy has and will continue to have on the construction industry. The emissions standards enumerated by the Paris Agreement will only get more restrictive, and making contractors aware of the constraints their business will face will allow contractors to adjust both their immediate and long-term operations accordingly. Contractors will then be able to institute company policies that ensure they are equipped to continue to operate while adhering to government regulations. Advance notice of future regulation reduces the likelihood that contracting companies encounter financial difficulties while instituting change. Smaller firms are especially at risk, as they are on smaller margins and have less free capital, which makes them less able to invest in sustainable practices rapidly.

Through conferences, seminars, and the Constructor Magazine, the AGC can both inform contractors of current and impending sustainability and emissions standards and explain what changes can be made to meet these standards. It will take a collective effort across industries to mitigate the already mounting effect of climate change, and contractors are uniquely able to implement meaningful, lasting change that will preserve the environment for generations to come.

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Effects of Climate Change in the Construction Industry

Nathan Keilholz

Abstract

Climate change is one of the greatest existential threats humanity has faced, and its source is the result of human actions. The construction industry has played a role in contributing to the issue and is responsible for large amounts of emissions. Policies enacted by the government and its agencies have sought to remedy this by reducing the impact construction has on the environment. This paper will explore some of these policies, their reception, and suggest potential options for the future.

Introduction

Climate change has been a prevailing global issue for well over a century, and with each passing year, the consequences grow more dire. The impacts of climate change are already being felt worldwide from droughts in China (Gunia, 2022), flooding in Pakistan (UNICEF, 2022), and crop failures across Europe (Mendes, 2022). The United States have also felt the repercussions of climate change in recent years with rampant wildfires in numerous western states, flooding in Appalachia, and increased intensity of hurricanes along the Gulf and East Coasts. There has never been a point in history where the effects of climate change have been more evident than as they are right now.

The construction industry has been notorious for its impact on the environment and is responsible for up to 38% of global greenhouse gas emissions (Neill, 2020). While this figure is contested by other sources (Architecture 2030, 2022), all believe that the industry is one of the largest contributors to global emissions. Construction processes like land clearing, use of gasoline-powered equipment, use of toxic or hazardous building materials, and erosion caused by construction all contribute to climate change. As demand for new projects continues to rise, the climate impact caused by construction will rise in turn.

Climate Change Policies

All is not lost with the fight against climate change. Countries around the world have committed to combatting the issue along with the United States. Policies have been implemented at both the state and federal level targeting to cut the construction sector's emissions.

The EPA has been steadily introducing regulations that target many construction related polluters. For instance, emission standards were set by the agency for nonroad diesel engines for the first time in 1994 (DieselNet, 2022). This marked the start of a phase- based implementation of emission regulations for new nonroad diesel engines. A total of 4 tiers were planned, though the 3rd was never implemented. These regulations restricted the amount of harmful chemicals that nonroad diesel engines could release. EPA Regulation 62.5 Air Control Standards highlights many regulations that cut back emissions from many sectors including construction. Section No. 4 specifically targets process industries, which includes emission standards for hot mix asphalt (HMA) manufacturing as well as on-site dust control (EPA, 2018).

Federal agencies aren't the only ones implanting policies that target construction emissions. Anti-idling regulations for large or diesel-powered vehicles have been introduced in 9 different states. While specifications vary, these laws seek to minimize the amount of time a vehicle can have its engine running without moving. This helps restrict fuel usage and carbon dioxide emissions. Many states also have their own sets of laws regarding construction processes, like acceptable water runoff levels, erosion control standards, and more.

Other Factors

Many other sources outside of government regulations are helping to reduce the construction sector's climate change impact. Perhaps the biggest of all is public perception. Being considered an environmentally friendly company is now a vital part to being held in a positive light by the public. When news of environmental malpractice by a construction company breaks, public backlash can be immense.

With the advent of social media, this information can be disseminated faster than ever and to a much broader audience. Backlash can cause economic losses for a company, as well as the potential loss of future work.

"Company Culture" is a buzzword that means the principles, ideas, and ways of doing things a company deems as integral to the way they conduct business. Company culture has been identified as one of the key factors in attracting new talent (Thompson, 2018). Many companies are now making building green as a key tenet in their culture, as many young workers entering the workforce believe environmental protection to be extremely important.

Construction Industry's Response to Policies

The construction industry is famously slow to adopt modern technologies and ideas, and its response to climate change policies is no different. It is easy enough for companies to circumvent regulations like anti-idling and runoff laws without oversight. Despite being behind other industries and struggling to adapt to policy changes, the construction sector has still seen massive progress in reducing its carbon footprint. Green buildings like those with LEED and WELL ratings have become increasingly more common with each year. Thanks to policies like engine emission regulations, the amount of pollution any given piece of equipment has been reduced. Public opinion has also pressured companies into being more welcoming to climate change policies.

My Suggestions

I firmly believe that more comprehensive policies need to be introduced to help progress the construction industry to being greener.

While the current policies are working, they haven't encompassed many parts of the construction process that generate pollution. One possibility is continuing the trend of lowering the maximum permissible emissions of new combustion engines. Large construction projects require many pieces of equipment, many of which generate emissions. Even a slight reduction to their emissions can remove significant amounts of greenhouse gases from entering the atmosphere. I also believe that the government should invest more into inspections. While very unpopular with construction firms and subcontractors, more inspections will keep companies accountable.

There are many steps I believe individual companies should take to help decrease their own environmental impact. Investing in research and development for new materials and processes that provide greener alternatives to existing methods can help greatly. In my personal experience, I have been able to see the benefits of companies experimenting with systems like prefabrication. Prefabrication can reduce the amount of equipment needed on a jobsite for specific tasks as well as the amount of personnel required. Most workers commute to jobsites via car or bus, and most heavy equipment runs on diesel.

With prefabrication, the total energy expended can be reduced. As stated before, having a company culture of building green can help reduce a given company's climate impact. If being environmentally responsible is at the forefront of every employee's mind, then positive results can be expected.

AGC's Role

The Associated General Contractors of America has already helped to make progress in helping the construction industry reduce its climate impact.

It holds discussions with industry leaders to communicate how companies can align themselves to build greener and has implemented a Climate Task Force (AGC, 2021). The Climate Task Force seeks to educate and influence the industry to building more sustainably. Going forward, AGC should seek to do multiple things. The first being to continue their current efforts of educating. This helps keep everyone in the industry stay informed on current climate issues and how they relate to the industry. The second is to advocate for more climate related policies. AGC already advocates for many different ideas and lobbying the government to implement more solutions is entirely within AGC's power. Lastly, AGC should celebrate the achievements of its members who complete green projects or have a history of being environmentally friendly. This will help motivate its member organizations to build green with positive reinforcement.

Conclusion

The construction industry is one of the major contributors to global emissions and has been slower than expected to adapt to climate-conscious ideas. However, progress is still being made. Policies are being introduced by the government to help bring down emissions and companies are looking to build greener for ulterior reasons. Organizations like AGC also continue to advocate and educate, further helping the industry progress towards becoming cleaner. Much progress has been made in the construction industry against climate change, but there is still a long way to go.

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