Fall 2022 | Volume 47 | Number 02

AIC

Accelerating Constructor Excellence

The Professional Constructor

Journal of the American Institute of Constructors

IN THIS ISSUE:

The Professional Constructor

Journal of the American Institute of Constructors

ABOUT THE AIC

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**.

OUR MISSION

- To promote individual professionalism and excellence throughout the related fields of construction.
- 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
- An environment to enhance the overall standing of the construction profession.

The Professional Constructor

Journal of the American Institute of Constructors

AIC PAST PRESIDENTS

1971-74 Walter Nashert, Sr., FAIC

1975 Francis R. Dugan, FAIC

1976 William Lathrop, FAIC

1977 James A. Jackson, FAIC

1978 William M. Kuhne, FAIC

1979 E. Grant Hesser, FAIC

1980 Clarke E. Redlinger, FAIC, CPC

1981 Robert D. Nabholz, FAIC

1982 Bruce C. Gilbert, FAIC

1983 Ralph. J. Hubert, FAIC

1984 Herbert L. McCaskill Jr., FAIC, CPC

1985 Albert L Culberson, FAIC

1986 Richard H. Frantz, FAIC

1987 L.A. (Jack) Kinnaman, FAIC

1988 Robert W. Dorsey, FAIC

1989 T.R. Benning Jr., FAIC, CPC

1990 O.L. Pfaffmann, FAIC, CPC

1991 David Wahl, FAIC

1992 Richard Kafonek, FAIC

1993 Roger Baldwin, FAIC, CPC

1994 Roger Liska, FAIC, CPC

1995 Allen Crowley, FAIC

1996 Martin R. Griek, FAIC

1997 C.J. Tiesen, FAIC

1998-99 Gary Thurston, FAIC

2000 William R. Edwards, FAIC, CPC

2001-02 James C. Redlinger, FAIC, CPC

2003-04 Stephen DeSalvo, FAIC, CPC

2005-06 David R. Mattson, FAIC, CPC

2007-09 Stephen P. Byrne, FAIC, CPC

2009-11 Mark E. Giorgi, FAIC

2011-12 Andrew Wasiniak, FAIC, CPC

2012-13 Tanya Matthews, FAIC, DBIA

2013-14 David Fleming, CPC, DBIA

2014-15 Paul Mattingly, FAIC, CPC

2015-16 Joe Rietman, CPC

2016-18 Greg Carender, FAIC, CPC

2018-21 Brian Holley, FAIC, CPC

Fall 2022 | Volume 47 | Number 02

The Professional Constructor

Journal of the American Institute of Constructors

EDITOR

Jason D. Lucas, Ph.D.

Associate Professor, Clemson University

ARTICLES IN THIS ISSUE

The Professional Constructor (ISSN 0146-7557) is the official publication of the American Institute of Constructors (AIC), 19 Mantua Road, Mount Royal, NJ 08061.
Telephone 703.683.4999, Fax 703.683.5480, **www.aic-builds.org**.

The Professional Constructor is a refereed journal. All papers must be written and submitted in accordance with AIC journal guidelines available from AIC. All papers are reviewed by at least three experts in the field.

Construction Management Internship: A key opportunity for assessment and continuous curriculum improvement

James S. Vaux, Ph.D., CPC, *University of Nebraska, Kearney,* vauxjs@unk.edu
Bree Dority, Ph.D., *University of Nebraska, Kearney,* doritybl@unk.edu
Dana E. Vaux, Ph.D., *University of Nebraska, Kearney,* vauxde@unk.edu

Abstract

The internship is an integral part of most Construction Management curricula. Studies have noted the importance and reciprocal value of internships for the student, the employer, and the academic program. However, to date, no studies have specifically outlined the value internships provide to the CM program for assessment and evaluation. This paper examines the value of the CM internship as an indirect measure to assess and incorporate change into program curricula. With 10 years of qualitative and quantitative data collected from CM student interns, industry employers, and university internship supervisors, this study supports that CM internships are a valuable tool for program assessment and support best practices for the development of an internship program.

Key Words: Construction Management, Internship, Experiential Learning, Construction Industry

James S. Vaux Ph.D. CPC is an associate professor and chair in the Industrial Technology Department at the University of Nebraska, Kearney, and teaches in the construction management program. His research focuses on relationship conflict in construction and its effect on profit and performance.

Bree Dority Ph.D. is an Associate Dean for the College of Business and Technology at the University of Nebraska, Kearney where she leads the assessment efforts of the undergraduate and graduate business programs. Bree's recent work is in relationship conflict in construction and she teaches an accounting and finance course for the Construction Management program.

Dana E. Vaux Ph.D. is an associate professor in the Industrial Technology Department at the University of Nebraska, Kearney, where she teaches design and construction management courses. A focus of her recent research is on professional practice and internships.

INTRODUCTION

Completing an internship is a requirement or highly recommended for many Construction Management (CM) programs in the United States. A structured internship provides practical experience that is necessary to prepare students for a career in construction management. Moreover, structured internships help students clarify career choices within the construction industry and ultimately lend to opportunities for job placement. Primary to the CM internship is its value as experiential learning. The internship facilitates the student's advancement from apprentice towards mastery, which benefits the student, the employer, and the CM program.

Previous studies have examined various aspects of the benefits provided by an internship for the student, the employer, and the CM program, but none have specifically outlined the value internships provide the CM program for assessment and evaluation to provide a feedback loop for the program's continual improvement. This study examines a required internship program for a CM program at a Midwest university. We briefly discuss the reciprocal benefits of CM internships for the student-industry-program triad, analyze intern and supervisor data collected from the required CM internships, and explain how the CM program used intern and supervisor data for program assessment to ensure continuous improvement in and currency of the curriculum.

Higher education programs must find ways to deliver curricula that are current, relevant, and cultivate agility while at the same time demonstrate evidence of student learning. Accrediting agencies for business programs (e.g., the Association to Advance Collegiate Schools of Business (AACSB) and the Association of Collegiate Business Schools and Programs (ACBSP)) and professional programs such as American Council for Construction Education (ACCE) Council for Interior Design Accreditation (CIDA), and Accrediting Council on Education in Journalism and Mass Communications (ACEJMC)) emphasize continuous improvement of academic programs; thus, holding educators accountable for quality assurance via assessment. Indeed, an outcome of program assessment is to provide criticism and feedback to faculty about their curricula (Bender 2021) and can be an important driver of curricula changes.

Through accreditation standards, advisory boards, and policies, institutions of higher education are building stronger links with industry, suggesting that businesses should be more involved in designing curricula and that higher education institutions should work more closely with industry partners to promote lifelong learning (Healy et al. 2014). Internships are a natural opportunity for businesses and higher education institutions to consistently provide curriculum feedback and to be tapped into current and relevant industry trends, respectively. However, limited information exists on how internships might inform curricula as a feedback loop (Bugeja and Garrett 2019).

This paper provides a template for Construction Management (CM) programs that are interested in incorporating a required internship, as well as using the internship as an opportunity to consistently assess and continuously improve the CM curriculum. A structured internship provides practical experience that is necessary to prepare students for a career in construction management. Previous research indicates students, employers, and schools all benefit from internships and identifies industry contacts for faculty, potential guest lectures, field trip locations, and job placement of graduates, among others as benefits for schools (Jackson 1995, Moore and Plugge 2008, Rosario et al. 2013); however, none have outlined the value internships provide the CM program for assessment. Using a required internship course for a CM program at a Midwest university for analysis, this paper discusses the reciprocal benefits of CM internships for the student-industry-program triad, analyzes intern and supervisor data collected from the required CM internships, and evaluates if existing supervisor evaluation questions adequately allow for an effective internship-curriculum feedback loop.

REVIEW OF LITERATURE

Chapin, Roudebush, and Krone (2003) note that most Associated Schools of Construction (ASC) colleges and universities have cooperative education opportunities for students in the form of industry internships, either as an elective course, a required course, or a general recommendation for employment marketability. The number of studies focusing specifically on CM internships is relatively small, therefore, this study also draws from relevant literature in other academic domains. Additionally, most of the literature specific to CM internships has focused on the benefits for the student and the industry, and relatively little on benefits to the CM program, therefore, we summarize the reciprocal benefit for all three stakeholders.

Value of Internships

Overall, the previous literature shows that internships are mutually beneficial to all three stakeholders: the student, the employer, and the CM program. For student interns, a primary benefit is to apply classroom knowledge to real work environments and gain real-world experience (Cannon & Arnold, 1998; Moore & Plugge, 2008; Hyman-Parker & Smith, 1998). Studies have shown this also affords the student intern opportunities to advance in workplace technical skills (Maulana, 2021; Short et al. 2014) and to enhance soft skills (Adcox, 2000; Short et al. 2014; Tovey, 2001). Through observation of working daily with industry professionals, interns engage in the mentorship process and network with experienced professionals (Cannon & Arnold, 1998; Moore & Plugge, 2008; Short et al., 2014). Other researchers have shown that student interns utilize the internship to evaluate areas of interest for full-time employment and career direction (Hauck et al., 2000; Perez, 2001), as a way to increase their marketability and job opportunities (Cannon & Arnold, 1998; Knouse et al., 1991; Moore & Plugge, 2008; Short et al., 2014) and to gain a better understanding of job expectations and job preparedness (Cannon & Arnold, 1998; Perez, 2001; Wandahl et al., 2012).

For industry employers, the primary benefits of internships are employers' ability to preview the skills and work performance of potential hires, and to develop current mid-level employees' mentoring aptitude which provides the opportunity to share in the growth process of future industry leaders and to work with students who are eager to learn and apply their skills (Moore & Plugge, 2008; Pearce & Bulbul, 2014). Studies have also shown that industry partners use internships to alleviate workforce shortages by filling current staffing needs with interns as temporary employees (Hauck et al., 2000).

Finally, studies have shown a key benefit for the CM program is to build connections and knowledge exchange between the university and industry (Moore & Plugge, 2008; Tovey, 2001; Wandahl, 2011) as well as to develop and strengthen partnerships with business and industry (Adcox, 2000; Moore & Plugge, 2008). On the academic side, studies have shown that internships enhance and deepen students' growth experience (Hauck et al., 2000) and boost job placement rates of graduates (Chapin 2003; Moore & Plugge, 2008; Short, 2014). Additionally, Adcox (2000) has argued a prime benefit for the CM program is to gain feedback from the industry for program development and assessment of student competencies and to strengthen industry program partnerships. Table 1 summarizes the benefits to the key stakeholders – students, employers, and programs highlighted in the literature.

Table 1

Benefits of internships for stakeholders

Stakeholder	Benefit
Student	Gain real world experience and apply classroom knowledge to real world experiences Advance workplace technical skills and enhance soft skills Participate in the mentorship process through observing and working with professionals Evaluate areas of interest for full-time employment/career direction Network with experienced professionals Increased marketability/job opportunities Understand job expectations/job preparedness
Employer	Share in mentoring and growth process of future industry leaders Work with students eager to learn and apply their skills Preview skills and work performances of potential hire of full-time employees Fill staffing needs with temporary employees Expose firm and its culture to talented young people
CM Program	Build connections and knowledge exchange between the university and industry Develop and strengthen partnerships with business and industry Enhance and deepen student's growth experience Gain feedback from industry for program development and assessment Job placement of graduates Assessment of student competencies

The benefits of the CM internship to all three stakeholders are apparent. As a result, researchers have contended for a required internship in CM programs (Moore & Plugge, 2008; Short et al., 2014; Wandahl et al., 2011). Based on benefits to students, Short (2014) has argued "participation in an internship program should be considered a pertinent part of the academic requirements for students enrolled in construction education programs" (24). Additionally, Moore and Plugge (2008) found that 79% of industry sponsors hiring interns preferred the internship to be a required, for-credit course, and Wandahl et al (2011) found 80% of companies involved in the internships favored required internships.

The CM program benefits from the required internship as well. Adcox (2000) has argued that CM programs can benefit from industry feedback development and assessment of student competencies, which a required internship makes possible as it includes all students in the program.

ASPECTS OF THE CM PROGRAM

Two important aspects of any academic program are the requirements of the program and the timely updating of the requirements to ensure the curriculum is current and relevant, the latter of which is often driven by program assessment. Because the focus of this paper is on the value of students completing an internship – one of many CM program requirements – and on the value of assessment data obtained from the internship – one of many CM program assessment measures, this section focuses on these two elements within the broader context of CM program requirements and program assessment.

Program Requirements

Students at the Midwest university in this study can earn a Bachelor of Science, Construction Management Comprehensive degree. For the degree, students are required to complete 30 credit hours of general education courses, 7-8 credit hours of additional math and natural science requirements, 69 credit hours of the comprehensive major courses, and 13-14 credit hours of unrestricted electives. Within the comprehensive major courses, students are required to complete a set of technology core courses (7 credit hours), construction core courses (42 credit hours), management core courses (15 credit hours), and an internship (3 credit hours).

Hager and Pryor (2003) analyzed internship standards across four educational fields for utilization in CM programs. These were business education, allied health professions, teacher education and construction education. Their findings suggest there are several categories of internship standards that are common across all four educational fields. These standards include (1) the internship as a semester-long for-credit course; (2) is a collaboration between the student, employer, and university; (3) the student is monitored by a trained university supervisor; (4) site visits are required by all three stakeholders; and (5) students are formally evaluated by the program. Also, a quality internship offers diverse work opportunities for students in the third and fourth year of the program. The required internship examined in this study includes these components and is outlined in what follows.

Before students can register for their internship, three conditions must be satisfied: students must have (1) a junior class standing, (2) a 2.5 cumulative GPA in core courses, and (3) either a minimum of 200 hours of documented construction experience or hold an associate of applied science degree in construction or a closely related field. These conditions help to ensure the students are adequately prepared through classroom and work experience resulting in an internship that is valuable for both the student and employer.

Students also have several responsibilities to secure, prepare for, and complete the internship. First, to secure an internship, students must declare their intention to enroll in an internship by completing an *Intent to Intern* form with the College Career Center. Then, students prepare application materials, review the internship course requirements, and attend University sponsored career fairs to apply for internship opportunities and network with potential employers. Once students have secured an internship, program approval is required to ensure the internship meets the CM program goals. This approval process requires that the company and the student complete separate *Internship Proposal* forms to the College Career Center for review. Once the internship is approved, students prepare for their internship by attending a required Internship Expectations Training course which outlines course requirements and procedures. After all these responsibilities are complete, the student is issued a permit to enroll in the internship course.

Finally, to successfully complete the internship, students must work a minimum of 460 hours over 12 full weeks at one company and complete course assignments that are accessed and submitted via the Canvas learning management system. Assignments include:

- Weekly Journal Entries: Each week students reflect critically on their internship experience, describing their reactions, observations, and thoughts,
- Weekly Discussion Board Posts: Each week students share their experiences and learn from the experience of others by completing posting and replying to other students' posts,
- Training Plan: By the end of week 2, students must submit a training plan that consists of goals for the internship experience and that was developed collaboratively with the company supervisor,
- Midterm Evaluations: Completed by both the intern and the supervisor, this midterm evaluation documents how the first six weeks of the internship has gone from the intern's and supervisor's perspective,
- Site Visit / Conference Call: Sometime during weeks 7-10, the College's internship director conducts a site visit that lasts approximately one hour. The internship director discusses the experience with both the intern and the supervisor, and then proceeds with questions just for the intern,
- Final Evaluations: During the final week of the CM Internship Program, a final evaluation is required to be completed by the supervisor and the intern,
- Final Presentation: Internships are typically completed during the summer, so when students return for the fall semester, they make a final presentation of their internship experience to CM faculty and the internship director,

Overall, the internship is designed as an experience that is an extension of the classroom with student reflection and supervisor mentorship being key aspects of the experience.

Program Assessment

It should be noted that several factors other than program assessment can lead to curriculum changes in the CM program at the Midwest university in this study. These factors include but are not limited to, adjustments in accreditation standards, industry trends, strategic priorities at the college and department levels, and recommendations from advisory boards, employers, and others. However, at the Midwest university in this study, the CM program assessment process is crucial for evaluating CM students' competency or lack thereof. In general, the activities within the CM program assessment process can be summarized as follows:

- Phase 1: Develop learning goals and objectives – identify what students should know when they graduate from the program,
- Phase 2: Curriculum alignment and mapping – identify where students learn these knowledge/skills/ competencies throughout the curriculum,
- Phase 3: Design measures and collect data – identify how we will know if students know these knowledge/skills/competencies,
- Phase 4: Analyze and report findings – analyze assessment data and identify if students know the knowledge/skills/competencies or not,
- Phase 5: Close the loop/develop an action plan – identify what we can do to enhance learning, what specific improvement initiatives will be launched, and the effectiveness of previous improvements.

Moreover, the CM program assessment process incorporates a combination of direct assessments (e.g., course-embedded assessments, standardized assessments, etc.) and indirect assessments (e.g., alumni surveys, internship feedback, advisory committee input, etc.), and we focus on the value of the final evaluations data obtained from interns and supervisors via the required internship.

During the last week of the CM Internship Program, a final evaluation is required to be completed by the supervisor and the intern. The final evaluation by the supervisor reflects honest feedback about the intern and the CM Internship Program. It does not affect the intern's grade but is valuable for continuous improvement efforts of the internship process and program. The final supervisor evaluation questionnaire consists of five-point Likert scale questions and open-ended questions. The Likert scale questions are used to evaluate the intern's workplace skills and professional attributes (e.g., appearance/dress, oral communication, written communication, detail-oriented, etc.) and soft skills and personal attributes/attitudes (e.g., accepting feedback, active listening, dependability, etc.). The open-ended questions are used to evaluate the strengths and weaknesses of the intern, to identify any course work, technical skills, and/or types of experiences that would improve the intern's potential, to describe the value and/or impact of the intern's project/contribution to the company, to understand what comments the supervisor has about the intern if he/she was contacted as a reference, and to obtain information about the supervisor's interest in another intern from the CM Internship Program.

The final evaluation by the intern also consists of five-point Likert scale questions and open-ended questions. The Likert scale questions reflect self-assessment of the intern's workplace skills and professional attributes, soft skills and personal attributes/attitudes, and the level of achievement on the training plan objectives, as well as the intern's evaluation of the internship company (e.g., given ample direction and guidance by the company, felt part of the work team, etc.), the CM Internship Program and requirements, the CM degree program, and the importance of several factors in selecting a full-time position. The open-ended questions typically allow the student to provide more details on the responses to the Likert scale questions.

The CM internships are typically completed during the summer and are administered by a qualified internship director working in the College Career Center. Each fall, the internship director summarizes and shares the final evaluation data obtained from the intern and supervisors with the CM faculty. The faculty use this data along with other assessment data and relevant information to initiate corrective action to improve student learning and/or alter the curriculum.

METHODS & DATA

Building on the work of Jackson (1995), Moore and Plugge (2008), and Rosario et al. (2013), whose work indicates students, employers, and schools all benefit from internships, we use a required internship course for a CM program at a Midwest university and examine the following research questions:

- What are the reciprocal benefits of CM internships for the student-industry-program triad?
- Do the existing supervisor evaluation questions adequately allow for an effective internship-curriculum feedback loop?

Moreover, this paper provides a template for Construction Management (CM) programs that are interested in incorporating a required internship with the intent of using the internship as an opportunity to consistently assess and continuously improve the CM curriculum.

The information and data used to address the research questions include the CM program curriculum from 2010 to 2020 and the final evaluation data of supervisors and interns from 2015 to 2020. On average over this period, 17 students completed one internship per year. In total, 103 students completed internships at 52 unique companies from 2015 to 2020.

RESULTS

Reciprocal Benefits of CM Internships for the Program

There are three primary benefits of the CM Internship Program. First, the program deepens connectivity to construction firms and provides an avenue to “new companies” that have not previously hired CM students. This is important as the school studied in this paper is a student-centric campus and experiential learning is part of its DNA; thus, interconnecting the CM program with practice through engagement with new and existing companies is critical for maintaining a high-quality learner experience. In 2015, 20 CM students interned with 16 unique companies; however, from 2015 to 2020, the partnerships between the CM Program and the construction industry developed and strengthened. Cumulatively by 2020, the total 103 students interning over these six years did so with 52 unique companies. The largest number of new companies that students interned with occurred in 2016 with 13 new companies added to the 2015 list of companies. The smallest number of new companies occurred in 2019 with two additional companies added to the 2015-2018 list of 42 unique companies. Overall, one-third of the 52 unique companies were “repeat” companies from 2015 to 2020, and seven of the 52 unique companies (13%) hired interns in three or more of the six years from 2015 to 2020 with two companies consistently hiring one or more interns each year. This behavior indicates that companies value the internship process and with the addition of new companies each year, the connectivity to companies has expanded beyond Midwest-based companies to companies in Arizona, California, Colorado, Iowa, Minnesota, Nevada, New York, Oregon, Washington, Florida, and Texas. Students also indicate they value these specific companies as 97 of the 103 interns (94%) said they would recommend the company to another student.

The second benefit of the CM Internship Program is that it is an important recruitment tool. This clearly benefits students and employers; however, it also externally validates the quality of the CM program. The CM program at the institution in this study has enjoyed a 100% employment placement rate for a number of years and the internship program is a key component that influences students' ability to secure employment. Additionally, prospective students and parents visiting the CM program often ask about the internship program since they have heard about the value of the program. Ninety of the 103 interns answered the final evaluation question about their career employment status, and only 5% indicated that they would not accept the company's offer nor would they consider working for the company they interned with. It should be noted that many students intern during their junior year and thus have a year or more before going out on the job market; however, 76% indicated they were offered a full-time position with their internship company or would strongly consider an offer if one was given. The remaining 19% indicated they are giving equal consideration to all companies after graduation including the company they interned with. Clearly, outside-the-classroom experiences allow students to obtain practical experience, gain new skills, and develop independent, creative, and critical thinking skills. These attributes are highly desirable to CM employers.

The final primary benefit of the CM Internship Program is that it provides an opportunity for curriculum feedback from supervisors who are working with and mentoring the interns. This feedback can show the CM program areas where students are progressing well in their competency level and areas that need work or are missing. In addition, feedback is also given on students' soft skills which are often much more difficult to observe and measure in the classroom; however, over the course of a semester-long internship, employers can more easily identify a student's current level of maturity in their soft skill development. This employer feedback is a critical aspect of the assessment process and is discussed more fully in the following assessment subsection. Utilizing this assessment process through feedback given by supervisors of interns, the institution's CM program made several changes to its curriculum during the years 2010-2015 and again in 2017 and 2019.

Assessment

At the university in this study, each curriculum assessment cycle is typically a five-year period. With each cycle, the assessment process itself generally improves, but more importantly, major and/or minor curriculum changes occur so the program improves. The assessment results focus on the two most recent five-year periods: 2010-2015 and 2015-2020. Assessment feedback prior to and during the first assessment cycle led to several major curriculum changes during the 2010-2015 cycle. The major curriculum changes occurred in 2012 and 2015 and were driven primarily from industry feedback via the supervisor evaluations at the end of the interns' work experience. Also, additional input was obtained from the industry advisory board which served as confirmation for the changes made.

To summarize the main changes made in 2012, the program added and required a second estimating course that included more emphasis on computer and manual estimating. The program also required a building codes and inspections course where students obtain a working knowledge of the elements associated with all phases of completing a structure in compliance with current building codes.

The feedback obtained also led to a program update in 2015. Those changes included modifying and updating several courses to incorporate current industry concepts and technology. In particular, the virtual design and construction course was updated to include BIM concepts; the human factors and productivity course was overhauled to emphasize soft skills that students often lack as they go on the job market such as negotiating, listening, conflict resolution, and communication skills; a business law course was replaced with a construction law course where contracts specifically used in the construction industry is a primary focus, and construction finance and accounting course was added to build on the principles of accounting course and teach students specific applications of construction finance.

Now that the changes have been implemented, the next step is to evaluate the effectiveness of the program improvements. For that, the quantitative data from the final supervisor evaluation for the period 2015-2020 is informative. An important emphasis of the 2010 – 2015 curriculum changes was to assess the interns' skills/professional attributes and soft skills/personal attitudes. Table 2 shows the assessment results based on responses by supervisors in five categories: consistently exceeds expectations, often exceeds expectations, meets expectations, some improvement needed, and major improvement needed. For Table 2, the first three categories were combined to represent "Meet and Exceed Expectations, 2015-2021". The data reveals that, overall, CM interns consistently meet or exceed expectations across the 30 items. That is, over the past six years, there were only five times when 90% or more of the interns did not meet or exceed expectations for a particular item.

Qualitative results confirm these positive quantitative results as the supervisors also provided comments on the interns' strengths in relation to soft skills. However, more details were also provided on the interns' areas of weakness. The most often cited weakness, which supervisors acknowledged comes with time, is the lack of experience among the interns. After lack of experience came oral and written communication skills and administrative skills including attention to detail, organization, and time management.

Because a goal of the assessment process is continuous improvement, CM curriculum revisions also occurred during the 2016-2020 period; however, those changes were not as extensive as the ones in 2012 and 2015. Table 3 summarizes the curriculum changes from 2016 to 2020, and all of the changes can be linked specifically to recommendations/themes obtained from the open-ended questions of the final evaluation by the supervisor.

Table 2

Mean Evaluation of Internship Supervisors (scale 1 to 5)

	2015	2016	2017	2018	2019	2020	2021
Appearance/Dress	4.30	4.17	4.43	4.33	4.10	4.29	4.32
Oral Communication	3.73	4.17	4.29	4.14	3.90	3.82	4.00
Written Communication	3.63	4.28	4.21	4.00	3.80	3.71	4.00
Detail oriented	3.80	4.06	4.07	4.19	3.90	3.88	4.05
Following instructions	4.45	4.33	4.36	4.33	4.00	4.12	4.26
Knowledge of work	3.61	3.88	4.14	3.71	3.50	3.24	3.74
Leadership	3.61	4.06	3.79	3.79	3.70	3.69	3.68
Organizing effectively	3.75	3.94	4.07	3.95	3.70	3.65	3.89
Problem solving	n.a.	n.a.	n.a.	3.90	3.80	3.53	4.00
Proficiency in technology	n.a.	n.a.	n.a.	4.29	4.30	4.12	4.16
Quality of work	3.80	4.22	4.14	4.20	3.90	4.00	4.26
Sensitivity to Cultural Differences	n.a.	n.a.	n.a.	4.26	3.90	4.06	4.37
Teamwork	4.15	4.50	4.71	4.48	4.10	4.18	4.37
Volume of work	3.75	4.22	4.14	4.19	3.70	3.71	4.16
Workplace protocols	n.a.	n.a.	n.a.	4.19	3.80	4.00	4.26
Accepting feedback	4.00	4.33	4.29	4.33	4.20	3.82	4.37
Active listening	4.15	4.28	4.43	4.29	4.10	4.00	4.26
Dependability	4.28	4.67	4.29	4.48	4.20	4.06	4.42
Enthusiasm	n.a.	n.a.	n.a.	4.33	4.10	4.29	4.42
Flexibility	4.35	4.61	4.29	4.43	4.10	4.41	4.42
Independence	3.98	4.17	3.86	4.14	4.00	4.00	4.05
Initiative	3.85	4.22	4.21	4.29	4.00	3.94	4.21
Interactions with Customers/Clients	3.65	4.28	4.07	4.17	3.80	3.76	4.26
Interactions with Supervisor	4.30	4.50	4.50	4.48	3.90	4.18	4.32
Interactions with Coworkers	4.45	4.56	4.64	4.48	4.00	4.24	4.42
Interest in work	4.25	4.61	4.50	4.52	4.20	4.35	4.42
Judgment	3.89	4.00	3.93	4.14	3.70	3.82	4.11
Patience	4.25	4.17	4.31	4.14	3.90	4.00	4.37
Self-Confidence	3.63	3.94	4.07	4.10	4.00	4.12	4.00
Overall Evaluation	4.08	4.39	4.21	4.38	3.90	4.06	4.16

n.a. The final evaluation was slightly modified in 2018; thus, several items are not available prior to 2018.

Table 3

Changes to CM Curriculum based on Internship Evaluations, 2015-2020 Answering the question: Indicate course work or types of experiences that would improve the student's potential.

	2017		2019		2019
Class	Human Factors and Productivity		Virtual Design and Construction		Estimating, VD+C, Capstone classes
Change	Add in an increased focus on Communication both written and oral, Soft Skills, Negotiation, and Emotional Intelligence		Add in Bluebeam		Add in use of RFI's and submittals to a greater depth in class
	"He could move ahead of the pack by expanding some of his soft skills. Look into classes or books on effective writing, communications & negotiation, and different styles of leadership". (2016)		"As I said in the midterm evaluation, I think teaching the students how to use Bluebeam would be hugely beneficial for everyone. Bluebeam is a widely used program across all of the construction industry". (2017)		Getting more exposure to working job sites, writing RFI's, using industry standard program for document management and document viewing. (2018)
	"As with any engineering degree, some more emphasis on speech and communications & technical writing would benefit a college grad as they head in to the workforce." (2016)		"A class that uses Bluebeam more would be great. Make sure you keep the class there they build a building. Keep encouraging part time job experience". (2018)		Courses associated with field coordination, RFIs, and submittals would be helpful. As would courses that teach subcontracts negotiation, and owner/architect relations. (2018)
	"Communication classes are critical for all interns." (2016) Anything related to growth in decision making, leadership, and verbal communication. (2014)		"Push more software that is relevant to his future position. Proficiency in programs such as BlueBeam will greatly increase value". (2018)		What contributions did the intern provide: "He provided management of the RFI and submittal process. He managed minutes for sub-contractor meetings for the water rec. facility". (2016)
	"I don't believe there are any technical skills the student is lacking. He did everything very well in this aspect. I would begin working on his soft skills and working with people he's never met before". (2018)		"Training in Bluebeam". (2016)		As a general rule, I think colleges should be set up to teach to the role of a Project Engineer. This would heavily involve RFI's, Submittals, Closeouts, Document Posting, etc. These are skills that we typically train but students have not had a lot of exposure prior to joining our team. (2019)

For example, the human factors and productivity course focuses particularly on important soft skills and emotional intelligence. These additions to this class came as a result of supervisor comments. Other changes included adding Bluebeam Revu to the virtual design and construction class as a response to interns describing what software they used in their internship as well as in response to supervisors' written responses. The virtual design and construction class occurs prior to the internship so the next cycle of assessment data will inform us of how effective this initiative was for improving the CM curriculum. The final significant change to the curriculum occurred in three separate classes, estimating II, VD+C, and the capstone course. Each of these classes incorporated an increase in the use of RFIs and submittals as a result of the supervisor's evaluation responses.

In summary, this study provides an example of how indirect measures from the required CM internship are not only used to evaluate students' knowledge/skills/competencies but also to continuously improve the CM curriculum so that students are adequately prepared for their internships and the job market. In addition, the supervisor evaluations inform the university of the industry's view of the interns' skills and lack thereof, and their level of cooperation to collaborate with the institution.

CONCLUSIONS, LIMITATIONS AND FUTURE RESEARCH

This study examines the CM internship as an indirect measure for program assessment. As discussed, the academic internship program provides a feedback loop for a process of continuous improvement that helps to shape and direct the program's curriculum assessment and support best practices for development of an internship program. Internships are a valuable component for a construction management program assessment, while also providing practical experiential learning for students useful for clarifying students' career choices, as well as the equivalent of a 12-week interview with a company. Companies participating in an internship program help train and mentor future construction management professionals and benefit from a preview of possible future employees. Students achieve significant growth in their learning and preparation process through a summer spent with industry mentors. As shown in this study, the assessment process is a useful and positive process that engages industry input into the construction management program.

For the construction industry, input into the internship process and quality of CM programs is essential for the health and growth of the industry. CM programs along with their internships and the construction industry are not separate entities, but reliant on each other for the future. The construction industry needs well-trained talent to manage projects and lead the next generation on constructors. Feedback and input from the industry helps achieve this end by shaping CM programs and their internships.

A limitation of this study is the use of one institution located in one region of the country. Expanding the study to include multiple programs and regions across the US and internationally would strengthen the study findings. A second limitation is all students regardless of their past construction experience were aggregated together in the results. A student's previous construction experience and whether they had done a previous internship can have bearing on the qualitative responses of the supervisors and the quantitative results and could be used as a factor in future studies.

Future research is needed to define and specify the development or structure of a CM internship program and the elements most valuable for program assessment. Researchers have noted the need to develop CM internship standards and guidelines (Hager, Pryor & Bryant, 2003; Moore & Plugge, 2008; Wandahl et al., 2011). This study presents one successful model, but future studies could review and coalesce the strengths from multiple models into an adaptable template for a required CM internship.

References

Adcox, J. (2000). Measuring Complex Achievement: The Construction Management Internship. *Journal of Construction Education.* 5(2), 104-115.

Bender, D. (2021). Internship assessment in professional program accreditation: a 10-year study. *Education+ Training*, 63(2), pp. 256-270.

Bugeja, M. and Garrett, M. (2019). "Making the connection": Aggregate internship data as direct and indirect measure informing curricula and assessment. *Journalism & Mass Communication Educator*, 74(1), pp. 17-30.

Cannon, J. A., & Arnold, M. J. (1998). Student expectations of collegiate internship programs in business: A 10-year update, *Journal of Education for Business*, *73*(4), 202-205.

Chapin, L. T., Roudebush, W. H., & Krone, S. J. (2003). Cooperative education in the Associated Schools of Construction, *Journal of Construction Education*, *8*(1), 55-68.

Ciofalo, A. (1992). *Internships: Perspectives on Experiential Learning. A Guide to Internship Management for Educators and Professionals*, Malabar, FL: Krieger Publishing Co.

Hager, C. J. (2005). *Developing standards for undergraduate university construction education internship programs* (Doctoral dissertation, Texas A&M University).

Hager, R. J., Pryor, C. R., & Bryant, J.A. (2003). A comparison of four domain area standards for internships and implications for utilization in undergraduate construction education internship programs.

Hauck, A. J., Allen, S. Y., & Rondinelli, D. F. (2000). Impact of structured internship programs on student performance in Construction Management curricula. *Journal of Construction Education*, *5*(3), 272-287.

Healy, A., Perkmann, Markus, Goddard, John, and Kempton, Louise. (2014). Measuring the impact of university-business cooperation. Publications Office of the European Union, NC-02-14-337-EN-N.

Jackson, S. (1995). Work-based learning for academic credit., *Journal of Geography in Higher Education*, 19(2), pp. 217-222.

Maulana, A., Ramadhan, M. A., & Mahaliandini, H. (2021, February). Internship Experiences. In *6th UPI International Conference on TVET 2020 (TVET 2020)* (pp. 25-28). Atlantis Press.

Moore, J. D., & Plugge, P. W. (2008). Perceptions and expectations: Implications for Construction Management internships. *International Journal of Construction Education and Research*, *4*(2), 82-96.

Rosario, L., Flemister, E., Gampert, R. and Grindley, C.J. (2013). Cross-campus collation and experiential learning at Hostos community college. *AACandU Peer Review*, 15(1), pp. 25-28.

Short, K., Pearce, A. R., Fiori, C.M., Bulbul, T. & McCoy, A. (2014). The Influence of Internship Participation on Construction Industry Hiring Professionals When Selecting New Hires and Determining Starting Salaries for Construction Engineering Graduates. *Paper presented at 2014 ASEE Annual Conference & Exposition, Indianapolis, Indiana.* 10.18260/1-2--2315, 24, 1.

Tovey, J. (2001). Building connections between industry and university: Implementing an internship program at a regional university. *Technical communication quarterly*, *10*(2), 225-239.

Wandahl, S., & Ussing, L. F. (2012, September). From Apprentice to Master of Science in Master of Science in Engineering—An Educational Experiment. In *Proceedings of RICS COBRA 2012 Conference* (pp. 712-719).

Wandahl, S., Olsen, W., & Ussing, L. F. (2011). Relevance of academic internship to the quality in Construction Management education. *International Journal of Engineering Education*, *27*(5), 1046.

Stick Built vs. Precut Wall Framing for New Home Construction: A comparison of framing labor hours, waste hauls, and purchase orders

Eric A. Holt, Ph.D., University of Denver, eric.holt@du.edu
Mark LaLiberte, Construction Instruction Inc., mark@constructioninstruction.com
Tristan Grant, MaGrann Associates, tristangrant@magrann.com
Jordan Dentz, MaGrann Associates, jordandentz@magrann.com

ABSTRACT

Due to many trends in the construction industry (material cost increase, labor shortages, supply chain issues, pandemic, market demand outpacing supply), the homebuilding industry is looking for alternative ways to frame homes. In response to the National Housing Endowment (NHE) Request for Proposal, the researchers reviewed the literature on the housing market's current state regarding the scale and scope of the skilled construction framers shortage and the current market share of single-family framing method; stick-built vs. precut framing packages. Working with industry partners, the team analyzed time studies for multiple new home builds. It was found that precut wall framing systems save labor hours and reduce cycle times vs. stick-built framing for building homes. But due to the framing labor shortages in many markets and how homebuilders purchase framing labor ($ per sf), homebuilders struggle to see cost savings due to the increased framing efficiencies, so they are hesitant to make the switch. Due to the varying regional cost of materials, labor, and logistics, a home builder needs to fully explore the total cost of ownership for their market to switch from stick-built to a precut framing construction system.

Keywords: Homebuilding, Wood Framing, Stick Built, Precut, Cycle Times

Eric A. Holt is a professor and researcher at the University of Denver (DU). He has 30 years of experience in the homebuilding industry. He teaches Building Systems, Intro to Architecture, and Estimating at DU. His research focus is on the homebuilding industry.

Mark LaLiberte is a partner at Construction Instruction. He has over 25 years of experience and devotes his time to educating the building industry on the benefits of constructing durable, energy efficient, and healthier homes through lectures, video series, and publications.

Tristan Grant is Director of Sustainability of MaGrann Associates NY, formerly The Levy Partnership. He has a background in sustainable design and construction, with a focus on design consulting and testing and verification for green building programs in North America.

Jordan Dentz is Vice President of MaGrann Associates NY, formerly The Levy Partnership. He has 22 years of experience providing consulting and research services to builders and building materials manufacturers with a focus on sustainability.

INTRODUCTION

Due to many trends in the construction industry (material cost increase, labor shortages, supply chain issues, pandemic, market demand outpacing supply), the homebuilding industry is looking for alternative ways to frame homes (McCoy, Koebel, Sanderford, Franck, & Keefe, 2015; Mosa Alomran, 2019; Nanyam, Sawhney, & Gupta, 2017; Tavares, Soares, Raposo, Marques, & Freire, 2021)but the overall environmental and cost trade-offs between the two construction methods are unclear and influenced by the choice of the structural material. A life cycle assessment was carried out to compare two constructive systems (prefabrication and conventional. These disruptive factors force the housing industry to seek innovative ways to build homes (Usher & Burgett, 2019). The National Housing Endowment (NHE) submitted a Request for Proposal to analyze the alternative home framing methodologies. The goal was to investigate current stick-built framing methodologies compared to precut, panelized, and modular construction and their impacts on the homebuilding industry. In response to the NHE RFP, the researchers reviewed the literature on the housing market's current state regarding the scale and scope of the skilled construction framers shortages and the current market share of single-family framing method; stick-built vs. precut vs. panelization vs. modulization. This paper aims to summarize the findings specific to stick-built vs. precut wall framing construction labor framing hours, waste hauls, and the cost of purchase order variance comparisons.

LITERATURE REVIEW

Scale and Scope of the Skilled Labor Shortage

A significant component of increased construction costs is a lack of skilled construction labor. The labor shortage is not a new phenomenon. For decades, builders have felt strapped for skilled labor (Allmon, Haas, Borcherding, & Goodrum, 2000; Chini, Brown, & Drummond, 1999). The U.S. Chamber of Commerce Commercial Construction Index 2019 Q1 shows 81% of firms ask skilled workers to work longer hours, 70% struggle to meet deadlines, 63% have to increase costs, and 40% reject new projects(Contractor Mag, 2019). During the Great Recession, home construction decreased significantly, generating a 26.8% overall decrease in employment, and 22 states experienced a decline of 30% or greater. In addition, in the Great Recession, residential building construction (-262,000 jobs) and specialty trade contractors (-945,000 jobs) lost their jobs. Many of those who left the industry either retired or switched industries completely. This left a large misalignment with the current supply and demand for skilled labor. The next wave of skilled workers to replace those retiring is nowhere to be found (Scopelliti, 2014). With a historically low national unemployment rate, many employment opportunities exist which do not require college degrees or manual labor. Yet younger workers prefer the safety and ease of non-physical labor jobs. Whether in extreme heat or cold, working outside does not appeal to most (Bigelow, Zarate, Soto, Arenas, & Perrenoud, 2019; van Eck & Burger, 2019). In addition, the safety hazards of commercial construction steer people away. The movement towards construction phases being completed in a factory makes the job safer and working conditions more appealing, so many builders want to construct as many parts in a factory before heading onsite (Bertram et al., 2019).

A framers' core job duties are to precisely measure, cut, and assemble the framing lumber needed to build residential buildings (Korpella, 2019). In a 2015 Associated General Contractors of America (AGC) survey, 73% of participants stated difficulty finding qualified carpenters for framing. The duties of a framer include constructing major permanent and temporary structural components of buildings. From this, it is reasonable to conclude there will be significant consequences for the construction firms that fail to obtain enough qualified framing carpenters (Nally, 2018). In this study, Nally focused on the skilled labor shortage in the Central California coast, specifically a job site in Templeton, CA. The framing construction cost increased from 9% to 42% due to the developer going through three framing subcontractors, affecting the timeline by three months. Although certain market factors of central cost California might make it more prevalent, developers across the country face similar problems. According to the national and regional builders surveyed, framing labor rates vary from $6 to $8 per sf on the west coast and east coast, $4 to $6 per sf in the Midwest, and $2 to $4 per sf in the south/southwest. The builders were paying an upcharge for the alternative framing package and were expecting a reduction in price for the labor from the framers. But due to the labor shortage, the framing crews are controlling the market pricing, and local divisions were hesitant to rock the boat with their local framing crews (Holt, Anzlovar, & Welsh, 2021). These cost increases and construction delays ultimately drive up consumer prices and squeeze developers' margins (Nally, 2018).

Current Market Share of Framing Methods

Precut construction is a framing package technique that uses BIM software to calculate framing lumber needs for a project, and precut and label the needed parts based on the home plan. The objective is to reduce site time, labor, waste, hazards, and errors. The precut and marked lumber package product is delivered to the home construction site to be assembled by the framers. Builders fit these pieces together and then add the other essential elements such as plumbing and electricity. The advantages of precut construction include cost reduction from mass production, lowering construction time through the ease of assembly, requiring a lower worker skillset, quality control, higher workplace safety, and less construction wood waste generated. The disadvantages include high factory capital cost, increased costs for planning and design, engineering requirements, and market perceptions (National Association of Home Builders, 2019).

Data on precut, panelized and modular housing market share is limited due to the lack of consistent definitions of both panelized and modular housing across studies. According to NAHB economist Dr. Robert Diez and the Census Bureau Survey of Construction data, 97% of homes built in North America utilize stick-built framing. Before the Great Recession, modular (4%) and panelized (3%) represented 7% of the market share of homes framed offsite, compared to stick-built. After the recession, the combined market share dropped to 3% (Dietz, 2018).

If precut construction can be reproduced at a high volume for the same product, then the upfront costs and time can justify the manufactured construction. Figure 1 represents the percentage of residential builders planning on using prefabricated construction for each construction system in the next year or five years, starting in 2019.

METHODOLOGY

The research team worked with a national homebuilder and national supplier that commissioned a study in partnership with a building science and innovation research firms to evaluate the impact of precut framing package vs. stick-built framing package. Their goal was to investigate current stick-built framing methodologies compared to precut faming methodology.

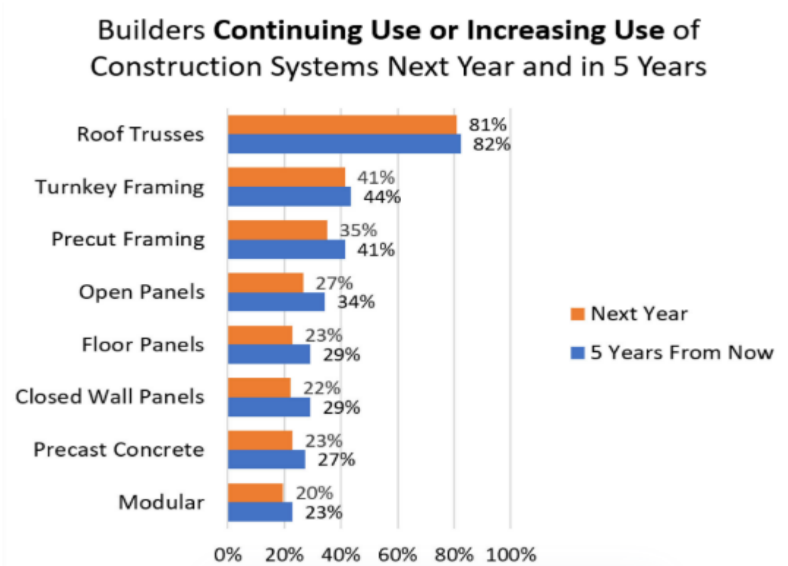


Figure 1: Construction Systems Forecasting (Home Innovation Research Lab, 2019)

Prior to observation, key performance indicators (KPIs) and other variables were identified to most effectively draw direct comparisons between the two construction methods while accounting for external influences. Influencing factors that were documented include the building plan, number of floors, gross square feet, average ambient air temperature, number of days with inclement weather (rain, snow, or heavy wind) during construction, the skill level of workers, and number of workdays missed due to weather.

The KPIs included total labor-hours worked per sf, the number of dumpster hauls from the job site during framing, and the quantity of leftover material. Additionally, KPIs relating to administrative and fulfillment work were documented, including the cost of Flexible Purchase Orders (FPOs) and extra materials incurred by the supplier. This paper discusses the top three KPIs that were impacted from the data research; framing labor hours, waste hauls and leftover materials, and FPOs, and their potential impacts on the homebuilding industry.

The framing construction of twelve homes was observed and documented to compare the use of precut framing to conventional stick-built construction. Six homes were built using precut kits, and six homes were built using conventional stick framing. The researchers were present on the jobsite every day during the framing stage and kept daily logs and observations of the identified KPIs. The jobsite observations were conducted in two batches: Batch 1 homes were framed in February, March, and April 2019. Batch 2 homes were framed in August and September 2019. See table 1.

For each home observed, the supplier gave the researchers the original framing packages purchase orders (POs) and follow-up invoices and POs. The researchers were able to calculate the total miscellaneous inventory and FPO's were generated by each home observed.

Table 1:The Twelve Homes Observed

Batch	Type	Address	Plan #	Floors	SF	Framing Start Date	Framing End Date
1	Precut	2247 Lombardy	2193	2	2193	2/19/2019	3/06/2019
	Precut	2241 Lombardy	1747	1	1747	3/06/2019	3/25/2019
	Precut	2229 Lombardy	2193	2	2193	3/06/2019	3/25/2019
2	Precut	835 Waterloo	2583	2	2583	8/12/2019	8/22/2019
	Precut	851 Waterloo	1685	1	1685	8/15/2019	8/23/2019
	Precut	845 Waterloo	2583	2	2583	8/20/2019	8/28/2019
1	Stick-Built	2259 Lombardy	1920	1	1920	3/27/2019	4/5/2019
	Stick-Built	2113 Summerlin	3489	2	3489	3/29/2019	4/10/2019
	Stick-Built	2263 Lombardy	2841	2	2841	4/12/2019	4/23/2019
2	Stick-Built	712 Vandriver	2583	2	2583	8/28/2019	9/12/2019
	Stick-Built	821 Waterloo	2583	2	2583	9/05/2019	9/16/2019
	Stick-Built	831 Waterloo	1685	1	1685	9/07/2019	9/19/2019

Framing Labor Hour Analysis

The framing labor-hour (FLH) worked per square footage of floor area was calculated for each home. Unfortunately, there were not a enough single story homes observed to run a meaningful comparison analysis of one story homes vs two story homes. Though the weather was observed every day, the workable inclement weather days did not have a significant impact on the FLH observed that day.

The framing labor hours per square footage of floor framed was 27% lower for the precut homes than the stick-built homes (average of 0.073 LH/SF vs. 0.100 LH/SF) despite some precut homes being constructed under more challenging weather conditions. See Table 2.

A regional wall and truss panel manufacturer supplied the research team with wall framing labor and cost data for analysis. They based their study on a 2500 square foot house and Denver labor rates for stick framing (Holt et al., 2021). Applying the data from the research above, the analyst found that the framing cycle time was decreased by almost five days (27%) per house and that by using a precut wall system, the framing crews could frame 3.7 houses per month compared to 2.4 houses using traditional stick framing, an increase of 71%. The builders could pay their framers $0.15 per sf less to break even on the precut framing package price increase (3% decrease in pay per home), but the framing contractor would net a $17,875 increase in monthly revenue (66%) by building one more home each month. See table 3.

Waste Hauls and Leftover Materials Analysis

There was significantly less waste produced on precut construction sites vs. the stick-built sites. Each of the precut sites needed one dumpster haul throughout the framing period, while stick built homes needed 2-5 dumpster hauls. The leftover lumber was counted after framing completion. The precut homes had 5-10 pieces of material left over after framing, while stick-built homes had 163-241 pieces. See Table 4.

Table 2: Framing Labor Hours (FLH) per Square Foot (SF) Framed

Type	Address	Plan #	Floors	SF	FLH	FLH/ SF
Precut	2247 Lombardy	2193	2	2193	165	0.0752
Precut	2241 Lombardy	1747	1	1747	88	0.0504
Precut	2229 Lombardy	2193	2	2193	145	0.0661
Precut	835 Waterloo	2583	2	2583	248	0.0960
Precut	851 Waterloo	1685	1	1685	112	0.0665
Precut	845 Waterloo	2583	2	2583	216	0.0836
Stick-Built	2259 Lombardy	1920	1	1920	199	0.1034
Stick-Built	2113 Summerlin	3489	2	3489	351	0.1006
Stick-Built	2263 Lombardy	2841	2	2841	192	0.0676
Stick-Built	712 Vandriver	2583	2	2583	272	0.1053
Stick-Built	821 Waterloo	2583	2	2583	246	0.0952
Stick-Built	831 Waterloo	1685	1	1685	216	0.1282
Precut Average FLH per SF						0.0730
Stick-Built Average FLH per SF						0.1000
% FLH Savings Precut vs. Stick-Built						27%

Table 3: Stick Built vs. Precut Labor Comparison

	Stick Framing	Precut	% Change	
Days Worked per month	26	26		
Cycle Time Per House (days)	12	7.02	27%	Decrease in cycle time
Houses Completed Per month	2.17	3.07	71%	Increase homes per month
Pay: $ per sf	$5.00	$4.85	-3%	Decrease in $ per sf
Pay per House	$12,500	$12,125	-3%	Decrease in $ per house
Pay Per Month	$27,125	$44,4907	66%	Increase in monthly pay
Income Benefit		$17,824		

Table 4: Waste Hauls and Leftover Materials for Batch 1 Homes

Type	Address	Waste Hauls	Leftover lumber/materials
Precut	2241 Lombardy	1	5 pieces
	2229 Lombardy	1	8 pieces
	2247 Lombardy	1	10 pieces
Stick-Built	2113 Summerlin	5	163 pieces
	2259 Lombardy	2	240 pieces
	2263 Lombardy	5	241 pieces

Assuming a 20-yard dumpster, 3 tons of materials, at $405 + $ 95-ton dump fees (Denver cost), the stick-built framing waste hauls for framing cost $ 500 to $ 4500 more than the precut framing packages.

This has a great potential impact on the homebuilding Industry. Using the 2019 SFH home start #s of 1.06 Million:

- 1.06 Million Homes x 4 Dumpsters = 4.24 million fewer dumpsters sent to landfills
- 4.24 million dumpsters x 3 tons per dumpster = 12.72 million tons of material saved from the landfills
- (4.24 Million dumpsters x $450 rental fees per dumpster) + (12.72 million tons x $95 dump fee) = $3.10 billion in dump fee savings.

Flexible Purchase Orders Analysis

The stick-built homes incurred more expenses relating to Flexible Purchase Orders (FPOs) and extra materials than the precut homes. The precut homes incurred minimal FPO costs, while the stick-built homes averaged $358 per site. The precut homes averaged $151 for extra materials, while stick-built homes averaged $418. The base cost of precut packages is $0.25 per sf more than the stick frame packages; however, when FPOs and miscellaneous framing-related invoices are included, precut packages averaged $0.15 per SF less than stick-built packages. See Table 5 below.

Table 5: Additional Cost per SF

Type	Address	Precut Fee	Misc. Inv. & FPO ($/SF)	Incremental cost / SF (Precut fee, misc inv. & FPO)
Precut	2241 Lombardy	$0.25	$0.06	$0.31
	2229 Lombardy	$0.25	$0.26	$0.51
	2247 Lombardy	$0.25	$0.03	$0.28
	835 Waterloo	$0.25	$0.15	$0.40
	845 Waterloo	$0.25	$0.09	$0.34
	851 Waterloo	$0.25	$0.10	$0.35
Stick Built	2113 Summerlin	$0	$0.48	$0.48
	2259 Lombardy	$0	$1.04	$1.04
	2263 Lombardy	$0	$0.57	$0.57
	712 Vandriver	$0	$0.59	$0.59
	821 Waterloo	$0	$0.24	$0.24
	831 Waterloo	$0	$0.12	$0.12
Average Additional Cost of Precut				$0.36
Average Additional Cost of Stick-Built				$0.51
Precut Savings per SF				$0.15

FINDINGS

This study shows that precut framing packages increase the speed at which homes can be framed. By utilizing precut framing systems, builders would be able to decrease their framing cycle time between two and six days, with an average of five days saved. Framers could increase their production and monthly pay by framing one more house per month. And builders could pay, on average, $0.15 per sf less on the framing labor per house to increase production. The builders would also have an average of 4 fewer dumpster hauls per house.

CONCLUSION AND RECOMMENDATIONS

The research data shows that precut framing can be more efficient in labor, materials, and logistics savings. So why are builders not changing framing methodologies? When the research team asked builders if they were changing their framing systems over to the precut and panel systems, they were hesitant. Even though the data shows increased productivity and reduced labor, the framing crews did not give the home builders a lower price. Part of the problem is that the way framing packages are priced. In most markets, framers typically bid the framing labor as a price per SF. As stated above, labor is one of the home building industry's most significant issues. The lack of experienced framing crews substantially affects stick-built, precut, and panel-built homebuilding. In practice, different field experience is needed for each method, with stick-built requiring the most while setting panels requires the least. Another challenge is that the math in Table 5 above works when builders can guarantee consistent and reliable weekly starts. If the weekly start schedule is disrupted for any reason (weather, logistics, supply chain, etc.), the framers move on to another job to keep their crews working.

The model of paying by the sf makes it hard to negotiate better labor framing rates due to efficiencies. According to the national and regional builders surveyed, framing labor rates vary from $6 to $8 per sf on the west coast and east coast, $4 to $6 per sf in the Midwest, and $2 to $4 per sf in the south/southwest. The builders were paying an upcharge for the alternative framing package and expecting a price reduction for the labor from the framers. But due to the labor shortage, the framing crews are controlling the market pricing, and local divisions were hesitant to rock the boat with their local framing crews. It takes careful negotiations and many discussions to convince the framing crews to change how they build and get paid (Holt et al., 2021).

Another challenge is that moving to precut wall framing means changing the industry's preconstruction practices. Builders must plan ahead, working with the lumber and manufacturer suppliers to resolve their plans structurally and for code compliance. The common practice of letting lumber yards prepare takeoffs for free, ship bunks of lumber to the site, and then rely on framers to manage the materials needs a culture shift. Many production builders and developers are considering home building in a controlled manufactured process, which may drive industry change. It takes the builder, framer, and supplier working together to realize the potential efficiencies in the field.

REFERENCES

Allmon, E., Haas, C. T., Borcherding, J. D., & Goodrum, P. M. (2000). US construction labor productivity trends, 1970–1998. *Journal of construction engineering and management*, *126*(2), 97–104. American Society of Civil Engineers.

Bertram, N., Fuchs, S., Mischke, J., Palter, R., Strube, G., & Woetzel, J. (2019). Modular construction: From projects to products. *McKinsey & Company: Capital Projects & Infrastructure*, (June), 1–34. Retrieved from https://www.mckinsey.com/~/media/mckinsey/industries/capital projects and infrastructure/our insights/modular construction from projects to products new/modular-construction-from-projects-to-products-full-report-new.ashx

Bigelow, B. F., Zarate, V., Soto, J., Arenas, J., & Perrenoud, A. (2019). Attracting and Retaining Tradespeople, an Evaluation of Influencers on Construction Workers in Two Different Trades in Texas. *International Journal of Construction Education and Research*, *15*(3), 163–178. Routledge. Retrieved from https://doi.org/10.1080/15578771.2017.1280103

Chini, A. R., Brown, B. H., & Drummond, E. G. (1999). Causes of the Construction Skilled Labor Shortage and Proposed Solutions. *ASC Proceedings of the 35th Annual Conference California Polytechnic State University - San Luis Obispo, California*. Retrieved from http://ascpro0.ascweb.org/archives/1999/chini99.htm

Contractor Mag. (2019). 70% of Contractors Struggling to Meet Deadlines as Labor Shortage Persists. *Contractor Mag*. Retrieved August 5, 2021, from https://www.contractormag.com/construction-data/article/20883834/70-of-contractors-struggling-to-meet-deadlines-as-labor-shortage-persists

Dietz, R. (2018). Modular and Other Non-Site Built Housing. *Eye On Housing*. Retrieved August 5, 2021, from http://eyeonhousing.org/2018/11/modular-and-other-non-site-built-housing/

van Eck, E., & Burger, M. (2019). Millennial quantity surveyors as workforce in the built environment. *International Journal of Construction Education and Research*, *15*(4), 241–255.

Holt, E. A., Anzlovar, J., & Welsh, A. (2021). AMERICAN INSTITUTE of CONSTRUCTORS THE MARK OF A PROFESSIONAL. *AMERICAN INSTITUTE of CONSTRUCTORS*, *46*(02), 31–41. Retrieved March 18, 2022, from www.aic-builds.org

Home Innovation Research Lab. (2019). When & Where Offsite Construction Technologies Will Emerge. Retrieved August 5, 2021, from https://www.homeinnovation.com/trends_and_reports/trends/when_and_where_offsite_construction_technologies_will_emerge

Korpella, R. (2019). The Job Duties of a Framing Carpenter. Retrieved August 5, 2021, from https://work.chron.com/job-duties-framing-carpenter-16027.html

McCoy, A., Koebel, C., Sanderford, A., Franck, C., & Keefe, M. (2015). Adoption of High-Performance Housing Technologies Among U.S. Homebuilding Firms, 2000 Through 2010. *Cityscape*, *17*(2), 167.

Mosa Alomran, O. (2019). *Manufacturing System Design For Low Income Panelized Housing Market*. Retrieved from https://digitalcommons.wpi.edu/mqp-all

Nally, T. J. (2018). *The Skilled Framing Carpenter Shortage on the Central Coast of California: A Focus on Residential Construction*. Retrieved December 31, 2019, from https://digitalcommons.calpoly.edu/cmsp/95/

Nanyam, V. P. S. N., Sawhney, A., & Gupta, P. A. (2017). Evaluating Offsite Technologies for Affordable Housing. *Procedia Engineering*, *196*, 135–143.

National Association of Home Builders. (2019). Panelized Building Systems. Retrieved August 5, 2021, from https://www.nahb.org/en/consumers/home-buying/types-of-home-construction/types-of-home-construction-panelized-building-systems.aspx

Scopelliti, D. M. (2014). Spotlight on Statistics Housing: Before, During, And After The Great Recession. *U.S. BUREAU OF LABOR STATISTICS*. Retrieved August 5, 2021, from https://www.bls.gov/spotlight/2014/housing/pdf/housing.pdf

Tavares, V., Soares, N., Raposo, N., Marques, P., & Freire, F. (2021). Prefabricated versus conventional construction: Comparing life-cycle impacts of alternative structural materials. *Journal of Building Engineering*, *41*.

Usher, T., & Burgett, J. (2019). Consumer Perception and Willingness to Pay for Extended New Home Warranties. *Journal of the American Institute of Constructors*, *44*(1), 23–32.

Best Practices for Reducing Construction Accidents involving Hispanic Construction Workers

Michael E. Asuquo, M.S. and Khalid Siddiqi, Ph.D., Kennesaw State University

ABSTRACT

The objective of this study was to determine best practices for reducing accidents among Hispanic construction workers. It was hypothesized that language barrier between the Hispanics and American workers contributed immensely to high rate of construction accidents on industrial projects. Accident case studies and questionnaire survey were both used. Data was collected through semi-structured interviews with Hispanic workers involved in industrial construction projects in Metro Atlanta. Findings from the study concluded that most accidents involving Hispanic workers were caused due to lack of communication from supervisors, ignorance of workers on work procedures, lack of equipment training, and worker negligence. Language barrier was found to be the underlying cause for construction accidents in some instances but not all. The intended audience for this study were sub-contractors who use Hispanic construction workers for industrial projects.

Keywords*:* Language barrier, Hispanic construction workers, Industrial projects, Construction accidents, Site safety

Michael E. Asuquo is an Experienced Project management professional with a demonstrated history of working in the construction industry. Skilled in project management using Procore, iSqFt, AutoCAD, Microsoft Office, Microsoft Project, On Screen, Bluebeam, and Primavera. Proficient in Estimating, Scheduling, and Value engineering. Strong operations professional with a Bachelor's degree in Architecture and a Master of Science MS focused on Construction Management from Kennesaw State University.

Khalid Siddiqi: Dr. Khalid Siddiqi is Professor Emeritus of Construction Management at Kennesaw State University. Khalid has served as the Chair of the Accreditation and Training Committees of the American Council of Construction Education (ACCE) entrusted with the task of granting accreditations to BS & MS Construction Management Programs in the US and Canada. Khalid had served as the Chair of Construction Management Department and lead the College of Architecture & Construction Management as College's Interim Dean at Kennesaw State University.

INTRODUCTION

The objective of this study was to explore and determine best practices for construction accident reduction involving Hispanic workers in industrial construction projects. It is a common belief in the construction industry that language barriers between American supervisors and Hispanic workers is the primary cause of construction accidents. This study was conducted to test the validity of the common belief. The findings from the study indicated that language barriers was a minor cause in addition to numerous other major causes for accidents involving Hispanic workers in industrial construction projects. This study intended was to provide guidance to subcontractors for who use Hispanic workers on industrial projects. The study has identified best practices for reducing accidents on industrial projects who employ Hispanic workforce.

BACKGROUND

Hispanic or Latino. Hispanics is a term used to describe a group of United States residents who have a common connection to the Spanish language, while Americans of Latin American descent are termed Latinos (Benson, 2014). According to Webster's Dictionary, Hispanics in the United States includes any person of Cuban, Mexican, Puerto Rican, South or Central American, or other Spanish culture or origin, regardless of race. Latinos are people of Latin-American descent (Webster's 3rd International Dictionary, 2002). Hispanics include workers speaking numerous dialects ranging from Spanish and Central American regional dialects, while Latino represents geographic origins (Benson, 2014) among workers from South America. The terms Hispanic and Latino are used interchangeably, though Hispanic usually refers to people with a background in a Spanish-speaking country, Latino is typically used to identify people who hail from Latin America(Brunette, 2005). According to Benson, the main differentiating aspect is that the label "Hispanic" is typically associated with opulence, whereas "Latino" is associated with a struggle for social and economic justice (Benson, 2014).

Hispanics are the rapid growing ethnic group in the United States today. Hispanics include a considerable proportion of immigrants as well as people whose families have lived within the extant boundaries of the United States for many generations (Brunette, 2005). The US Bureau of the Census uses the term "Hispanic" to tag people of Spanish/Hispanic origin. According to its categorizing system, a person of Hispanic origin may be of any race (Benson, 2014).

Point of Departure. According to Pew Research center, "the Latino population in the United States has reached nearly 58 million in 2016 and has been the principal driver of the U.S demographic growth, accounting for half of the national population growth since 2000 (Flores, 2017)." The Hispanics account for 18% of the nation's population and based on their projections, the Hispanic share of the U.S. population is expected to reach 24% by 2065 (Flores, 2017).

With rapid economic development following the recession experienced between 2008 and 2012, the construction industry has witnessed unprecedented growth. With growth comes an increase in demand for construction workers. Construction, being a major contributor to the U.S. economy, has more than 650,000 employers with over 6 million employees and creates nearly $1 trillion worth of structures each year (Simonson, 2018). This industry has one of the highest rate of construction accidents when compared to other industries. In 2016, construction laborers accounted for 12 of the 32 fatalities among construction and extraction workers in Georgia (Bureau of Labor Statistics, 2018).

Hispanics in the Construction industry. According to Al-Bayati et al, (2017), jobs in the construction industry that are filled by Hispanic workers vary from daily laborers to construction managers (Al-Bayati et al, 2017). In 2013, the Center for Construction Research and Training (CPWR, 2013) remarked that Hispanic workers are typically employed as laborers (26%), carpenters (12%), painters (9%), and drywall installers (4%), to name a few. It also pointed that only 4% of the Hispanic workforce fill management-level positions (CPWR, 2013). In view of this data, it is obvious that 96% of Hispanics, by their nature of work are more vulnerable to Occupational Safety and Health Administration (OSHA)'s big four construction hazards: falls, electrocution, caught in, and struck-by (CPWR, 2013). CPWR (2013) concludes that injuries and fatalities among Hispanic workforce will be higher. The number of Hispanics in the construction work force continues to grow and their fatal and nonfatal occupational injuries are higher than those in any other ethnic group in the United States (Brunette, 2005). The Economic News release of Bureau of Labor Statistics indicate that Hispanics or Latinos had 879 out of 5,190 (17%) fatal occupational injuries in 2016 (Bureau of Labor Statistics, 2017).

Industrial Construction Projects. Industrial projects refer those projects that involve specialized skills in design and construction. They include manufacturing, processing, research and development, warehouse and distribution facilities. Apart from having construction experience, workers in such projects must possess the right knowledge and skills to deal with the aspects of difficulty and compliance to more government regulations as this also covers government assigned projects (Harper and Sons, 2013). Special trainings and programs are provided by the employees and government to ensure that the project is compliant with the rules and regulations set by the government with regards to large industrial construction projects. Industrial projects involve a great amount of risk, and construction accidents are bound to happen. (Harper and Sons, 2013).

RESEARCH METHODOLOGY

Data was collected through semi-structured interviews with Hispanic construction workers who took part in a survey that was designed to evaluate potential factors that could improve their safety on site.

Hispanic workers that partook in the survey included mostly carpenters, laborers, rodbusters, mechanics, electricians, and brick layers who work for sub-contractors engaged in industrial projects in Metro Atlanta. Previous research paper by Thompson and Siddiqi (2007) evaluated potential methodologies that employers in the construction industry could implement to improve safety performance. This paper seeks to add to the earlier study by evaluating inputs from the Hispanic workers who were directly involved in daily construction activities. The responses were analyzed, for similarities and differences with the earlier study.

RESULTS

The survey was sent to American Supervisors, and they were requested to organize the survey among the Hispanic worker-teams, working for them. Each supervisor was requested to use a bilingual worker (English Spanish) to verbally administer the survey and collect responses from Hispanic workers. The questionnaire was administered over a period of two weeks, with 34 responses received at the end of the exercise. It was designed to encourage participation with emphasis on achieving the objective of this study. The survey questions are listed in Table 1 and the response will be analyzed in this section.

Feature	Questions
Origin	Are you Hispanic (from a Spanish speaking country)? What is your country of origin? (Or where are your parents from?)
Language	Which of these languages do you speak/understand? (Check/fill all that apply) Which of these languages do you speak/ understand? (Check/fill all that apply). In your native country, does everyone speak the same language? Does your language/dialect have a name? If yes, please provide… If you don't speak English, how do you interact with your co-workers and your company? Do you speak or understand any other Spanish based language in your country or other countries apart from your language?
Construction Experience	Do you work on only industrial projects? Have you been involved or witnessed any construction accident? What do you think causes accident on construction site? What is your job on the con-struction site?
Safety	Do you think that not speaking English affects your safety on site? Do you believe that not speaking/ understanding English is a major cause of accidents on site? What can be done to increase safety on site? Does your construction site have a Spanish version of Safety guides?

Table 1. Questions asked during the Survey

Origin. Origin can be viewed as the heritage, nationality group, lineage, or country of birth of the person or the person's parents or ancestors before their arrival in the United States (U.S. Census Bureau, 2000).

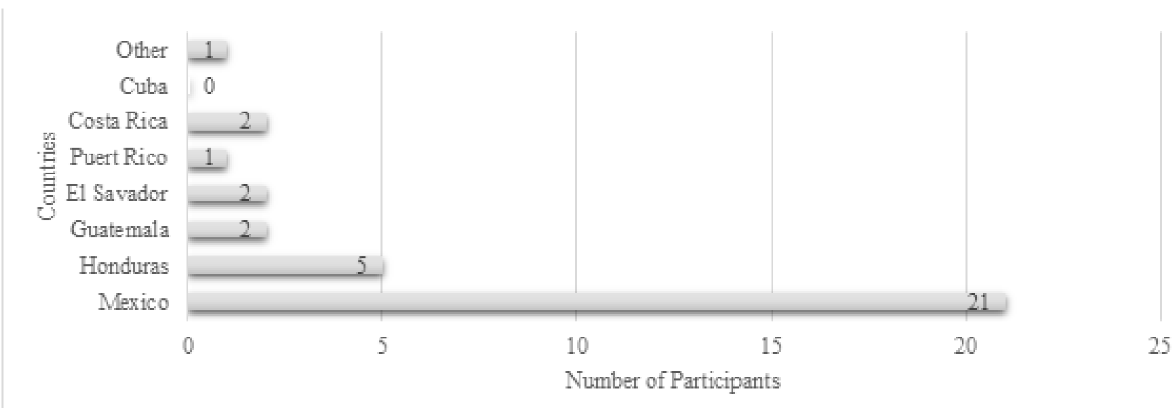


Figure 1: Data Showing country of origin of participants

Mexican-origin Hispanics was the largest Hispanic-origin group in the survey with 21 participants (61.8%) (***Figure 1***). According to Bureau of Labor Statistics, Mexican Americans accounted for 61 percent of the Hispanic or Latino labor force in 2016, around the same share as in 1988 (Bureau of Labor Statistics, 2017).

Language/Communication. About 85.3% of the participants spoke Spanish while 52.9% understood the language. Spanish is an important part of Latino culture and identity, with 95% of Latinos saying it is important for future generations to speak Spanish (Lopez, 2016). A majority of the workers could read and or write Spanish but few of the participants could only speak, understand, read or write English (Figure 2). It was also noted that the participants that could speak, understand, read or write English were the younger ones who were born in the United States. They also acted like interpreters to those who couldn't communicate in English.

A majority of participants acknowledged that their local dialect wasn't the only Spanish language. This meant that Hispanics, though affiliated with Spanish origin, had different dialects. The most common was Espanyol.

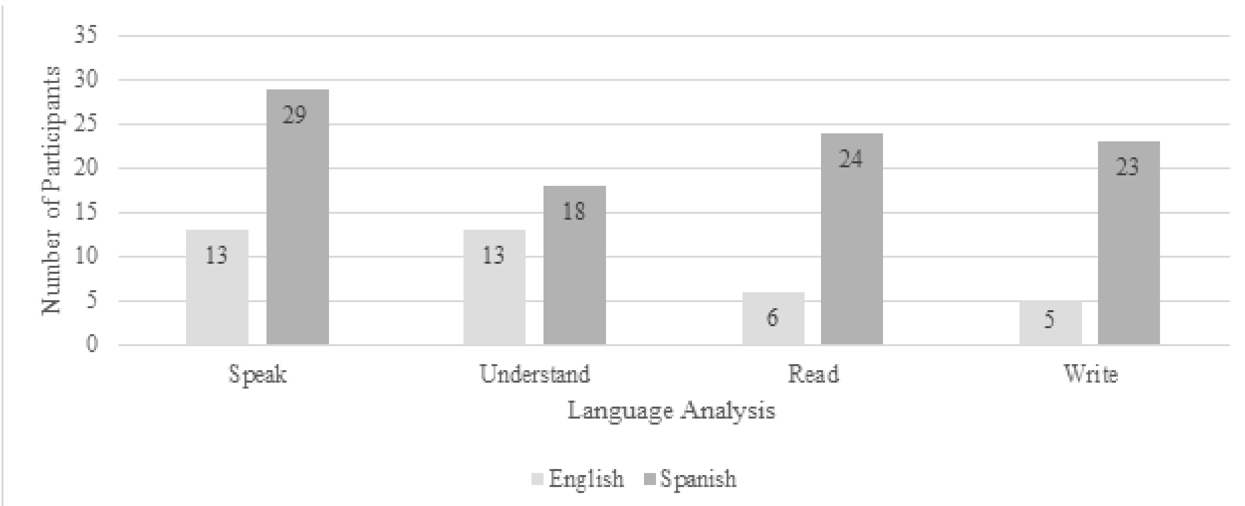


Figure 2: Data showing language statistics for Hispanic workers surveyed

Participants in the survey who speak or understand only Spanish were asked how they interact with their English-speaking co-workers. 71.4% of the participants answered that they interact with their co-workers through non-verbal cues. Others preferred interacting through an interpreter while some avoided interacting with non-Hispanic workers (***Figure 3***).

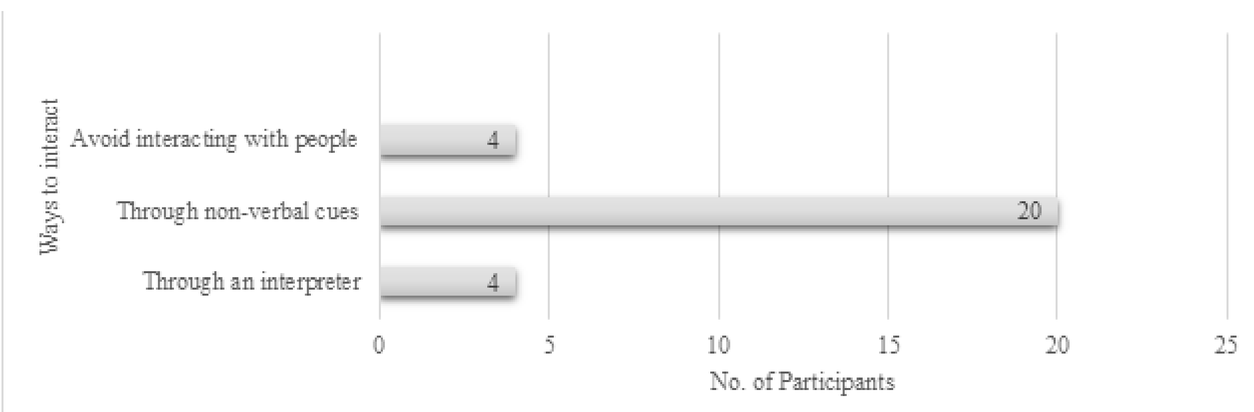
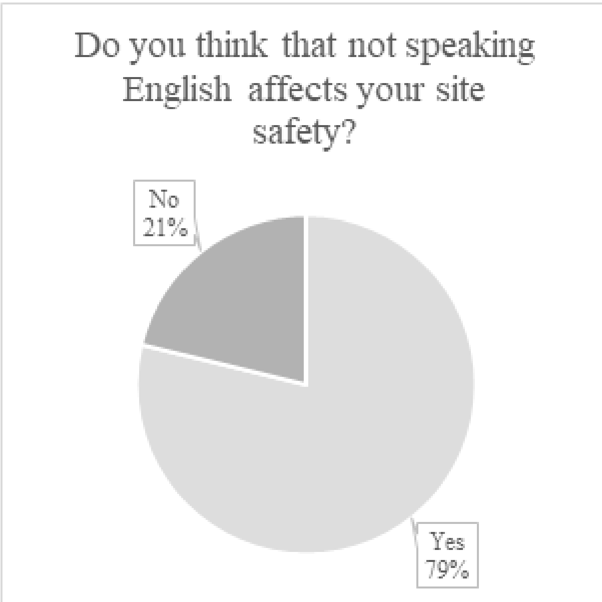


Figure 3: Data showing how non-English speaking Hispanic construction workers interact with their co-workers

Language barrier and Safety. It is pertinent to note that there were divergent views on the role of English language with respect to site safety and construction accidents. While 79% of participants in the survey supported the fact not speaking English affected their safety on site, 51.5% did not believe that it was a major cause of accidents on site (***Figure 4***).



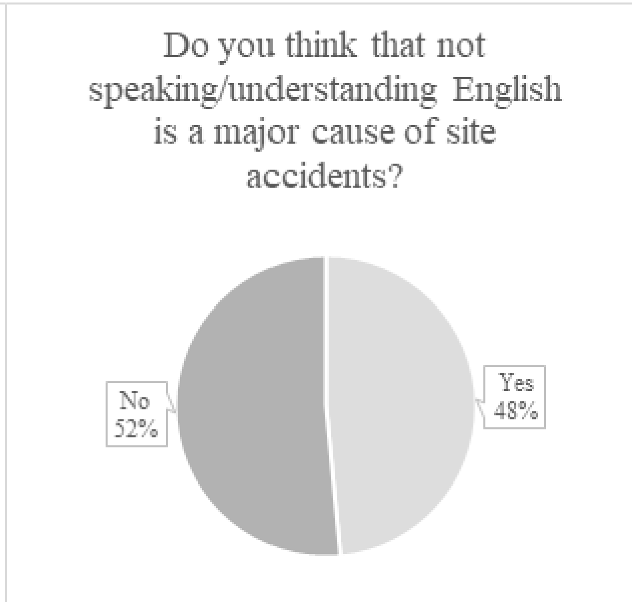


Figure 4a: Data on English and site safety **Figure 4b: Data on English and construction accidents**

Construction Experience. Varying reasons for construction accidents on site were given but 57.6% of participants cited lack of communication as a major cause of construction accidents on site. 39.4% of participants cited language barrier and ignorance of work procedures respectively. Other causes of construction accidents mentioned were lack of equipment training (27.3%), lack of safety orientation (24.2%), and negligence (18.2%) (***Figure 5***).

The participants that the following issues should be addressed to increased safety on site. They include:

a. More communication
b. Interpreters to assist non-English speaking workers
c. Constant training and re-training on use of equipment and machines
d. More safety orientation and meetings
e. Posts in Spanish (English translation)
f. Being more careful and non-negligent

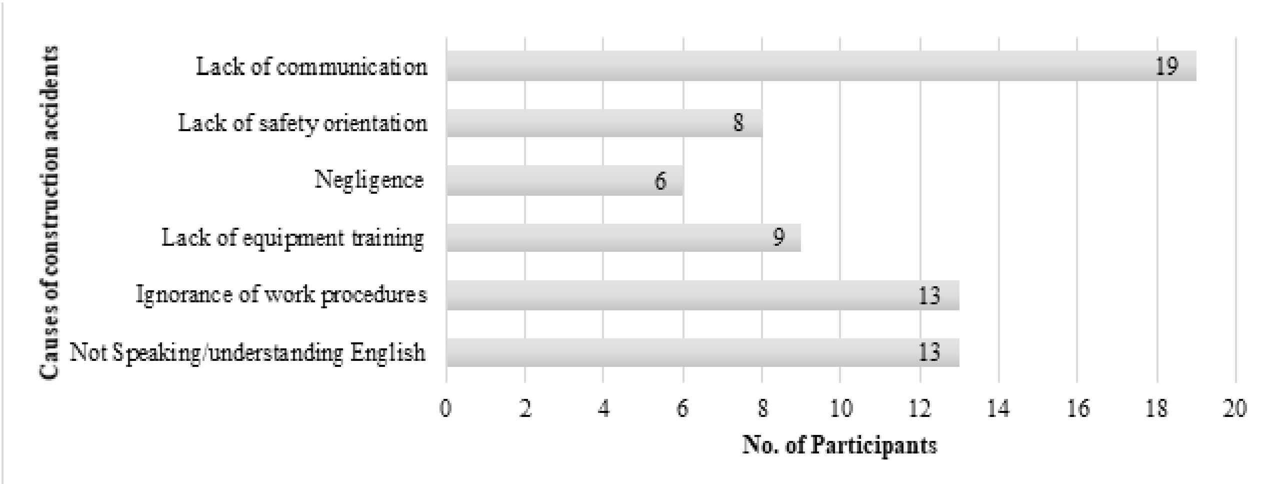


Figure 5:Data on causes of accidents on construction site

These categories are discussed in detail below.

Communication challenges. The participants who had difficulty communicating in English observed that it is tough to understand and follow directives, or to ask questions because of a lack of proficiency with the English language. They further echoed that the translation from English to Spanish is often very poor, and this in turn leads to difficulty in understanding the safety training materials and other rules and expectation on site. In addition, workers have the perception that non-Hispanics feel bothered when communicating with Spanish-speaking workers. These findings also support past literature findings (Jaselskis, 2008); CPWR, 2013. Seven participants in the survey observed that safety communication between Hispanic and non-Hispanic workers can be severely limited because Hispanic workers are unsure of how non-Hispanic workers will react to criticism.

Most participants rely on non-verbal cues like facial expressions and hand and body movement to gain a better understanding of communication on site. Some watch out for keywords when communicating with non-Hispanic workers.

Interpreters to assist non-English speaking workers. Language is one of the major obstacles that Hispanics construction worker face on site. This is because it limits communication between Hispanic and non-Hispanic construction workers involved in a construction project. As mentioned earlier, most participants who are foreign born Hispanics depend on the younger, American born Hispanics for interpretation during safety orientation and meetings, when a general announcement is made, and when instructions are given to them by their English-speaking superintendents. Most participants clamored for their companies to acknowledge the language barrier and provide a designated interpreter who speaks both English and Spanish fluently. This would instill more confidence in them when communicating with their superiors and co-workers.

Constant training and re-training on use of equipment and machines. Several respondents believed that lack of proper training on use of equipment contributed to accidents on construction site. Due to constant innovations, some construction machineries are becoming more complex and needs proper training and retraining to understand its operations. The respondents believed that they should be properly trained, in their language, on how to operate those equipment to minimize construction accidents.

More safety orientation and meetings. Hispanic workers discussed that they prefer to perform their work quickly while paying less attention to safety when compared with non-Hispanic workers. Many of the foreign-born Hispanic workers say that in their native country they are taught to work hard, to get their hands dirty, and not to complain (Roelofs, 2011). According to Kyle Morrison (2015), among workers in some Hispanic cultures, reporting injuries or safety hazards to a supervisor can be considered inappropriate or an inconvenience. Most of the participants stated that they are not to miss work if they became injured. Instead, they should take care of it and continue to work. The result is an increased likelihood of on-the-job injuries (Morrison, 2015). Proper safety orientation should be organized for workers before the start of their job tasks. Emphasis should be placed on JSA and the Hispanic workers should be made aware of their rights and responsibilities. For example, a non-native worker may fear deportation for reporting unsafe conditions (Flynn, 2015) and younger workers may accept work injuries as "part of the job" because of their inexperience and lack of job control (Breslin, 2007). There should be assurance of protection from their management if they report unsafe working conditions and activities on site.

Posts in Spanish (English translation). Most participants noted that there was an improvement in translating English posts and training materials on site. They however advised that these posts be made more visible at site and at strategic locations. They advocated for Spanish version of safety manuals to be made available on site.

Being more careful and non-negligent. For the foreign born Hispanic construction workers, the working conditions in their countries of origin influence their level of safety awareness. Working in unsafe physical environment, little or no safety training, exposure to crude and dangerous tools, machines, and equipment, lack of appropriate personal protective equipment, little or no experience with governmental enforcement of safety regulations among others, form the mindset and experience which in turn is replicated at construction sites in the United States. Hispanic workers may tend to ignore safety issues because they feel that they are less "manly" if they bring them up to a supervisor (Thompson & Siddiqi, 2007). Workers should be made aware of working in a safe environment through orientations and training manuals.

CONCLUSION

The results from the study identified the causes of construction accidents involving Hispanic workers and the best practices for reducing them. It was believed that language barrier between the Hispanics and American workers contributed immensely to high rate of construction accidents on industrial projects. Results from the survey showed that inability to speak English affected the site safety of Hispanic construction workers who participated in the survey. A slight majority argued that inability to speak English was not the major cause of accidents on site. Findings from the survey identified other causes of construction accidents involving Hispanic workforce. The causes include lack of communication; the need for interpreters to be hired to assist non-English speaking workers; constant training and re-training on use of equipment and machines especially the sophisticated ones; more safety orientation and meetings using Hispanic-language manuals and materials; availability of posts in Spanish; and the need to be non-negligent when performing tasks at a construction site. Authors strongly believe that these findings will assist sub-contractors who use Hispanic construction workers on industrial projects. The above are the best practices for reducing construction accidents industrial projects involving the Hispanic workforce.

This study only focused on industrial projects within Metro Atlanta. Future studies are needed on other areas of construction and in other states of US to substantiate the findings from this study. Further research is needed on the impact of government policies on the safety of Hispanic construction workers. Another area of interest would be to identify differences in safety outcomes between unionized and non-unionized Hispanic workforce.

REFERENCES

l-Bayati, A. J., Abudayyeh, O., Fredericks, T., & Butt, S. E. (2017). Reducing fatality rates of the hispanic workforce in the U.S. construction industry: challenges and strategies. *Journal Of Construction Engineering And Management, (3)*.

Benson, A. K. (2014). *Hispanic vs. Latino.* Salem Press Encyclopedia.

Breslin, F.C., Polzer, J., MacEachen, E., Morrongiello, B., Shannon, H.,. (2007). Workplace injury or "part of the job?": towards a gendered understanding of injuries and complaints among young workers. *Social Science & Medicine 64 (4)*, 782-793.

Brunette, M. J. (2005). Development of Educational and Training Materials on Safety and Health: Targeting Hispanic Workers in the Construction Industry. *Family & Community Health*, 253-266.

Bureau of Labor Statistics. (2017, December 19). *Table 1. Fatal occupational injuries counts and rates by selected demographic characteristics, 2015-16*. Retrieved from Bureau of Labor Statistics Website: http://bls.gov/news-releases/cfoi.t01.htm

Bureau of Labor Statistics. (2018, February 22). *Fatal Occupational Injuries in Georgia – 2016.* Retrieved February 13, 2007, from Bureau of Labor Statistics: http://www.bls.gov/regions/southeast/news-release/2018/fatalworkinjuries_goergia_201802222.htm#table3

Bureau of Labor Statistics, U. D. (2017, September 25). 26.8 million Hispanics or Latinos in the U.S. labor force in 2016. *The Economics Daily*. Retrieved April 28, 2018, from https://www.bls.gov/opub/ted/2017/26-point-8-million-hispanics-or-latinos-in-the-u-s-labor-force-in-2016.htm

CPWR. (2013). *The construction chart book: The U.S. construction industry and its workers.* Silver Spring, MD: Center for Construction Research and Training.

Flores, A. (2017, September 18). *Facts on U.S. Latinos, 2015: Statistical portrait of Hispanics in the United States.* Retrieved from Pew Research Center: Retrieved from http://www.pewhispanic.org/2017/09/18/facts-on-u-s-latinos/

Flynn, M.A., Eggerth, D.E., Jacobson, C.J.,. (2015). Undocumented status as a social determinant. *American Journal of Industrial Medicine*, 1127-1137.

Harper and Sons. (2013, September 1). *Construction Works: What is Industrial Construction?* Retrieved from LinkedIn Corporation Web Site: Retrieved from https://www.slideshare.net/harperandsons/harperandson-25802964

Jaselskis, E.J., Strong, K.C., Aveiga, F., Canales, A.R., Jahren, C. (2008). Successful multi-national workforce integration program to improve construction site performance. *Safety Science, 46*(4), 603-618.

Lopez, M. H. (2016, February 19). *Is speaking Spanish necessary to be Hispanic? Most Hispanics say* *no.* Retrieved from Pew Research Center Web Site: Retrieved from http://www.pewresearch.org/fact-tank/2016/02/19/is-speaking-spanish-necessary-to-be-hispanic-most-hispanics-say-no/

Morrison, K. W. (2015, August 23). Why are workplace injuries and deaths increasing among Latino employees? *Safety+Health*.

Paul Thompson, Khalid Siddiqi. (2007). Best Practices for Improving Safety among Hispanic Construction Workers. *Associated Schools of Construction Conference.* Marietta: Southern Polytechnic State University.

Roelofs, C., Sprague-Martinez, L., Brunette, M., Azaroff, L.,. (2011). A qualitative investigation of Hispanic construction worker perspectives on factors impacting worksite safety and risk. *Environ. Health, 10*(1), 84.

Simonson, K. (2018). *Construction Data*. Retrieved from The Associated General Contractors.

U.S. Census Bureau. (2000). *Census 2000.* Washington, DC. https://www.census.gov/history/www/through_the_decades/overview/2000.html

Webster's 3rd International Dictionary. (2002). *latino.*

Total Cost of Ownership of Battery-Powered vs. Hardwired Sensor Faucets in Commercial and Educational Construction Projects

Marie Patterson, California State University, Chico, mepatterson@csuchico.edu

Blake Wentz, California State University, Chico, bwentz@csuchico.edu

ABSTRACT

Owners who are pursing the construction of a new commercial building are becoming increasingly more interested in the sustainability, energy efficiency and life cycle costs of their proposed project. These owners are asking designers and construction companies to develop innovative strategies to lower their utility use and total cost in their projects. One area of opportunity to meet this owner need is the decision to use sensor lavatory faucets that are either battery-powered or hardwired. Several construction projects of various types and locations were analyzed to determine the total cost of ownership of both types of sensor faucets over a 12-year and 25-year timeframe. The results of the unit cost calculation showed that the battery-powered faucets had a lower cost of ownership at 12 years, while hardwired fixtures installed in intervals of six had the lower cost of ownership over 25 years. Although, when researching actual construction projects, where installation in multiples of six faucets isn't realistic, battery-powered faucets had the lower cost of ownership over the hardwired options in both the 12-year and 25-year timeframes in all building types.

Key Words: Sustainability, Life Cycle Cost, Energy Efficiency, Water Efficiency, Plumbing

Mrs. **Marie Patterson** is an Assistant Professor California State University, Chico's Department of Construction Management. She is focused on energy efficiency and sustainability research on various building types in the US. She has also conducted research to improve diversity, equity and inclusion in the construction industry.

Dr. **Blake Wentz** is the Dean of the College of Engineering, Computer Science and Construction Management at California State University, Chico. His research has been in high performance buildings, as well as leadership in construction.

INTRODUCTION

Technology is ever-changing, from computer electronics to cars to even plumbing fixtures. William Sloan patented his flushometer style toilet flush valve in 1906, which revolutionized the plumbing industry by reducing water and energy without the need of a tank, and plumbing manufacturing companies have continued to improve and introduce new technical innovations in their products. Companies such as Sloan Valve Company (Sloan) offer a variety of products such as faucets with hands-free sensing technology with battery-powered operation and power-harvesting technologies, such as solar and turbine products. The variety of product options give designers of new construction projects many options in function, aesthetics, upfront cost, energy efficiency, and water efficiency.

Owners who are engaged in building new commercial buildings have many different requirements for their projects, and owners' needs must be met as they are the key stakeholder on each project. Depending on the type of building and expected occupants, different buildings may have different needs to be met. In recent years owners have become more knowledgeable in the sustainability, energy efficiency, life cycle costs, and ease of maintenance of their buildings. The increased frequency of rating systems such as Leadership in Energy and Environmental Design (LEED), Energy Star, and ASHRAE Building Energy Quotient (bEQ) have shown that it is more common for owners to make energy and water efficiency a requirement on their projects.

One option that is often investigated in commercial and educational projects is the decision to use faucets with sensing technology. Faucets with sensing technology can allow for water savings as the faucets automatically shut off the flow of water while the faucet is not in demand. In addition to water saving technology, faucets with sensors also provide a hands-free operation, which helps reduce the spread of disease and virus (Sloan, 2011).

Sensing faucets require some form of power supply to operate an internal solenoid valve to turn on and off the flow of water. Power can either be battery-powered or hardwired. Each option has its advantages and disadvantages, and each is prevalent in projects across the United States. Many owners prefer the hardwired faucets because of the reliability, reduced maintenance, and perception that this will lead to lower maintenance expenses. However, most contractors prefer battery-powered faucets due to the reduced up-front cost of installation by eliminating the electrical wiring to the device and decreased coordination needed between plumbing and electrical contracting firms. Battery technology is constantly evolving which has led to improving battery life, extending the time between replacements, therefore lowering the maintenance cost of these systems. This study investigated which of these two options had the lower total cost of ownership over the estimated lifespan of the faucet to help owners make informed decisions.

LITERATURE REVIEW

Owners are the key stakeholder for construction projects in this market, and it is critical to identify their ultimate needs within the building (Alshubbak, Pellicer, Catala, & Teixeira, 2015). Many owners are highly concerned about energy and water efficiency and are interested in strategies to reduce their operational and maintenance costs. A study by Gliedt and Hoicka in 2015 showed that many owners and property managers were motivated by economic return and made technology and funding decisions based at least in part on the expectation of direct or indirect economic returns. The commercial building sector in the United States consists of 93 billion square feet of real estate and accounts for 18% of U.S. primary energy use (U.S. Energy Information Administration, 2020). While there is not an inventory of education spaces, it is estimated that PK-12 public schools account for over 6.6 billion square feet (National Forum on Education Statistics, 2012). Based on the size of the building sector, the decisions owner's make during the design stage can have substantial impacts on energy demand and use.

The total cost of ownership of different construction materials relates to the interest of owners in energy efficiency. There have been studies on individual components, such as a 2014 study by Mader and Madani, that showed the total cost of ownership of various control systems for an air-water heat pump. Manufacturers of plumbing fixtures provide similar costs listing different advantages of their products, such as ease of use, reduced maintenance, as well as energy efficiency. But after reviewing the literature there are no peer reviewed studies on the total cost of ownership of battery-powered vs. hardwired sensing faucets.

One of the key benefits of sensing faucets according to manufacturers is the water efficiency achieved (Sloan, 2011). Non-sensing faucets are turned on manually by the occupant while starting to wash one's hands, while continue to run while lathering, when the water is not in demand. Sensing faucets automatically sense an individual's hand placement and turn the water on and off based on the integrated sensor. While each use may save only a small amount of water, when this is multiplied by multiple faucets uses each day per occupant, over many days, the amount of water can be substantial.

But studies have been done to determine if sensor faucets are actually more efficient than manually operated faucets. One such study by the American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) that was looking at the energy efficiency of photovoltaic water heaters showed that when the researchers switched their faucet configuration from a manual faucet to a sensor faucet, average daily hot water volume increased 58% (Fanney, Dougherty, Richardson, 2002). Another study at the Millennium Dome in London over a one-year period showed that the manual faucets used significantly less water, roughly half, than an infrared sensor faucet (Koeller, 2012). Both studies indicate a water savings and energy savings by using a manual faucet, contradicting manufacturer's claims.

Another key benefit of sensing faucets is the hands-free benefit that decreases the transmission of disease and viruses (Sloan, 2011), especially of importance during recent pandemics. Although users often believe flush handles are the dirtiest touch point in a restroom, sink areas are usually more germ-laden, as this is where bacteria are shed from hands during washing (Lozier, 2016). This was further studied by Kurgat et al. (2019) that showed in an office building the most contaminated areas of the building were the refrigerator, drawer handles, sink faucets, the push bar on the main exit of the building, and the soap dispensers in the women's restroom.

When analyzing the faucets life cycle, it must take into consideration the estimated life of the products installed. Product life cycle cost includes three primary phases: production, use and final disposal (Kalbusch & Ghisi, 2016; Gnoatto, Kalbusch, & Henning, 2019). For production, the analysis should involve the manufacturing of the faucets in both scenarios, and amount of conduit and wiring compared to battery production. For the use phase, the analysis would include the maintenance and operation (evaluated as part of this study), in addition to the energy and batteries used. For the disposal, the analysis would include disassembly and recycling of the electrical wire and conduit compared to batteries. Batteries, depending on what type, can be easily recycled, or taken to a manufacturer for recycling. All phases would ultimately include the evaluation of water consumption, energy consumption and global warming potential for all manufactured components (Gnoatto et al., 2019).

METHODOLOGY

The purpose of this research was to identify the total cost of ownership of lavatory sensor faucets and compare different faucet power applications in order to identify any significant differences in installation costs and applications. The researchers partnered with Sloan Valve Company (Sloan) to evaluate their faucets in a variety of settings and applications. The goal of this research is to help owners make informed decisions on the best products for their building projects in terms of the total cost of ownership.

An evaluation of various faucet product lines was conducted, and Sloan provided data on which models of faucets were most popular in terms of use. Sloan provided the product data sheets on these items, as well as preventative maintenance frequency for individual components, replacement part costs, typical life span, and recommended intervals for battery replacement. The researchers and Sloan determined that the following products would be used for this study based the popularity of use based on historic sales for the corresponding building types of the study:

- Sloan Optima Sensor Faucet EBF-425 AA battery-powered (optional turbine) with underdeck mounted manifold
- Sloan Optima Sensor Faucet EAF-350 6V battery-powered with integral temperature mixer
- Sloan Optima Sensor Faucet ETF-420 wired
    - Hardwired with transformer
    - Hardwired for plug-in
- Sloan Basys Sensor Faucet EFX-275 solar-powered

In consultation with Sloan the researchers then evaluated the total cost of ownership in the types of buildings that their faucets were most often installed in; commercial office and educational buildings (K-12 and higher education). To gather the building information, the researchers enlisted a variety of construction firms, including General Contracting and Mechanical Contracting companies, in the United States to participate in the data collection for this research. Companies were recruited from different geographic areas of the United States in order to get a cross-section of projects. The firms that participated in the study were Turner Construction Company, Mortenson Construction Company, DPR Construction Company, JF Ahern Company, and Southland Industries.

Each firm was originally asked via email to participate in the study, and a conference call was followed up to confirm the request and to discuss timeline expectations and project deliverables. The firms were asked to provide the researchers at least two examples of buildings in each category for evaluation. They were asked to provide the design drawings and documents, and upload through a cloud-based folder structure. The researchers requested a variety of projects in terms of size, scope, and geographic location, but no other parameters were given. The researchers then evaluated each project submitted for inclusion in the study.

For the installation costs, the installation instructions provided by Sloan were reviewed, and the researchers consulted with the mechanical and electrical contracting firms to develop the installation steps and materials necessary. The labor hours were then calculated from the installation steps to ensure the total cost of installation was correctly captured. Since the plumbing of hot and cold-water supply was the same for all faucet types, the labor and material cost for the water was not included in the researcher's study. Table 1 shows the installation steps necessary between the different types of faucets evaluated.

The installation of all battery-powered faucets included the labor for plumbing skilled tradespeople for the installation of the faucet and activation of the sensor. No electrical hours are included, as an electrician is not required for the installation of battery-powered faucets.

The installation of all hardwired faucets required electrical tradespeople, in addition to the plumbing trade for setting of the faucet and sensor activation. The electricians had rough-in electrical work inside the walls, that included running conduit and wire from the closest electrical panel to near the location of the faucet. The electrician also had finish work once the drywall was completed to either complete the hardwiring for the transformer model or install the electrical outlet for plug-in model. For the transformer wired faucets there is the opportunity to power up to six faucets from one transformer, reducing the per faucet installation costs when intervals of six were found. For the plug-in faucets there is also the opportunity to daisy-chain up to six faucets together to plug into one outlet, also reducing the cost per fixture. For multiple faucets the installation of conduit and wire from the panel to the restroom were divided into the number of faucets, which reduced the installation cost per fixture.

Table 1. Installation steps of primary faucet types

Installation Steps	**Battery Deck Mount and Solis**	**Hardwired Transformer**	**Hardwired Plug-In**	**Battery Underdeck Mount**
Install conduit and wiring from panel to transformer	-	X	X	-
Install transformer and wiring to faucets	-	X	X	-
Surface mount control box and connect faucet wires	-	X	X	X
Connect control box cable to faucet	-	X	X	X
Install battery pack	X	-	-	X
Activate sensor	X	X	X	X

For the operation and maintenance costs, the data provided by Sloan identified the timeframes, parts, and costs for the recommended maintenance of the faucets. The recommended battery replacement was every three years for normal-use restrooms for fully battery-powered faucets, every six years for the solar-powered faucets, and every ten years for hardwired fixtures that had a battery backup. Each faucet was evaluated over a 12-year and 25-year period to determine if length of operation affected the total cost of ownership.

The estimated labor hour durations for all installation and maintenance requirements were developed with the mechanical and electrical contracting firms. The labor rates used were the national average as provided by the Mechanical Contractors Association of America (MCAA) and the National Electrical Contractors Association (NECA). Union plumbers were assumed for installation of the faucets, activation of the sensors, plug-in of wired faucets, and all preventative maintenance and repair items. Union electricians were assumed for the installation of all conduit, wiring, and transformers required for the hardwired option. There was no shared time savings to perform maintenance and battery replacement simultaneously as it was determined that these are typically different maintenance tasks performed by different maintenance trades. The battery replacement was assumed to be by custodians. Material costs were provided by the electrical contractors based on large project pricing and battery costs were provided by Amazon. Maintenance and labor costs did not consider inflation, escalation, or wage rate increases.

The researchers then calculated the total cost of ownership of the various faucets in both an individual analysis to determine unit cost, as well as cost per each commercial and educational building project. This then allowed for total and average costs per building type for comparison purposes. Each individual project had quantities taken off calculating the total number of restrooms for both women, men and unisex, and the number of faucets in each women's restrooms, men's restrooms, and individual unisex restrooms. For the wired fixtures, if there were two restrooms that shared a wall with one another, and the faucets were both on either side of the wall, similar to shown in Figure 1, those faucets were estimated to share a transformer or outlet to identify potential installation costs savings; instead of individually wired faucets. Figure 1 also shows one of the ideal layouts for a restroom to maximize the installation efficiency of the hardwired faucets. The preferred restroom would either be three faucets back-to-back as shown, or six faucets in a row.

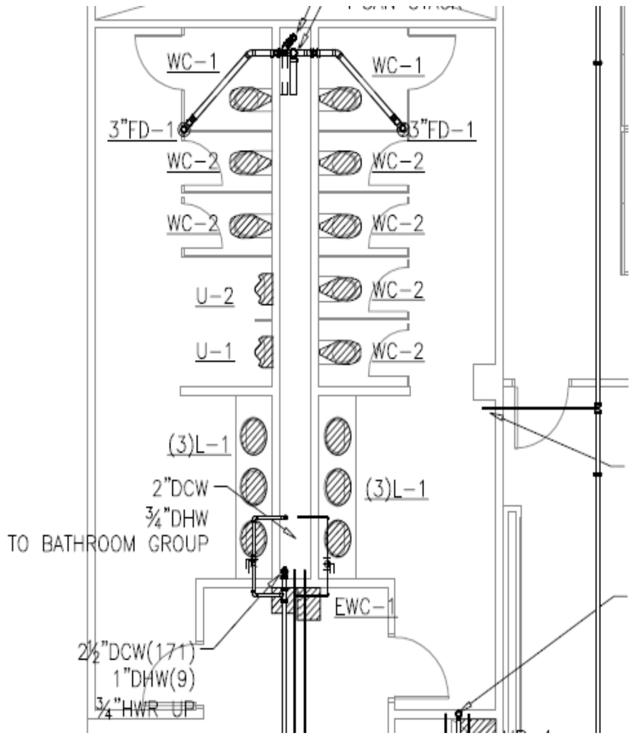


Figure 1. Ideal restroom of three faucets back-to-back to maximize hardwire configuration

RESULTS

A total of twelve projects were submitted by the partnering contracting firms for use in this study. There were six educational buildings and six office buildings submitted and all were included in this study. Of the educational buildings, two are located in Wisconsin, three in California, and one in Illinois. For the office buildings, four are located in Wisconsin and two in California.

While conducting the quantity take-offs for the installation of the faucets, it was discovered that for both the battery-powered and the hardwired faucets there were multiple installation options that could affect the cost. For the battery-powered faucets the battery pack could be either deck mounted (above the countertop) or underdeck mounted (under the countertop). Both options were evaluated. For the battery-powered faucets there is an option for an internal turbine that can be used to generate power and that option was also evaluated.

For the hardwired faucets, each faucet could be wired using a plug-in power connector that could be daisy chained, or a bank of up to six faucets could be hardwired together in series with a transformer. Both options varied the electrical installation and were therefore evaluated. There was also the option to have hardwired faucets include a battery back-up, or not. This option might be recommended to owners who may want an additional power source in the event of a power outage. After consulting with Sloan, they stated that most owners want the battery back-up as a safety measure. The only way to combat the additional maintenance associated with a battery would be to make sure that the electrical circuits the faucets were wired to were tied to an emergency generator, or other form of back-up power. Based on the calculations, the unit rate cost for hardwired with no battery-backup was calculated and found to be most advantageous over 25 years when installed in multiples of six faucets.

The quantity take-offs for each building were completed and all maintenance costs were tabulated for each option on each project. Table 2 shows the results of the total cost of ownership for each faucet option in a 12-year timeframe as well as a 25-year timeframe for commercial building projects. Table 3 shows the total cost of ownership for educational buildings.

Table 2. Total cost of ownership for faucets in office building projects

Faucet	Average Count per Project	12-Year Total	25-Year Total	Percent Increase 12-Year	Percent Increase 25-Year
Battery – AA Deck Mount	38	$39,420.82	$62,089.34	-	-
Battery – AA Underdeck	38	$39,873.78	$62,542.30	1.011	1.007
Battery – SOLIS	38	$43,903.68	$68,073.96	1.114	1.096
Battery – Turbine (SOLIS)	38	$43,980.06	$68,150.34	1.116	1.098
Hardwired – Transformer	38	$45,601.16	$65,032.08	1.157	1.047
Hardwired – Plug-in	38	$45,743.38	$65,174.30	1.160	1.050

The data shown in Table 2 shows that the total cost of ownership is lowest for deck mounted, battery-powered faucets compared to the other styles of battery-powered faucets as well as the hardwired applications. Generally speaking; the traditional battery-powered faucets are the most cost effective in all applications except for the SOLIS solar-powered faucet and the SOLIS turbine option. It is interesting to note that the two SOLIS faucets become the most expensive option at the end of the 25-year period. This is due to the high cost of replacement parts for the solar components and turbine at the end of the maintenance period.

As can be seen in Table 3, the total cost of ownership for deck mounted battery-powered faucets continued to be lower than that of other battery and hardwired applications when compared during both the 12-year and 25-year timeframe. Also, the instance of having the SOLIS faucets become the most expensive at the end of the 25-year period also presents itself in this building type. But when comparing the two building types, the total ownership cost per faucet is almost identical within each faucet type.

Table 3. Total cost of ownership for faucets in educational building projects

Faucet	Average Count per Project	12-Year Total	25-Year Total	Percent Increase 12-Year	Percent Increase 25-Year
Battery – AA Deck Mount	42	$43,687.98	$68,580.96	-	-
Battery – AA Underdeck	42	$44,135.70	$69,028.68	1.010	1.007
Battery – SOLIS	42	$48,231.12	$75,195.54	1.104	1.096
Battery – Turbine (SOLIS)	42	$48,315.54	$75,279.96	1.106	1.098
Hardwired – Transformer	42	$49,083.04	$70,938.85	1.123	1.034
Hardwired – Plug-in	42	$49,708.05	$71,618.40	1.138	1.044

Results show that over a 25-year timeframe that hardwired showed a total cost of ownership of less than 1.034-1.050% from the lowest battery-powered faucet. While additional years were not calculated, the data trends that over time the cost could improve for the hardwired faucets due to the decreased maintenance of battery replacement.

RECOMMENDATIONS AND CONCLUSIONS

The results show that the deck mounted, and underdeck battery-powered faucets have a slightly lower cost of ownership over the life of the product compared to hardwired faucets and the SOLIS faucets. There are significant up-front costs to install hardwired faucets due to the electrical conduit and wiring, which is not present in the battery-powered fixtures. The overall cost of maintenance for the battery faucets is not significantly more than that of the hardwired faucets, except for the SOLIS units, and over the life of the faucet this is not enough to overcome the additional upfront installation costs of the wiring through 25 years.

Ultimately, it is up to the owner to determine their project needs and communicate them to the designers and contractors. They should understand the potential use requirements and whether battery-powered or hardwired are more beneficial based on the use requirements of their building. The estimated life of the building and whether the initial additional costs are worth the reduced maintenance and inconvenience after construction is complete. Commercial buildings might have a shorter life span and owners may choose the battery option, while educational buildings often will last for many decades and stakeholders may prefer hardwired faucets.

Owners of education and commercial construction projects can be informed by the results of this study to make decisions about which types of faucets will produce the lowest total cost of ownership. There are many owners, architects, and construction firms that may believe the total cost would be lower by selecting the hardwired options, and they may be giving inaccurate advice believing that the maintenance costs of the battery-powered and specifically the battery replacement would eventually have a higher total price. Further, the results of this study are similar to studies such as the ASHRAE study in 2002 that showed the marketing claims of the manufacturer that sensor faucets are more efficient can be misleading. The results of this study indicate for these type of projects owners should select a deck mounted, battery-powered faucet for all their bathrooms to achieve the lowest cost of ownership. Owners preferring hardwired fixtures should coordinate and request the building design maximize the installation of six, or multiple, faucets to minimize the installation costs. Where single unisex restrooms are, design two side-to-side or back-to-back to maximize installation efficiencies.

One item of concern that was raised during the investigation of this research was the variability in how owner's maintenance staff monitor the battery-powered faucets for maintenance during the life of the product. The sensors on the faucets have an indicator light to notify facilities staff that a battery is weakening and needs to be replaced. It is up to the staff to be proactive in monitoring the fixtures to replace the batteries before failure. This will require training for the custodial staff to not only monitor the faucets, but also how to properly replace the batteries. This study assumed all custodial staff were trained, followed the recommended procedures and did so in a timely manner. Failure to do so could result in non-operational faucets, increase total costs, and change the results of the study. It was also discussed how most maintenance is performed, which are individual components at a time. For each maintenance or battery replacement, one 30-minute trip was calculated therefore, presenting no time savings for performing multiple maintenance items at once. Future research can be conducted to study the level of understanding of custodial staff in these procedures as well as their effectiveness and associated costs in how they are currently maintaining their faucets.

Another area of possible future research would be to investigate the actual use of the faucets and determine if the recommended maintenance schedules provided by the manufacturer are indeed accurate. The methodology used in this study did not account for actual use, and some buildings may be high-use, or low-use and that could cause the maintenance and battery life to increase or decrease accordingly. Future research could also be conducted on various other building types such as hospitals, healthcare facilities, and athletic facilities to see if the conclusions of this study are valid for those building types. Remodel projects also were not investigated as part of this research, and future research on these types of projects may indicate different results because of the unique constraints of those projects.

A final item that could be investigated is the life cycle analysis and costs of the faucets. This project only investigated the total cost of ownership to the owner of the building project, but life cycle costs include additional costs of the product that could have impact to the client as well as to the community. A study could be done to determine these additional costs as well as the environmental impacts to determine the true overall impact of these devices.

While Sloan is a major supplier of sensor faucets, there are other manufacturers in this market that were not evaluated. Results may differ due to installation methods and recommended maintenance intervals and is a future study that could be performed as well.

REFERENCES

Alshubbak, A., Pellicer E., Catala, J., & Teixeira, J. (2015). A model for identifying owner's needs in the building life cycle. *Journal of Civil Engineering and Management* (pp. 1046-1060).

Fanney, A., Dougherty, B., Richardson, J. (2002). Field Test of a Photovoltaic Water Heater. *ASHRAE Transactions*, [online], https://tsapps.nist.gov/publication/get_pdf.cfm?pub_id=860840 (Accessed January 5, 2022).

Gliedt, T. and Hoicka, C. (2015). Energy updates as financial or strategic investment? Energy Star property owners and managers improving building energy performance. *Applied Energy*, Volume 147, pages 430-443.

Gnoatto, E. L., Kalbusch, A., & Henning, E. (2019). Evaluation of the environmental and economic impacts on the life cycle of different solutions for toilet flush systems. *Sustainability (Basel, Switzerland)*, *11*(17), 4742–. https://doi.org/10.3390/su11174742

Gonçalves, F., Kalbusch, A., & Henning, E. (2018). Correlation between water consumption and the operating conditions of plumbing fixtures in public buildings. Water Science & Technology. *Water Supply*, 18(6), (pp. 1915–1925). https://doi.org/10.2166/ws.2018.013

Kalbusch, A., & Ghisi, E. (2019). Energy consumption in the life cycle of plumbing fixtures. *Water Supply,* 19, (pp. 70–78). doi: https://doi.org/10.2166/ws.2018.053

Kalbusch, A., & Ghisi, E. (2016). Comparative life-cycle assessment of ordinary and water-saving taps. *Journal of Cleaner Production*, 112, (pp. 4585–4593). https://doi.org/10.1016/j.jclepro.2015.06.075

Koeller, J. (2012). More or Less? Studies Find that Actual Results Contradict Efficiency Claims About Sensor-Activated Valves. *Official*, Volume 34, Number 4, (pp26-27). https://www.map-testing.com/assets/reports/IAPMO%20Official%20Mag-Sensor%20Faucets.pdf

Kurgat, E., Sexton, J., Garavito, F., Reynolds, A., Contreras, R., Gerba, C., Leslie, R., Edmonds-Wilson, S., Reynolds, K. (2019). Impact of a hygiene intervention on virus spread in an office building. *International Journal of Hygiene and Environmental Health*, Vol. 222, Issue 3, pp. 479-485

Lozier, Paige. (2016). Electronic Sensor Faucets Improve Hygiene and Conserve Water in Commercial Restrooms. *Architect*, Vol. 105, Issue 1, pp. 74-77.

Mader, G. and Madani, H. (2014). Capacity control in air-water heat pumps: Total cost of ownership analysis. *Energy and Buildings*, Volume 81, pp. 296-304.

National Forum on Educations Statistics (2012). Forum Guide to Facilities Information Management: A resource for state and local education agencies. https://nces.ed.gov/pubs2012/2012808.pdf

Sloan Valve Company. (2011). The battery balancing act - technology vs. application needs. White Paper [online], https://sloan.com/resources/education/white-papers/battery-balancing-act-technology-vs-application-needs (Accessed November 15, 2021).

U.S. Energy Information Administration (2020). Annual Energy Outlook 2020. [online] https://www.eia.gov/outlooks/aeo/ (Accessed January 2, 2022).