AIC

Accelerating Constructor Excellence

The Professional Constructor

Journal of the American Institute of Constructors

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The Professional Constructor

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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.

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The Professional Constructor (ISSN 0146-7557) is the official publication of the American Institute of Constructors (AIC), P.O. Box 15, Custer City, OK 73639. Telephone 580.246.2230, **www.aic-builds.org**.

Call for Applications for the American Institute of Constructors Education Foundation

Dr. Dennis C. Bausman National Construction Education Program Certification Award

The Dr. Dennis C. Bausman National Construction Education Program Award was created by the American Institute of Constructers (AIC) Education Foundation (EF) as the result of the establishment of an endowment in memory of Dr. Bausman to recognize and reward those university construction accredited education programs that serve as AIC Constructor Certification test sites and who prepare their students to take the Certified Associate Constructor (CAC) examination along with performing other initiatives that promote constructor ethics and certification including participating in the AIC National Ethics Competition. The award consists of a custom-designed plaque and a monetary stipend of $4,000. The funds must be used to enhance the education of the award recipient students on the value of construction ethics and professional certification.

Eligibility

1. Be an accredited baccalaureate construction education program and,

2. Serve as an AIC Constructor Certification Commission-approved CAC examination administration test site and administer the examination at least once a year, and

3. Require and/or encourage and effectively prepare students to take the CAC examination and,

4. Demonstrate what the program does to motivate those students who pass the CAC exam to become certified and,

5. Describe what other initiatives during the past year the program has done and/or is currently doing to promote construction ethics and certification involving their students, such as participating in the AIC Ethics Competition.

6. Eligible construction education programs can only receive the award once in any five-year period.

Application Process

1. Eligible construction education programs will submit a formal letter on College or University letterhead, limited to four typed pages. The letter must contain at a minimum the following information:

A. Description of how the program meets the following award eligibility criteria.

i. Be an accredited baccalaureate construction education program and,

ii. Serve as an AIC Constructor Certification Commission approved CAC examination administration test site and administer the examination at least once a year and,

iii. Require and/or encourage and effectively prepare students to take the CAC examination and,

iv. Demonstrate what the program does to motivate those students who pass the CAC exam to become certified and,

v. Describe what other initiatives during the past year the program has done and/or is currently doing to promote construction ethics and certification involving their students, such as participating in the AIC Ethics Competition.

vi. Eligible construction education programs can only receive the award once in any five-year period.

B. Description of how the funds will be used to enhance the education of the program's students on the value of construction ethics and professional certification. Examples include conducting CAC examination preparation courses or sessions, participating in the AIC Ethics Competition, supporting guest speakers who present on construction ethics and/or certification, conducting joint industry advisory committee – student ethics/certification activities, and similar activities.

C. A statement agreeing to submit a written report within one year of the receipt of the award describing the results of how the program expended the award funds.

2. The letter must be signed by the education program head and submitted to the AIC Education Foundation by March 31, 2026 to Dr. Roger Liska (riggor@clemson.edu) with cc: to Andy Wasiniak (awasiniak@walbridge.com).

Selection and Award Process

1. The selection of the award recipient will be done by the AIC Education Foundation Trustees.

2. The designated Foundation representative will receive and review all applications to ascertain whether they are complete in that they answer to all of the award criteria.

3. All Trustees will receive all complete applications and asked to vote for their choice of award recipient that most effectively meet the award criteria.

4. The education program that receives the most votes will be the successful recipient. In the case of a tie, the Trustees will meet to determine the successful recipient.

5. The award will be presented to a representative of the education program at a called meeting of the AIC Education Foundation.

Call for Applications for the American Institute of Constructors Education Foundation Construction Education Faculty and/or Student Travel Award

The Construction Education Faculty and/or Student Travel Award was created by the American Institute of Constructors Education Foundation (AICEF) to help support faculty and/or students of ABET and ACCE accredited two-year, four-year and graduate construction education programs travel to construction-related events such as student competitions, construction education meetings and similar activities. Up to three $2,000 awards will be given each year by the AICEF.

Eligibility

1. Be an ABET or ACCE accredited associate, baccalaureate or graduate construction education program and,
2. Describe what specific initiatives the program has taken during the past year and/or is currently taking to promote the mission of AIC such as taking the CAC examination, participating in its ethics competition, students and/or faculty becoming a member and other similar ways.
3. Eligible construction education programs can only receive the award once every three years.

Application Process

1. Eligible construction education programs will submit a formal letter on College or letterhead, limited to three double-spaced typed pages. The letter must contain at a minimum the following information:

A. Description of how the program meets the following award eligibility criteria.

1. Is an ABET or ACCE accredited associate, baccalaureate or graduate construction education program and,
2. Describe what specific initiatives the program has taken during the past year and/or is currently taking to promote the mission of AIC (such as taking the CAC examination, participating in its ethics competition, becoming a member and other similar ways).

B. Description of how the travel funds will be used to enhance the professional growth of the program's faculty and/or students. Examples include participating in construction student competitions, attending meetings of national construction associations, presenting papers at national construction organization meetings and other similar activities.

C. A statement agreeing to

1. Submit a 1-to-3-page written report within 60-days of using the funds describing the results of how the program expended the award funds.
2. Post 3 social media posts on LinkedIn, Instagram, and one other appropriate outlet, mentioning the AIC Education Foundation, the event that was attended, and the positive learning or value gained from the experience.

D. The letter must be signed by the construction education program head and submitted by March 1, 2026, to chair Andy Wasiniak (awasiniak@walbridge.com), with cc: email to Roger Liska (riggor@clemson.edu) indicating the submittal has been sent. Also, contact Andy Wasiniak with any questions.

Selection and Award Process

1. The selection of the three award recipients will be made by the AICEF Trustees.
2. A designated AICEF representative will receive and review all applications to ascertain whether they are complete in that they have responded to all of the award criteria.
3. All Trustees will receive the complete applications and asked to vote for their choice of the top award recipients that most effectively meet the award criteria.
4. The top construction education programs that receive the most votes will be the successful recipients. In the case of a tie, the AICEF Trustees will meet to determine the successful recipients.
5. The awards will be presented to representatives of the selected construction education programs at a called meeting of the AICEF Trustees.

January 19, 2026

Heat-Related Injuries and Fatalities in Roofing: OSHA Investigations from 2003-2024

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Abstract

This study examines 52 heat-related roofing incidents recorded by the Occupational Safety and Health Administration (OSHA) between 2003-2024 to describe patterns in outcomes and identify trade-specific prevention opportunities. Researchers built a structured dataset from OSHA investigation summaries and analysed frequencies of the incidents and their associations with month, time of day, project type, end use, and age to complement a thematic review of narrative abstracts. Fifty-eight percent of cases were fatalities, with the remainder split between hospitalized and non-hospitalized injuries; these statistics underscore the consequences of heat events that trigger OSHA reporting. There was a clear relationship between number of incidents and season, with nearly 70% of incidents occurring from June to August (although the month was not associated with severity). Time of day showed the highest raw counts of fatalities at midday, but the association with severity was not significant. Project type was the strongest contextual factor, with fatalities disproportionately concentrated in maintenance and repair. Even though it was not significant, there was an overrepresentation of fatalities on single-family and duplex dwellings. The abstract narratives reinforced these findings, highlighting early hospital care as protective and unresponsiveness or collapse at height as a tipping point. Findings support the case for continuous summer controls, rapid escalation to medical care, and targeted planning for maintenance and repair tasks conducted at elevation.

Keywords: Heat Safety, Heat Stress, Roofers, Construction, OSHA

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INTRODUCTION

Roofing consistently ranks as one of the most hazardous construction trades. Roofers face physical demands such as lifting, bending, and balancing at heights, while also working in environments with little shade or ventilation (CPWR 2025; USBLS 2025). The thermal burden of roofing is particularly severe, as dark membranes and asphalt-based materials absorb and radiate solar heat, magnifying exposure to already high ambient temperatures. Combined with heavy exertion, these conditions significantly increase the risk of heat-related illnesses among roofers (CPWR 2025; USBLS 2025).

On a national level, there are a significant number of heat-related illnesses. A study by Dong et al. (2019) reveals that while construction workers make up only about 6% of the U.S. workforce, they account for more than one-third of all occupational heat-related deaths. Roofers are at the second-highest risk index among construction workers for heat-related deaths.

OSHA accident investigation reports provide further insight into why these deaths occur (OSHA 2025a). These reports, combined with the abstracts in case reviews, reveal not only the immediate contributing factors (like absence of rest breaks, shade, water, or acclimatization) but also how proposed federal standards could codify direct protections. The 2024 NPRM *Heat Injury and Illness Prevention in Outdoor and Indoor Work Settings* (Heat Injury 2024) proposes a new standard that would be a "programmatic standard that would require employers to create a plan to evaluate and control heat hazards in their workplace." Roofing falls squarely under the obligations outlined for the construction sector in the rule, which mandates heat injury and illness prevention plans, monitoring of heat exposure, and graded protections once defined heat triggers are exceeded (Heat Injury 2024). The proposal offers various recommendations. However, small entity representatives (SER) providing comments noted that portable shelters cannot be used on work surfaces such as roofs; this reduces the ability to provide adequate shade for workers. Additionally, SERs whose employees worked at height (e.g., roofing) expressed concerns that employees may be put at more danger if they were required to "climb down from their working position for a break and back up afterwards." This illustrates the importance of known data on the impact of heat on varying industry sectors, identifying noticeable trends, and telling stories of those who have been impacted by working in severe heat.

Despite these risks, roofing-specific studies remain limited. Much of the literature aggregates construction, obscuring the distinct combination of thermal stress and elevated work unique to roofing. As a result, the dual hazard of "heat at height" is not well documented.

This study addresses that gap by analyzing OSHA accident investigation reports involving roofing contractors from 2003-2024. By focusing specifically on heat-related injuries and fatalities in roofing, the authors provide a two-decade perspective on incident characteristics, risk factors, and prevention failures.

LITERATURE REVIEW

Heat-Related Illness & the Importance of OSHA Narratives

Occupational heat-related illness (HRI) is driven by "exertional work tasks" while being exposed to ambient temperatures, which inevitably increase a worker's vulnerability to heat-related health

effects. The physical stress and "increased metabolic heat load may trigger incidents through physical fatigue, impaired mental capacity, and misuse of personal protective equipment (PPE)" (Gubernot et al. 2014; Ramsey 1995; Park et al. 2009; Rowlison et al. 2014). As previously established, roofing concentrates several of these factors: workers perform tasks in direct sunlight, work with material with high solar absorptance, and perform heavy work at elevations that limit measures to increase shade. OSHA investigation summary narratives add task, site, and control-level detail, which provide context to incidents and allow researchers to move toward prevention and mitigation strategies that consider key contributors to these incidents and potential causal relationships.

OSHA Case Findings Relative to this Study

Expansive OSHA-based studies show how narrative evidence isolates actionable prevention targets and provides a path towards improvement by clarifying trends and relationships. Huang and Hinze (2003) analysed thousands of OSHA construction cases documenting systematic fall patterns (e.g., predominance of <30-ft fall on new work) and recurring program gaps. Notable to this study was the time of fall occurrence. During July, there were 820 observed accidents (peak); in February, there were 493. Analysis reveals that falls happen more frequently over the summer months (June to August) than they do during the winter months, consistent with other construction worker injuries. With similar findings, Kang et al. (2017) reveal that fall accidents occur mostly on residential housing project types and that when observed by Standard Industry Classification (SIC) code (Kang et al. 2017; Daidj 2014), workers in SIC 1761 (Roofing, Siding, and Sheet Metal Work) have the highest frequency of falls; commercial building projects show the highest frequency of fall accidents, and this is consistent with findings from Huang and Hinze (2003). An analysis of >11,000 reports also identifies falls to lower level as most common, with ladders, roofs, and skylights as frequent sources, reinforcing the high-consequence nature of elevated surfaces where heat and fall risks can potentially co-occur (Alsharef et al. 2023). The significance of fall investigations for roofing and heat-related illness is the additional data that helps determine if some falls are related to the impaired mental capacity experienced by a worker affected by heat stress.

Chi et al. (2013) demonstrate how unsafe conditions and behaviours jointly shape severity and that causal distributions vary by project context—i.e., working actions, required tools, PPE use, temperature, noise level, safety training, and weather conditions, among others.

Heat-specific OSHA enforcement reviews converge on two findings that are relevant to roofing. First, there is a high risk of heat-related injury to workers who are not acclimatized. In a review of 84 enforcement cases from 2012-2013, Arbury et al. (2016) found that 74% of fatalities occurred in the worker's first three days on the job—while 35% occurred on the first day; these statistics indicate a lack of acclimatization programming. Additionally, their study reported a general inadequacy of employer heat-illness prevention programs, with evidence suggesting that the weather was not monitored enough to make workplace adjustments. Tymvios et al. (2016) used OSHA accident investigation summaries from a five-year period and analysed 58 for heat-related cases in construction. They found that accidents were more likely to occur during the summer months of June (*n=15*) and July (*n=21*).

Tustin et al. (2018) reviewed 38 OSHA enforcement investigations from 2011- 2016 supported by consultation records from the Office of Occupational Medicine and Nursing. They stratified cases

by severity to assess whether some risk factors were more prevalent than others. The research team determined that almost half of fatalities occurred on the first day of tenure on the job or a worker's first day back after an extended absence. Both Arbury et al. (2016) and Tustin et al. (2018) show patterns that align with roofing mobilizations that often introduce new workers during peak summer demand. Adding to these contributing factors, Mirhosseini et al. (2024) analysed 370 HRI reports specific to construction and found that the age of the victim as it relates to heat exposure risk played a significant role in determining the severity of heat-related illnesses; the approximate mean age of the victim was 42 in fatal cases, 39 in hospitalized injury cases, and 33 in non-hospitalized injury cases.

Gaps in the Literature and Contribution of this Study

There are gaps in the existing literature about working in the heat and resultant injury. There is an understanding of the general severity of working in the heat, but there is no identifiable work specific to roofing; most HRI research bundles construction work into one category, but roofing combines the microclimate of radiant surfaces with work at heights.

This study advances the body of knowledge by studying roofing-specific evidence from OSHA investigations through the lens of occupational heat risk. By performing quantitative and qualitative analysis on the reports and focusing on variables identified as causal by the broader literature (acclimatization, working environment, temperatures, HRI controls), the study can benchmark these trade-level findings against prior construction-wide heat evidence and enforcement reviews to identify the roofing industry's alignment to or departure from them and confirm established patterns. The team hopes to provide roofing-specific guidance toward further heat-related illness prevention for those in the trade.

METHODOLOGY

Data Source and Case Identification

The researchers electrically identified OSHA accident summary reports and grounded them in OSHA's Integrated Management Information System portal (OSHA 2025a). They used filters to ensure that they acquired data pertinent to this investigation. First, they used the NAICS code for roofing contractors (NAICS 238160). Additionally, they identified cases using keyword selection through the website's interface. The following keywords and corresponding total occurrences in the portal were selected: heat (*n=1,573*), heat index (*n=212*), heat exhaustion (*n=1,073*), heat stroke (*n=660*), and heat-related illness (*n=445*). Searches encompassed Federal OSHA and OSHA-approved State Plan investigations. The data came from OSHA incident reports, and researchers compiled a table that included date of incident, time of incident, age, sex, degree of injury, project type, and end use.

Study Window and Analytic Sample

Filtering resulted in a sample window spanning from August 16, 2003, to July 8, 2024. Initial retrieval yielded 53 roofing- and heat-related reports. After de-duplication and consistency checks, the final analytic sample was reduced to 52 incidents throughout the selected timeframe. All retrieved cases were validated against their OSHA detail pages and retained only if the abstract narrative clearly indicated heat exposure as a direct or contributory factor. In the final dataset,

researchers categorized the severity of injury as "Fatality" (*n*=30), "Hospitalized Injury" (*n*=17), and "Non-Hospitalized Injury" (*n*=5).

Data Analysis

From OSHA records, the authors identified the following variables: incident date, incident time, incident month, age, sex (as reported), severity of injury, project type, and end use. The team performed statistical data analysis using JASP (JASP Team 2025) for descriptive and inferential statistics, complemented by MS Excel® (Microsoft Corporation 2025). Descriptive statistics provided summary data for the cases, while contingency tables and chi-squared tests (x^2) allowed for observation of a pattern of distribution and identification of association. Additionally, standardized residuals allowed the team to determine the associations between the categorical variables (exploratory in nature). Qualitative data analysis involved initial review of all abstracts, followed by initial coding and thematic analysis (Creswell 2009) in MS Excel. This combination of quantitative and qualitative data allowed the team to triangulate statistical patterns with contextual explanations from abstracts; clarify associations; and suggest actionable, trade-specific recommendations for prevention, training, and policy.

FINDINGS

The analysis of 52 OSHA roofing- and heat-related incidents from 2003-2024 provides insight into the characteristics and distributions of cases. The average age of reported victim was 38, and all cases where sex was reported were male workers, which is consistent with the gendered nature of the roofing workforce.

Severity of Outcomes

Fatalities dominated the dataset, representing 58% (*n*=30) of cases. Figure 1 illustrates this stark imbalance. Hospitalized but non-fatal injuries accounted for about 33% (*n*=17), and only 10% (*n*=5) of incidents caused injuries that did not require hospitalization. This distribution highlights the life-threatening nature of heat exposure in roofing, with mortality representing the most likely outcome of an OSHA-recorded case.

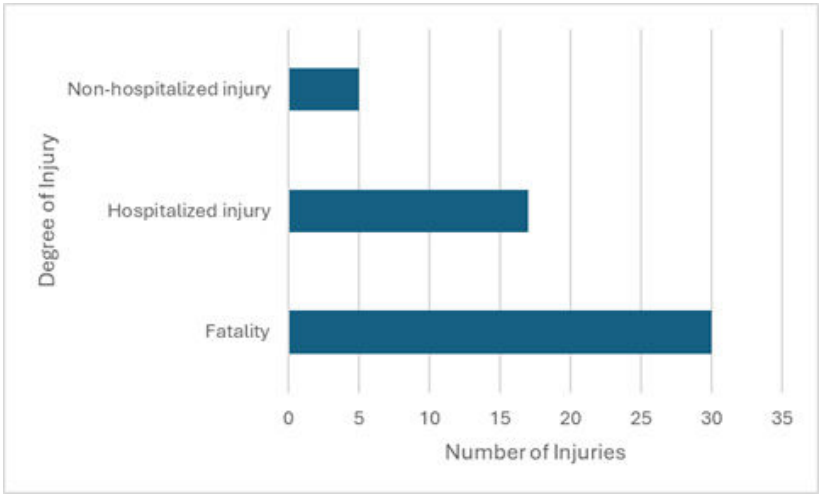

Figure 1. Frequency of Accident by Degree of Injury (*n*=52)

Temporal Patterns

As shown in Figure 2, case frequency was not evenly distributed across years, peaking in 2019. Incident reports were more heavily concentrated in 2017 (*n*=7) and 2019 (*n*=9), with small peaks in 2005, 2008, 2012, and 2020. More recent years (2021–2024) reflect lower incident counts, though this could be influenced by reporting lags. There were no reported cases in 2006.

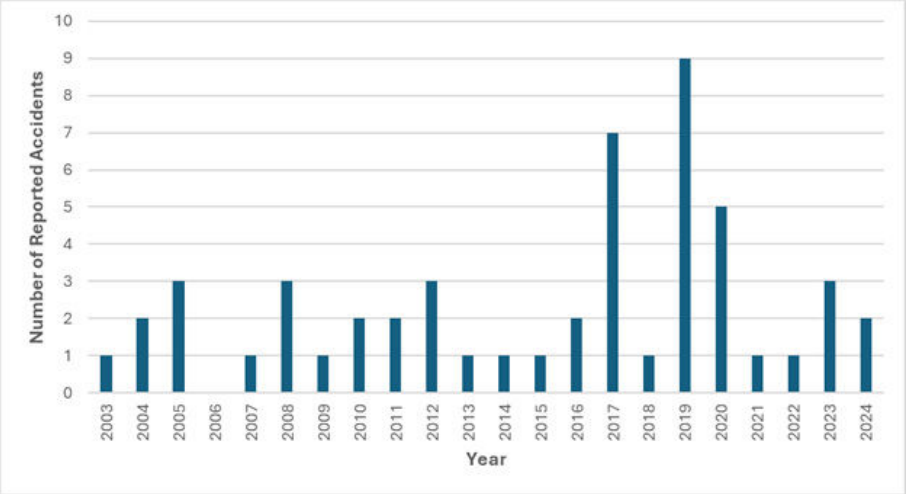

Figure 2. Frequency of Accident Reports by Year, 2003-2024 (*n*=52)

Incidents clustered during peak summer conditions, with July (25%), August (23%), and June (21%) collectively accounting for nearly 70% of all cases. Figure 3 shows a steep rise from May through July, followed by a decline in September, mirroring seasonal temperature patterns. A substantial share of incidents (15%) occurred in September, whereas cooler months like April, October, and November saw only isolated events. This pattern reinforces the temporal relationship between environmental heat and incident rates. It is notable that there were no recorded events in December, January, February, or March.

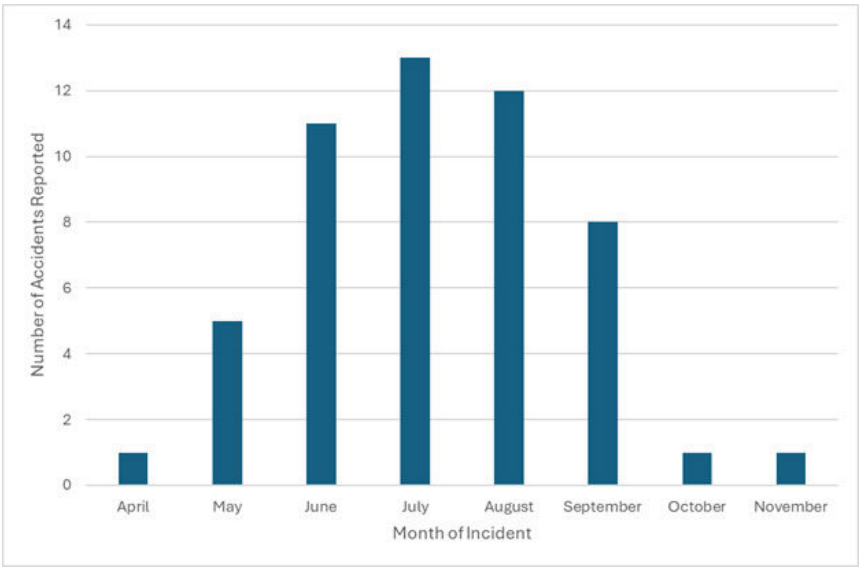

Figure 3. Frequency of Accident by Month

Month vs. Degree of Injury

To test whether injury severity varied significantly by month, the researchers performed a chi-squared test of independence (see Table 1). Results showed no statistically significant association between month of event and degree of injury, $\chi^2(14, N = 52) = 12.733$, p = .548, V = 0.350. In other words, while the frequency of incidents clearly peaks in summer months, the likelihood of those incidents resulting in a fatality versus a non-fatal injury did not differ enough across months to reach statistical significance.

Examination of standardized residuals provides further insight. There were more fatalities in June than would be expected and fewer in July, though July had the highest overall count. Hospitalized injuries were more common than expected in July and April, while less common in June. Non-hospitalized injuries clustered in June and May, suggesting that less severe outcomes may be somewhat more likely earlier in the warm season.

Taken together, the findings indicate that while the absolute number of heat-related incidents among roofers is highly seasonal—peaking in the summer months, the severity of those incidents is not strongly related to calendar month.

Table 1. Contingency Table Comparing Degree of Injury by Month of Event

Degree of Injury		**Month**								
		Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Total
Fatality	Count	0.00	3.00	8.00	5.00	8.00	5.00	0.00	1.00	30.00
	Residuals	-1.18	0.110	1.137	-1.62	0.72	0.30	-1.18	0.87	
Hospitalized Injury	Count	1.00	1.00	1.00	7.00	3.00	3.00	1.00	0.00	17.00
	Residuals	1.45	-0.64	-1.88	1.88	-0.65	0.315	1.45	-0.70	
Non-hospitalized Injury	Count	0.00	1.00	2.00	1.0	1.00	0.00	0.00	0.00	5.00
	Residuals	-0.33	0.83	1.09	-0.27	-0.17	-1.00	-0.33	-0.33	
Total	Count	1.00	5.00	11.00	13.00	12.00	8.00	1.00	1.00	52.00

Time of Day vs. Degree of Injury

The researchers also tested whether the time of day was associated with the severity of outcomes using a chi-squared test of independence (see Table 2). Results showed no statistically significant association, χ^2 (4, $N = 42$) = 4.126, p = .389, V = 0.222. While not statistically significant, the distribution patterns are still informative.

Fatalities were concentrated in midday hours ($n = 16$) and evening hours ($n = 7$), with no deaths reported in the morning. Standardized residuals show that fatalities occurred slightly more often than expected at midday and less often than expected in the morning. Hospitalized injuries, by contrast, were somewhat more common in the morning and underrepresented at midday. Non-hospitalized injuries showed no strong deviation from expected values.

These results suggest that while the highest raw number of fatalities occur (unsurprisingly) around midday, morning hours may be disproportionately associated with hospitalizations. This could

reflect workers beginning exertion before acclimatization, with early symptoms recognized and reported; later in the day, workers may progress more rapidly to fatal heat stroke before intervention.

Table 2. Contingency Table Comparing Degree of Injury by Time of Day

Degree of Injury		Time Group			
		Evening	Midday	Morning	Total
Fatality	Count	7.00	16.00	0.00	23.00
	Residuals	-0.08	0.79	-1.59	
Hospitalized Injury	Count	5.00	8.00	2.00	15.00
	Residuals	0.25	-1.10	1.94	
Non-hospitalized Injury	Count	1.00	3.00	0.00	4.00
	Residuals	-0.27	0.47	-0.47	
Total	Count	13.00	27.00	2.00	42.00

Project-Specific Context

Project Type

To examine whether the type of project influenced the severity of heat-related outcomes, the team performed a chi-squared test of independence. This test allows us to determine whether the observed distribution of fatalities, hospitalizations, and non-hospitalized injuries differs significantly from what would be expected if project type and injury severity were unrelated. The results indicated a statistically significant association between project type and degree of injury, χ^2 (6, N = 52) = 18.592, p = .004, V = 0.427, suggesting a moderate effect size.

The concentration of fatalities in maintenance and repair work is apparent in Table 3, where those cells show the largest positive residuals (+2.29). By contrast, alteration/rehabilitation projects showed a more balanced mix of fatal and non-fatal outcomes, and new projects exhibited distributions close to expected counts. Interestingly, cases where the project type was not reported were more likely to involve injuries (rather than fatalities), as indicated by positive residuals in those cells. These patterns suggest that maintenance and repair work may pose vulnerabilities for roofing crews in hot environments.

Table 3. Contingency Table Comparing Degree of Injury by Project Type

Degree of Injury		Project Type				
		Alteration or rehabilitation	Maintenance or repair	New project or new addition	Not reported	Total
Fatality	Count	13.00	13.00	4.00	0.00	30.00
	Residuals	1.19	2.29	-0.89	-3.59	
Hospitalized Injury	Count	5.00	3.00	4.00	5.00	17.00
	Residuals	-0.74	-1.43	0.83	1.95	
Non-hospitalized Injury	Count	1.00	0.00	1.00	3.00	5.00
	Residuals	-0.81	-1.57	0.17	2.91	
Total	Count	19.00	16.00	9.00	8.00	52.00

Project End Use

A similar chi-squared test was performed to evaluate whether the end use of the facility was associated with injury severity (see Table 4). Results were not statistically significant, χ^2 (12, N = 52) = 15.960, p = .19, V = 0.392, indicating no strong evidence of dependence. Even so, the raw counts highlight that fatalities were most frequent in single-family/duplex dwellings (n = 12) and commercial buildings (n = 8), which together represented two-thirds of fatal outcomes. Standardized residuals in Table 4 indicate that fatalities were overrepresented for single-family or duplex dwellings (+2.07). Although not statistically significant, these patterns may suggest that smaller residential projects may pose a higher heat-related fatality risk.

Table 4. Contingency Table Comparing Degree of Injury by End Use

Degree of Injury		**End Use**							
		Cmrcl. Building	Mfg. Plant	Multi-family dwelling	Not reported	Other	Other Bldg.	Sgl. Fmly or duplex dwelling	Total
Fatality	Count	8.00	1.00	2.00	2.00	1.00	4.00	12.00	30.00
	Residuals	-0.41	0.87	-0.84	-2.69	0.87	1.06	2.07	
Hospitalized Injury	Count	5.00	0.00	3.00	5.00	0.00	1.00	3.00	17.00
	Residuals	0.06	-0.70	1.37	1.30	-0.70	-0.64	-1.24	
Non-hospitalized Injury	Count	2.00	0.00	0.00	3.00	0.00	0.00	0.00	5.00
	Residuals	0.58	-0.33	-0.77	2.43	-0.33	-0.77	-1.50	
Total	Count	15.00	1.00	5.00	10.00	1.000	5.00	15.00	52.00

Age

Researchers performed a similar chi-squared test to evaluate whether worker age influenced the severity of outcomes. The results again revealed no statistically significant association, χ^2 (8, N = 35) = 8.633, p = .374, V = 0.351. However, the age distribution highlights meaningful trends.

Fatalities were most common among workers aged 35-44 (n = 8) and less common among those 55 and older (n = 4). Standardized residuals indicate that the 35-44-year-old age group experienced fatalities more often than expected, while the 25-34-year-old group showed fewer fatalities than expected. Conversely, the 25-34 group was more likely to experience non-fatal hospitalizations.

Table 5 summarizes age distribution and reveals mid-career vulnerability. This pattern suggests that roofers aged 35-44 may be at heightened risk of fatal outcomes—potentially due to cumulative exposure and physical demands—while younger workers (age 25-34) are more likely to survive with hospitalization. Older workers (55+) also demonstrated slightly higher-than-expected fatalities, aligning with literature indicating pre-existing health conditions and reduced thermoregulatory capacity as contributing factors.

Table 5. Contingency Table Comparing Degree of Injury by Age Grouping

Degree of Injury		Age Group					
		18-24	25-34	35-44	44-54	55+	Total
Fatality	Count	2.00	3.00	8.00	3.00	4.00	12.00
	Residuals	-0.84	-2.05	1.73	0.14	1.12	
Hospitalized Injury	Count	2.00	5.00	2.00	2.00	1.00	3.00
	Residuals	0.29	1.24	-1.13	0.29	-0.73	
Non-hospitalized Injury	Count	1.00	2.00	0.00	0.00	0.00	35.00
	Residuals	0.99	1.53	-1.15	-0.74	-0.74	
Total	Count	5.00	10.00	10.00	5.00	5.00	20.00

Thematic Findings from OSHA Abstracts

The authors began their analysis by reviewing the set of OSHA accident abstracts compiled in Excel, with each case represented as a single row. They read each abstract carefully and tagged with changed text color portions of text that reflected early symptoms (such as dizziness, feeling ill, or cramping), signs of escalation (collapse, unresponsiveness, or convulsions), care decisions (on-site rest, water, calling 911), care settings (distinguishing between on-site cooling efforts and hospital admission), and outcomes (including survival, death, or heat-related falls). This step complemented the initial review and allowed for initial coding and theme generation.

Across multiple cases, employees reported feeling ill and were transported or admitted for treatment; these pathways typically ended in recovery. The abstracts described these events in straightforward language, such as “The employee experienced a heat-related illness and was hospitalized” or “He was transported to the hospital and admitted for treatment of the injuries and illness.”

Another theme that emerged was the role of loss of consciousness as a critical turning point. In fatal cases, abstracts often noted that employees were “found unresponsive” or “collapsed,” after which survival was rarely reported. Examples included descriptions such as “Shortly after, the employee was found unresponsive next to a dumpster” or “The employee was found unresponsive in the vehicle and was driven to the nearest fire station.” Once workers reached this state, the progression almost always ended in death, with language such as “The employee died of a heat stroke.” This theme highlights how unresponsiveness marked a near-irreversible stage in the illness trajectory.

A less pronounced but significant theme involved collapse on rooftops leading to fatal falls; this is supported in the literature review, where a significant number of fall accidents occur during the summer months (Figure 3), potentially providing more insight into the significance of HRI and mental impairment. In these cases, heat stress appeared to act as the underlying driver of a chain reaction of confusion, loss of footing, and, ultimately, a fall. For instance, one abstract stated, “Employee became confused, failed to respond to instructions…collapsed on the roof…became unresponsive,” while another noted, “An employee was performing roofing … the employee fell… heat exhaustion or heat stroke were determined to be either contributors to or the cause of the fall.” These accounts illustrate how heat-related collapse creates a dual hazard: the illness itself and secondary trauma from a fall.

A further theme pointed to the limits of on-site rest and hydration once severe symptoms had developed. Several abstracts described efforts to provide shade, rest, or water, but these measures were not sufficient to reverse advanced heat illness. One case reported, "The supervisor instructed the employee to sit under a tree and rest;" the worker later died. Another abstract noted that an employee "did not drink any fluids, although ice and water were available…died as a result of the heat illness." These examples suggest that while shade and hydration are crucial preventive measures, they are not substitutes for urgent medical care once symptoms escalate.

It should also be noted that the abstract included that "the employer had not established or implemented an effective program to prevent heat-related illnesses on their job sites. The company had not trained its permanent employees, managers, and temporary employees to recognize and avoid the risk factors for heat-related illnesses." Although whether the employer had a heat-prevention program was often missing from the abstracts, this specific example—which provides a detailed account—may suggest the importance of an HRI prevention program for those working in the heat.

Convulsions and diagnosed heat stroke formed another theme in the data. Abstracts used blunt descriptions such as "While working on the ground, the employee began to shake and possibly lost consciousness" or "Roofer began convulsing while returning from job; admitted for heat stroke and later died." These accounts underscore the severity of advanced heat illness, with convulsions and heat stroke almost always leading to fatalities.

Finally, transport decisions emerged as a theme, with delays or improvised responses often associated with deaths. Several cases described workers being driven to a fire station or transported only after delays, such as "Found unresponsive in the vehicle and driven to the nearest fire station," or "Coworker sent another to call 911…transported to hospital, later died." These narratives suggest that time lost before receiving definitive care further reduced the chances of survival.

DISCUSSION AND CONCLUSION

Discussion of Quantitative Findings

The analysis of 52 OSHA roofing heat-related incidents confirms several patterns noted in the broader literature while adding trade-specific insight. The majority of cases were fatalities (Figure 1), which reinforces research showing that heat stress in construction often causes severe outcomes and that roofing is among the highest risk trades due to direct sun exposure, heavy exertion, and limited shade at elevation (Gubernot et al. 2014; Park et al. 2009; Ramsey 1995; Rowlinson et al. 2014).

Incidents clustered around peak summer months (Figure 3), consistent with earlier work documenting seasonal concentration of construction injuries (Huang & Hinze 2003; Tymvios et al. 2016). However, the severity of outcomes did not significantly vary by month, suggesting that once a roofing heat incident occurs, timing within the season is less predictive of fatality. Similarly, while fatalities were concentrated at midday and hospitalizations were more common in the morning (Table 2), these differences were not statistically significant despite being in line with studies highlighting the cumulative strain of heat across the workday (Arbury et al. 2016; Tustin et al. 2018).

Project type showed the clearest association, with fatalities disproportionately occurring in maintenance and repair work (Table 3). This aligns with prior findings that project context is related to severity (Chi et al. 2013) and points to the particular vulnerability of smaller roofing crews that face logistical barriers to rest and rescue. By contrast, project end use did not significantly relate to severity, suggesting that the form of work may be more important than the building's function. Also important to note, although not statistically significant, is that smaller residential projects may pose a higher heat-related fatality risk based on standardized residuals (Table 4).

Age patterns also paralleled previous research (Table 5), with roofers within the age range 35–44 showing higher-than-expected fatalities while younger workers were more likely to survive with hospitalization. This supports findings that older and mid-career workers may face greater risk due to cumulative exposure and reduced thermoregulation (Mirhosseini et al. 2024).

Overall, these findings indicate that roofing shares many of the risks identified across construction, but with sharper vulnerabilities tied to project type and workforce age. They highlight the importance of continuous summer prevention efforts, acclimatization programs, and rapid EMS involvement.

Discussion on Thematic Findings of OSHA Abstracts

The reviewed OSHA abstracts fall into several general categories, reflecting both the progression of heat-related illness among roofing workers and the responses from coworkers or employers. These categories include cases where the worker survived and those that resulted in death, with distinct patterns in the actions, or lack thereof, that influenced each outcome.

Scenarios where the worker lived

Cases in which the worker survived typically involved early recognition of symptoms and timely medical intervention. In these instances, workers reported symptoms of heat exhaustion—such as dizziness, cramping, or nausea—either directly or through concerned coworkers. Supervisors or family members then facilitated hospital admission, where the workers recovered. These cases underscore the importance of symptom awareness and prompt response.

Scenarios where the worker died

Fatal cases exhibited greater variability. In some instances, workers attempted to cool down by resting or hydrating but resumed work too soon, leading to heat stroke. In other cases, symptoms were not reported at all, and the worker collapsed without warning. Several reports involved individuals who were new to roofing or to working in high-heat environments, and no precautions were taken to mitigate heat illness. Others wore clothing that was inappropriate for the conditions, such as dark or heat-retaining garments. Several cases also revealed the presence of hyperthermia-inducing substances in the bloodstream during postmortem examinations.

A recurring pattern in fatal cases involved workers who initially experienced heat exhaustion and took short breaks or drank fluids, but not long enough to reduce their core body temperature. Upon returning to work, they progressed to heat stroke and lost consciousness—often fatally.

Reinforcing the implications of Huang and Hinze (2003), there were several reported falls due to heat stroke, either from the roof or from construction equipment.

Another trend involved workers who did not report symptoms and were later found unconscious in secluded areas after taking unsupervised breaks. These cases highlight the dangers of working alone and neglecting to monitor systems.

Several reports note that the deceased workers were new to roofing or heat-intensive environments, aligning with findings from Arbury et al. (2016) and Tustin et al. (2018) on the risks of unacclimated labor. Additionally, Tustin et al. (2018) identified substance use as a contributing factor to heat-related deaths, which researchers confirmed in multiple OSHA cases.

Notably, none of the reviewed reports mentioned the presence of a formal heat illness mitigation plan, reinforcing Arbury et al.'s (2016) conclusion that such plans are often absent in practice.

Implications for Practice

Quantitative study results point to several practical steps for roofing contractors, owners, and safety professionals. First, treat early symptoms as triggers for immediate medical evaluation. Second, keep in mind that midday carried the highest raw fatality counts and that maintenance and repair projects showed a disproportionate share of fatalities. This combination argues for work-rest planning that favors morning productivity windows, scheduled cooling opportunities that are feasible on roofs, and explicit rescue and EMS activation procedures that account for ladder or lift access. Establish shade, hydration, and monitoring that do not depend on leaving the roof, and pair fall protection checks with heat checks since confusion and collapse can lead directly to falls. Third, project teams should align training and supervision to the age pattern observed in the dataset by reinforcing coaching and monitoring for workers within certain age groups while ensuring acclimatization and symptom reporting for newer crews. Fourth, the residual patterns suggesting a great risk of heat-related fatality while working on smaller residential projects warrant targeted prevention efforts. These actions follow directly from the seasonality, time-of-day patterns, and project-type association observed in the quantitative results.

Qualitative data also aided in suggesting actionable steps. The most immediate and actionable strategy for reducing heat-related illnesses and fatalities in roofing is worker education. Training should focus on recognizing early symptoms of heat exhaustion and heat stroke and promoting adherence to OSHA's guidelines: regular hydration, shaded breaks, appropriate clothing, heat acclimatization, and peer monitoring.

A particularly concerning subset of cases involved workers who reported symptoms and received some form of cooling intervention yet resumed work prematurely and later died. This pattern, which appeared in approximately one-quarter of the cases reviewed, suggests a need for more objective criteria to determine when a worker has sufficiently recovered and is fit to return to work. Such criteria might include body temperature monitoring or medical clearance protocols.

Another key takeaway is the frequency of cases in which workers descended from the roof to take breaks, often without any supervision, and were later found unconscious. This occurred in roughly 15% of the cases and supports anecdotal evidence from the small entities representatives (SER) of roofers that descending from the roof for breaks is burdensome and may discourage proper rest. These findings suggest that roofing companies should consider implementing shaded rest areas on roofs, establishing buddy systems to ensure workers are regularly checked on, and developing

supervisory protocols for monitoring workers during breaks. These interventions could reduce the risk of fatal outcomes by ensuring that workers are not left alone during critical moments of heat illness progression.

Conclusion

Roofing presents a dual challenge of heat and elevation that makes late recognition and delayed care especially dangerous. In this two-decade sample, most OSHA-investigated cases were fatal, clustered in summer months, and more likely to be fatal during maintenance and repair work. Month and time of day were not statistically associated with severity, which suggests that once a heat incident occurs on a roof, the calendar is a poor guide to outcome. The narrative abstracts help explain why: early hospital care interrupts progression, while collapse or irresponsiveness often marks a point of increased fatalities. The industry can translate these insights into practice with continuous summer protocols, rapid escalation to medical care, and targeted planning for maintenance and repair tasks to avoid midday sun. Continued tracking of trade-specific patterns and improvement of on-roof cooling and rescue logistics can help close the gap between symptom recognition and definitive care.

Limitations

Consider several limitations when interpreting the results of this study. First, OSHA data represent only reported and investigated cases, which likely underestimates the true incidence of heat-related illness in roofing. This means that the observable data is limited to severe cases. Second, some of the data were incomplete, as we saw with age, sex, and some of the project details. Third, narrative details varied considerably across cases (from a single sentence to paragraphs), which constrained the ability to conduct deeper qualitative analysis. Finally, the relatively small sample size over a 21-year period limits statistical power and generalizability. Despite these limitations, the findings provide valuable trade-specific insight into roofing-and-heat-related risks and highlight critical avenues for prevention and future research. Additionally, abstract reporting was inconsistent throughout; some abstracts were very detailed, while others were very brief. This limited the ability to provide a proper qualitative analysis and comparison across cases.

Generative AI Use Statement

The authors used ChatGPT 5 to guide the data analysis procedure using JASP and guided qualitative data analysis and interpretation. These results were then reviewed and confirmed by the authors for accuracy. Grammarly, Copilot, and ChatGPT 5 were used for writing clarity. The authors have reviewed all content for accuracy.

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The Development of a Convenient and Consistent Methodology for Flight Proficiency to Certify Multi-Rotor UAS Pilots for State Departments of Transportation

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ABSTRACT
To fly an unmanned aircraft system (UAS), commonly referred to as a "drone," the Federal Aviation Administration (FAA) requires pilots to pass a knowledge test. There is no requirement at the state or federal level for drone operators to demonstrate the ability to operate a UAS. The National Institute of Science and Technology (NIST) has created an exam for public and private entities to assess basic UAS flight proficiency. It is the only nationally recognized flight proficiency protocol. NIST does not provide a scoring recommendation and leaves it to the user to determine the minimum criteria to pass. There is limited literature on scoring recommendations and none for state departments of transportation (DOT). This research will fill this gap by evaluating the flight performances of state DOT UAS pilots who participated in this study. Their performance will be used to provide recommended benchmarks that state DOTs can use with their flight skills assessments.

Keywords: UAV, UAS, NIST, drone, proficiency

Author Bios

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Joseph Burgett is an associate professor at Clemson University's Nieri Department of Construction and Real Estate Development. His area of research is unmanned aerial systems with specific applications to the built environment. He is also the Founding President and Director of the South Carolina Interagency Drone Users Consortium (SCiDUC).

INTRODUCTION

Unmanned Aircraft Systems (UAS) are widely used in applications such as medical deliveries, infrastructure inspections, disaster response, construction monitoring, traffic management, and land surveying. A UAS includes the drone, controller, and necessary flight equipment. As of December 2024, over 870,000 drones were registered in the United States (Dees & Burgett 2022).

To operate drones commercially, pilots must obtain a Remote Pilot Certificate from the Federal Aviation Administration (FAA) by passing a written knowledge test. However, there is no requirement for a practical flight evaluation. This creates potential risks for large organizations such as the state DOTs that depend on the widespread use of UAS technology. The absence of federal guidelines for flight proficiency creates challenges in ensuring operational safety. The lack of a convenient method of assessing flight proficiency creates risk for state DOTs, organizations with drone pilots, and the drone community (Dees & Burgett 2023).

The National Institute of Standards and Technology (NIST) has developed a five-maneuver UAS test suite to assess flight control skills. The test suite provides structured evaluations but lacks scoring recommendations and certification guidelines. Given the growing need for proficiency assessments, DOTs struggle to match pilot skill levels with mission complexity.

This research investigates flight proficiency for DOT pilots through interviews, surveys, and flight examinations. Researchers evaluated pilots at various experience levels using a flight simulator replicating NIST maneuvers. The study aims to align flight proficiency with mission complexity and develop standardized certification guidelines.

Key Research Question

As state DOTs expand their use of unmanned aircraft systems (UAS), the absence of practical flight assessment requirements under current FAA regulations poses challenges in ensuring pilot proficiency. To address this, the authors answer the following research question:

What scoring criteria should be used to certify that state DOT personnel have the minimum flight proficiency to operate a multirotor UAS based on mission complexity?

By answering this question, the study's authors seek to establish standardized, quantifiable benchmarks for assessing UAS flight proficiency, enabling DOTs to improve training, enhance safety, and implement cost-effective certification methods.

BACKGROUND AND LITERATURE REVIEW

The rapid adoption of UASs across diverse industries has heightened concerns regarding the safety, reliability, and effectiveness of drone operations (Grazioso 2022). As organizations increasingly rely on UAS technology for tasks ranging from infrastructure inspections to emergency response, ensuring that pilots possess adequate flight proficiency has become essential. This growing reliance has led to a demand for standardized methods to assess pilot competence and implement effective training programs that align with operational needs and risk-management strategies (Harper et al. 2022).

UAS Use by State Departments of Transportation (DOTs)

State DOTs in the United States use drones to track, monitor, inspect, evaluate accidents, survey roadways, assess risk, and perform other vital task (Grazioso 2022). DOTs benefit from the flexibility of drones, reducing cost and response times. The American Association of State Highway and Transportation Officials (AASHTO) identifies the top five drone missions as:

- Capturing photo and video for infrastructure projects.
- Surveying land.
- Inspecting bridges, signage, light poles, and pavement.
- Responding to emergencies and disasters.
- Educating and reaching out to the public.

Additional missions include monitoring endangered species, underwater vegetation, and traffic patterns (Government Fleet Staff 2019). Missions vary in complexity, requiring different skill levels and certification standards. While some tasks (such as mapping) can be automated, others (like bridge inspections) demand highly skilled pilots capable of handling GPS-denied environments and high winds.

Manned vs. Unmanned Aircraft Licensure

The FAA classifies both UAS and crewed planes as "aircraft" but has differing licensure requirements for each. Manned aircraft pilots undergo extensive training, demonstrating their ability to fly through practical exams; drone pilots do not have to meet specific flight proficiency standards. Manned aircraft certifications range from student to commercial pilot levels, each with specific requirements. Training may follow either Part 141, a structured flight school program, or Part 61, which sets knowledge and experience benchmarks (DeVito et al. 2022). For example, a commercial pilot certificate requires 190 flight hours under Part 141 or 250 hours under Part 61 (Johnson, 2014). The specific requirements for flying commercial manned aircraft include:

- Private pilot certificate
- Passing grade on a knowledge test
- Passing grades on oral and practical tests
- 250 flight hours logged under Part 61 or 190 flight hours logged under Part 141
- Training with an instructor, solo flights, cross-country flights, and night flights.

Evolution of Flight Simulators

Flight simulators have been integral to aviation training since World War II (Myers et al. 2018). Early simulators were part of training over 500,000 pilots, and the simulators evolved as technology advanced (Mairaj et al. 2019; Figure 1). Simulators provide an effective training tool for pilots in various industries, including aviation and medicine. However, real-world scenarios—especially

stressful ones—often differ from simulations.

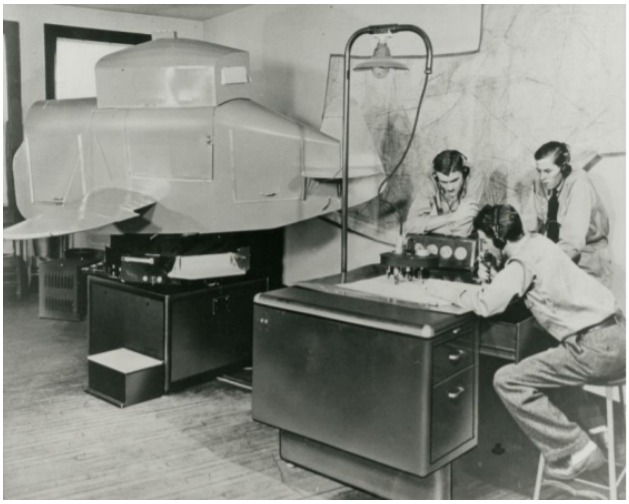

Figure 1. Early Flight Simulators (Myers et al. 2018)

Role of the National Institute of Standards and Technology (NIST)

Founded in 1901, NIST promotes innovation by advancing science, standards, and technology to enhance security and quality of life (NIST 2019). The institute develops methods to evaluate UAS pilot proficiency but does not train or certify pilots. The Open Test Lane and BPERP exams help assess capabilities objectively, though NIST does not set scoring metrics and instead leaves that to the organizations who choose to adopt their assessments (NIST, 2019).

Airborne Public Safety Association (APSA)

APSA, established in 1968, promotes the safe and effective use of both manned and unmanned aircraft in public safety through training, networking, advocacy, and education (APSA 2025) APSA offers a nationally recognized flight proficiency certification based on the BPERP exam, which is a condensed version of the NIST Open Test Lane Exam. Notably, the APSA BPERP certification is the only nationally recognized credential that evaluates and attests exclusively to a pilot's flight skills without assessing other competencies (such as mission planning, crew management, or program organization).

FAA Part 107 Knowledge Test

In 2016, the FAA introduced Part 107, which governs UAS operations for drones under 55 lbs. The certification requires passing a written exam that covers airspace regulations, aeronautical charts, meteorology, and decision-making. The test consists of 60 multiple-choice questions, and drone operators must renew their certification every 24 months through a free recurrent training course. However, because Part 107 does not include a practical flight assessment, there is no nationally mandated standard to evaluate or ensure a drone pilot's operational flight proficiency (Frazier 2020).

American Society for Testing and Materials (ASTM) Standards for UAS Proficiency

The ASTM, founded in 1898, is one of the world's largest international standards organizations and is dedicated to developing voluntary consensus standards to improve safety, quality, and performance across a wide range of industries (ASTM International - Standards Worldwide 2023). One such standard, ASTM F3266-18, provides a comprehensive guide for training remote pilots in command of UAS. It outlines the essential knowledge, skills, and abilities required for the safe operation of unmanned aircraft in commercial settings. The standard is designed for both educators developing training curricula and individual pilots seeking to enhance their competencies. ASTM F3266 establishes a structured, four-tiered framework for assessing UAS pilot proficiency with a focus on task performance, task knowledge, and subject knowledge. While the FAA Part 107 exam addresses general aeronautical knowledge, this research specifically supports ASTM F3266-18 Section 6.4.2.7 (which defines maneuvering and flight performance benchmarks). Table 1 presents a detailed breakdown of proficiency criteria based on this standard to help pilots understand the expectations for demonstrating flight competence.

Table 1. ASTM F3266-18 - Task and Knowledge Levels (ASTM 2023)

Task & Knowledge Levels		
Task Performance Levels	1	IS LIMITED - Can do simple parts of the task. Needs to be told or shown how to do most of the task
	2	IS PARTIALLY PROFICIENT - Can do most parts of the task. Needs only help on the hardest parts
	3	IS COMPETENT - Can do all parts of the task. Needs only a spot check of completed work
	4	IS PROFICIENT - Can do the complete task quickly and accurately. Can tell or show others how to do the task
Task Knowledge Levels	a	KNOWS NOMENCLATURE - Can name parts, tools, and simple facts about the task
	b	KNOWS PROCEDURES - Can determine step-by-step procedures for doing the task
	c	KNOWS OPERATING PRINCIPLES - Can identify why and when the task must be done and why each step is needed
	d	KNOWS ADVANCED THEORY - Can predict, isolate, and resolve problems about the task
Subject Knowledge Levels	A	KNOWS FACTS - Can identify basic facts and terms about the subject
	B	KNOWS PRINCIPLE - Can identify the relationship of basic facts and state general principles about the subject
	C	KNOWS ANALYSIS - Can analyze facts and principles and draw conclusions about the subject
	D	KNOWS EVALUATION - Can evaluate conditions and make proper decisions about the subject

NIST Open Test Lane

To address the growing need for standardized evaluation of UAS pilot flight skills, the NIST

developed the Open Test Lane. This testing framework provides a structured and replicable method to assess a pilot's ability to maneuver a multirotor drone through a series of physical tasks that simulate real-world operational challenges. Organizations such as APSA and DRONERESPONDERS have adopted the NIST Open Test Lane as a standardized method for assessing and certifying flight proficiency within public safety and emergency response programs.

The NIST Open Test Lane consists of a launch pad, a flight line, and four bucket stands with targets. The test lanes include five sets of maneuvers (Figure 2). Pilots must align the drone with targets and capture images showing a continuous green ring. The test consists of the following five maneuvers:

- **Position** – Capturing images while moving forward and backward.
- **Traverse** – Rotating in an oval pattern around bucket stands.
- **Orbit** – Circling a bucket stand in alternating directions.
- **Spiral** – Moving in a rotating pattern around all bucket stands.
- **Recon** – Flying in a straight path from the launch pad to a bucket stand.

Each maneuver is scored based on correctly aligned images, with a maximum of 100 points.

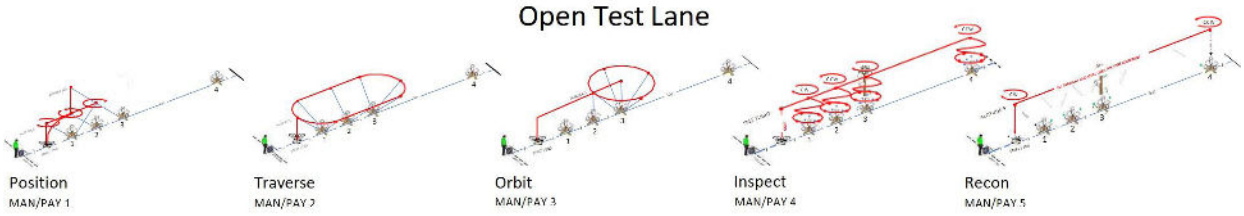

Figure 2. Open Test Lane Maneuvering (NIST 2025)

NIST Basic Proficiency Evaluation for Remote Pilots (BPERP)

The BPERP combines the first two maneuvers of the Open Test Lane. While NIST does not define scoring metrics, APSA suggests completing the test within 10 minutes. The exam can be conducted indoors or outdoors in a 50- by 20-ft area using a tape measure and a stopwatch (Frazier 2020).

METHODOLOGY

This research project involved three phases of experiments aimed at increasing UAS pilot proficiency and establishing more effective methods of evaluating flight skills. The authors have published the findings from the first two phases in the *Journal of the American Institute of Constructors* (Dees & Burgett 2022) and *The Journal of Advanced Technological Education* (Dees & Burgett 2023). Below are summaries of the first two phases along with a detailed description of the methodology associated with the final phase of the research project.

Summary of Phase 1

The objective of Phase 1 was to determine whether a flight simulator could assess UAS pilot proficiency as effectively as a traditional in-person test. To explore this, researchers employed a two-part methodology. First, they distributed a survey to 190 members of a local UAS nonprofit to gauge pilot experience; 24 participants responded. The survey found that these 24 participants were slightly to moderately experienced.

For the testing component, participants completed both in-person and simulator-based versions of the NIST Open Test Lane. The test course consisted of three test lanes with a 10-ft S shape on a level soccer field. Participants used either a DJI Mavic 2 Pro or DJI Phantom 4 Pro V2 to maintain consistent flight characteristics. Researchers conducted a paired t-test to compare in-person and simulator scores. Results revealed no statistically significant differences in overall performance except for flight times for Maneuver 1; simulator times were faster for Maneuver 1, likely due to controlled conditions and increased familiarity in the lab environment.

The key finding from phase one was that the Zephyr simulator, developed in part by the research team, could serve as a viable alternative to in-person testing—especially for organizations facing logistical and environmental challenges. Simulator-based exams offer benefits in standardization, cost-efficiency, and accessibility. These results indicate a need for further research into determining passing thresholds and enhancing simulator realism, laying the groundwork for future phases of study.

Summary of Phase 2

The objective of Phase 2 was to evaluate whether all five maneuvers in the NIST Open Test Lane were necessary to accurately assess flight proficiency or if a shorter test—specifically the BPERP exam (Maneuvers 1 and 2)—could serve as a reliable substitute. Reducing the number of required maneuvers would help mitigate the logistical challenges associated with administering the full exam, including time, space, and personnel constraints.

Using flight data from 90 tests completed by participants in Phase 1, the research team conducted a statistical regression analysis to examine how well individual maneuvers or combinations predicted overall performance. Researchers used RStudio to develop a multi-linear regression model that utilized adjusted R-squared values to measure the strength of correlation between subsets of maneuvers and the full five-maneuver test. Additionally, they applied percentile-based scoring and flight time requirements to categorize proficiency levels and identify passing thresholds for novice practitioners.

Key findings revealed that while 93% of participants passed based on flight accuracy (image scoring), only 48% met the time requirement, indicating that flight time was a more sensitive measure of proficiency. Regression analysis demonstrated that all individual maneuvers and combinations correlated strongly with overall performance, with the BPERP test yielding an adjusted R-value of 0.9213 for flight times—validating its effectiveness as a predictor of pilot proficiency. This data supports its use as a streamlined assessment tool without compromising evaluation quality, setting the foundation for the final phase—which provides recommendations for scoring criteria for state DOTs.

Phase 3 Methodology

The goal of Phase 3 was to evaluate pilot performance across varying levels of flight proficiency using a revised scoring model. The process began by identifying UAS program directors or administrators at each of the 50 state DOTs. Researchers contacted these individuals via email and phone to assess their program's status and to invite them to participate in the study. To encourage engagement, researchers offered three incentives: ten complimentary licenses for the required simulator software, BPERP certification for pilots who passed the exam, and free compatible flight controllers.

The Federal Highway Administration UAS program provided contact information, and 28 pilots from 14 state DOTs agreed to participate. Interested participants scheduled one-on-one sessions through a calendar booking link. Each session included an interview and a flight proficiency assessment using the NIST Open Lane Exam conducted through a simulator. The interview consisted of 17 questions focused on pilot experience and details about the agency's UAS program. All interviews and flight assessments were recorded in accordance with Institutional Review Board protocols and stored for up to 18 months for potential data analysis needs (Dees & Burgett 2022).

Researchers collected and stored data from each session for statistical analysis to support the development of scoring thresholds and classification criteria. This methodology provided a structured foundation for refining scalable, standardized tools to assess UAS pilot proficiency. Figure 3 displays the roadmap for conducting the final research in Phase 3.

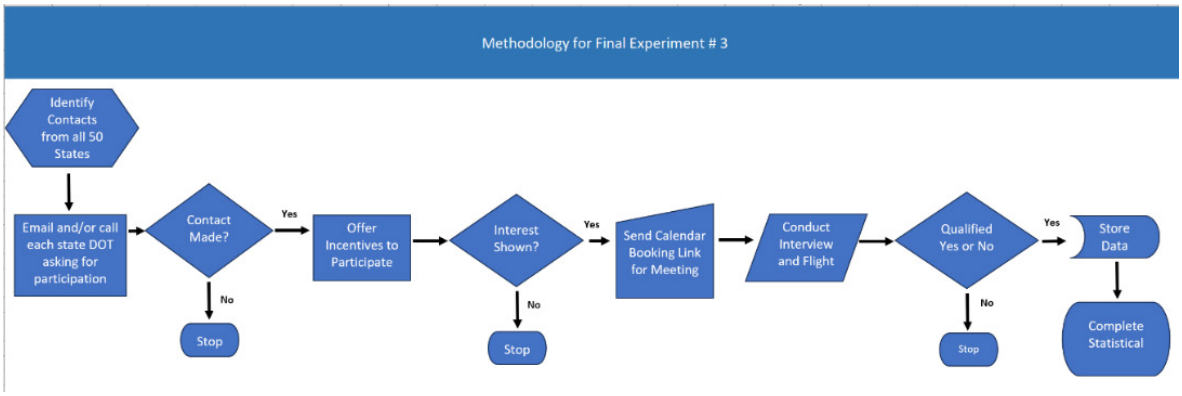

Figure 3. Roadmap for Phase 3

RESULTS & FINDINGS

This section presents the results and key findings from Phase 3 of the study, which assessed the flight proficiency of state DOT pilots and explored how mission complexity correlates with performance. Structured interviews and simulator-based flight exams with 28 pilots from 14 state DOTs provided data for analysis. The analysis focused on pilot experience, mission types, training requirements, and performance metrics such as flight scores and times. These findings offer insight into the current proficiency levels of DOT pilots and inform the development of a tiered certification model based on mission complexity.

Findings from the Interviews

The goal of the interviews was to identify factors that contribute to mission complexity, the skills required for safe and effective drone operations, and the frequency and types of missions flown. The researchers used this information to classify pilots into groups based on the complexity of their typical missions, enabling a comparative analysis of experience levels and performance. The findings from these interviews offer valuable context for understanding the operational challenges faced by DOT pilots and inform the development of proficiency benchmarks tied to mission demands.

Researchers asked each pilot to define what makes a mission complex or dangerous. Their responses highlighted numerous factors contributing to mission difficulty, including navigating in tight spaces; flying near obstacles such as trees, power lines, bridges, and structures; and dealing with challenging weather conditions like wind and rain. The group also mentioned the risk of limited visibility, GPS signal loss, and the need for manual control—particularly in congested environments like urban areas, around traffic, and near people. The interviews revealed that operating in these constrained environments adds significant complexity to UAS missions.

When discussing the skills required for flying complex missions, pilots emphasized the importance of being familiar with their drones and having strong hand-eye coordination, stick-and-rudder skills, and situational awareness. Additionally, they highlighted the significance of muscle memory, practice, and confidence, especially in challenging conditions such as strong winds or when the drone battery is low. The pilots also identified risk assessment, crew resource management, and effective communication as critical factors for ensuring safe operations during complex missions.

When asked about missions that might make them uncomfortable, pilots mentioned confined spaces, bridge inspections, and airport inspections as particularly challenging tasks. This theme further underscores the importance of operating in tight or restricted spaces, such as around towers or near structures. The answers suggest that handling such missions requires a high level of expertise and careful planning.

Researchers used the information obtained from the interviews to categorize pilots into two groups for further analysis: those who typically fly both complex and simple missions and those who fly only simple missions. This distinction allowed the research team to examine the performance metrics separately for each group, identifying variations in experience and skills.

Researchers also asked pilots about the frequency of missions flown each month. The group handling both complex and simple missions averaged seven missions per month, while those focusing only on simple missions averaged just three per month. This distinction highlights a disparity in the number of missions flown, with more experienced pilots handling a greater variety of tasks.

Table 2 shows that 77.8% of pilots report that their state DOT has a formal UAS program, while 22.2% indicated that their DOT did not. This gap in formal program adoption suggests that many state DOTs are still in the process of developing comprehensive UAS policies.

Table 2. Does Your State DOT Have a Formal UAS Program?

Answer	# of Pilots	% of Total
Yes	21	77.8%
No	6	22.2%
Total	**27**	**100.0%**

Pilots also reported that to operate drones for their state DOT, they were required to have a Part 107 license and had to undergo various training programs, such as flight training with instructors. Approval from supervisors and adherence to organizational policies were also common requirements.

Findings from the Flight Proficiency Exam

The flight proficiency exam was a central component of this research and designed to assess pilot skill through two key metrics: image-based scoring and flight time. Each of the participating pilots completed five flight tests, with a maximum of 20 points per test for a total possible score of 100 points. Researchers also measured performance using flight times for each maneuver and cumulatively. Additionally, all pilots completed the BPERP portion of the test (Maneuvers 1 and 2), which allowed for comparison across participants.

Overall, image scores were high across all participants. Nearly 70% of pilots achieved perfect scores of 20 points on most maneuvers, indicating that the scoring metric alone was not sufficiently sensitive to differentiate between varying levels of proficiency. This aligns with findings from Phase 1, which suggested that flight time was a more meaningful and discerning criterion when evaluating pilot skill.

Flight times ranged between 4:07-4:47 min per maneuver, with significant differences observed between pilot groups. Pilots who regularly flew both complex and simple missions completed their tests faster than those who flew only simple missions, reflecting greater skill and familiarity with flight controls. On average, pilots who handle complex missions completed their tests nearly one minute faster per maneuver than those who fly only simple missions.

To provide a structured basis for certification, researchers categorized pilot performance into three proficiency tiers based on percentile rankings:

- Proficiency Level A (top 25%): Demonstrated high proficiency with consistent, efficient performance; well-suited for complex missions near obstacles.
- Proficiency Level B (middle 50%): Moderately proficient; capable of basic operations but may benefit from additional practice.
- Proficiency Level C (bottom 25%): Less consistent and slower performance; may require further training and supervision.

This tiered framework allows DOTs to identify pilot readiness and tailor training accordingly. Notably, pilots flying complex missions had nearly 9% more experience and exhibited higher and more consistent scores with lower standard deviations, indicating not only better outcomes but

also more reliable performance.

Furthermore, 78% of state DOT pilots reported operating under a formal UAS program, while 22% did not; this statistic highlights the need for greater standardization across agencies. The results underscore the value of using both image scores and flight times—particularly the latter—to differentiate pilot skill levels and inform a practical, scalable certification process based on real-world mission complexity.

CONCLUSIONS & RECOMMENDATIONS

This research assesses the proficiency of UAS pilots through three phases using mixed methods. The study aimed to standardize UAS certification for state DOT pilots. The first phase validated the effectiveness of drone flight simulators compared to traditional in-person testing methods (Dees & Burgett 2022). The second phase revealed that not all maneuvers are necessary to effectively evaluate flight proficiency. By analyzing data, the researchers found that a subset of maneuvers from the BPERP exam adequately assesses pilot skills, streamlining the testing process (Dees & Burgett 2023).

The third experiment built upon the previous findings, incorporating both interviews and flight simulator tests to assess the proficiency of state DOT UAS pilots. The researchers sought to understand the skills required for complex missions and establish scoring criteria to establish a minimum flight proficiency necessary for missions of varying complexity.

Answering the Research Question

The research question that drove this study was: what scoring criteria should be used to certify that state DOT personnel have the minimum flight proficiency to operate a UAS based on mission complexity? Based on interviews and flight exam results, the study identified different levels of proficiency required for pilots handling simple versus complex missions. Flight time and image score percentiles categorized pilots into proficiency levels that could help establish a certification framework. Pilots flying complex missions demonstrated greater proficiency by completing tests more quickly and with fewer errors.

Flight Scoring Recommendations for Simple and Complex Missions

Table 3 presents a three-tiered scoring recommendation for pilots only involved in simple missions or missions that are not near obstructions. These recommendations are based on the top 25th percentile, middle 50th percentile, and the bottom 75th percentiles, and the times have been rounded for ease of use in the field or in a classroom-style setting.

Image Scoring Recommendations for Pilots Flying Simple Missions

Table 3. Image Scoring Recommendations for Pilots Flying Simple Missions

Proficiency Level	Man1	Man2	Man3	Man4	Man5	TOTAL 1-5	BPERP
A (top 25%)	20	20	20	20	20	100	40
B (middle 50%)	20	20	20	20	20	100	40
C (bottom 25%)	18	18	18	18	18	90	36

Flight Time Recommendations for Pilots Flying Simple Missions

Table 4 recommends flight times using a similar three-tiered proficiency scale for pilots who only fly simple missions. These recommendations are based on the top 25%, middle 50%, and bottom 25% of scores, and the times have been rounded for ease of use in the field or in a classroom-style setting.

Table 4. Time Recommendations for Pilots Flying Simple Missions

Proficiency Level	Man1	Man2	Man3	Man4	Man5	TOTAL 1-5	BPERP
A (top 25%)	4:00	4:00	4:00	4:00	4:00	20:00	8:00
B (middle 50%)	6:00	6:00	6:00	6:00	6:00	30:00	12:00
C (bottom 25%)	7:00	7:00	7:00	7:00	7:00	35:00	14:00

Image Scoring Recommendations for Pilots Flying Complex Missions

Table 5 applies the same three-level categorization approach to pilots who fly more complex missions. Based on the percentiles obtained from the data set of pilots flying complex missions, the authors recommend that all pilots reach the maximum score of 20.

Table 5. Scoring Recommendations for Pilots Flying Complex Missions

Proficiency Level	Man1	Man2	Man3	Man4	Man5	TOTAL 1-5	BPERP
A (top 25%)	20	20	20	20	20	100	40
B (middle 50%)	20	20	20	20	20	100	40
C (bottom 25%)	20	20	20	20	20	100	40

Flight Time Recommendations for Pilots Flying Complex Missions

Table 6 recommends proficiency levels categorized by flight times for pilots flying more complex missions. These recommendations are based on the top 25%, middle 50%, and bottom 25% of flight time scores, and the times have been rounded for ease of use in the field or in a classroom-style setting.

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Table 6. Time Recommendations for Pilots Flying Complex Missions

Proficiency Level		Man2	Man3	Man4	Man5	TOTAL 1-5	
A (top 25%)	3:00	3:00	3:00	3:00	3:00	15:00	6:00
B (middle 50%)	5:00	5:00	5:00	5:00	5:00	25:00	10:00
C (bottom 25%)	6:00	6:00	6:00	6:00	6:00	30:00	12:00

Final Recommendations to State DOTs

Based on the findings from Phase 3 of this study, the authors recommend that state DOTs implement a mission-based framework for certifying UAS pilots, distinguishing between those who primarily fly simple missions and those who fly complex missions. This approach acknowledges the differing skill requirements and operational risks associated with each mission type.

To support consistent and effective evaluation, DOTs should utilize the BPERP test—a validated, condensed version of the NIST Open Test Lane that focuses on Maneuvers 1 and 2. This test offers a practical and standardized method for assessing flight proficiency that is suitable for use in both field and classroom settings.

Certification benchmarks should be based on performance percentiles observed during the study. For pilots conducting simple missions as defined as flights in open environments without obstructions, the recommended passing criteria should reflect a proficiency level B, shown in Table 5 which is the middle 50th percentile of pilot performance. Specifically, these pilots should achieve a BPERP score of 40 points with a maximum flight time of 10 minutes. These criteria reflect a reasonable level of proficiency suitable for pilots engaged in lower-risk operations. Although this flight time is slightly shorter than the 12-minute mark shown in Table 4, the 10-min standard aligns with current APSA guidelines; this consistency with pre-established benchmarks adds value. These criteria reflect a reasonable level of proficiency suitable for pilots engaged in lower-risk operations.

In contrast, pilots tasked with complex missions—such as flights near traffic, bridges, and power lines or in confined spaces—should be held to a higher standard due to the increased potential for property damage or injury in the event of a collision. For these higher-risk missions, the authors recommend that pilots perform at the 75th percentile or higher. This requires achieving a perfect BPERP image score of 40 points with a maximum flight time of 6 min. The stricter standard is justified by the elevated risk profile of these missions, which demand greater precision, situational awareness, and control.

By adopting these mission-based recommendations, state DOTs can align pilot certification with real-world operational demands, enhance safety, and ensure that pilots are adequately prepared for the complexity of their assigned tasks. The BPERP test provides a scalable solution that promotes consistency and accountability across diverse UAS programs.

NAHB Production Home Competition as a Learning Tool towards Incorporating Business Skills in Construction Management Programs

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ABSTRACT

There is a growing realization in the construction industry that the traditional focus of Construction Management (CM) education on technical competencies (such as scheduling, estimating, and construction methods) is insufficient in preparing graduates to meet the strategic and leadership demands of the modern construction profession. A successful construction company requires more than project execution; it demands expertise in business development, financial management, marketing, risk management, and organizational leadership. The disparity between the technical and business aspects of CM education has produced graduates who may succeed in project management yet find it challenging to engage with comprehensive business operations.

This study analyzed the present condition of CM education and its alignment with industry demands, utilizing the NAHB Production Homes Competition as a case study. The authors analyzed ten accredited CM programs, surveyed past NAHB competition participants, and conducted follow-up interviews to identify key deficiencies in CM education.

The NAHB competition serves as a useful model for applying business-focused learning in a real-world context, but its effectiveness is limited without sufficient academic support. This research indicates that whereas technical skills are prioritized, business and leadership abilities are often insufficiently cultivated. It emphasizes that CM programs must move beyond technical skill development to equip students with the leadership and business competencies necessary for success in the competitive and evolving construction industry. Key recommendations include revising Student Learning Outcomes (SLOs), creating related courses focused on business acumen, and incorporating the revised SLOs with experiential learning opportunities such as the NAHB competition.

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INTRODUCTION

The construction industry is a cornerstone of global economic growth and development. From providing homes and shaping skylines to building critical infrastructure, the industry plays a pivotal role in addressing society's evolving needs. However, as society becomes increasingly interconnected, the demands placed on construction professionals are rapidly changing. No longer confined to technical expertise alone, today's construction leaders must navigate challenges such as globalization, sustainability, and technological advancements while fostering innovation and collaboration across diverse teams and organizations.

At the heart of this transformation lies the need for a new kind of professional—one who combines deep technical knowledge with advanced leadership and strategic skills. While technical competencies such as project scheduling, cost estimation, and construction methods remain essential, the industry increasingly values professionals who can lead teams, manage risks, and make strategic decisions in high-pressure environments. This shift highlights a critical gap in traditional CM education, which has historically emphasized technical skills at the expense of broader leadership and business acumen.

In this paper, the authors explore the growing importance of leadership and business competencies in the construction industry and examine how these skills can be integrated into CM education to better prepare graduates for the challenges ahead. Using the National Association of Home Builders (NAHB) production home competition project as a case study, this research investigates the potential of applied learning models to bridge the gap between academic preparation and industry demands. By rethinking traditional curricula, the authors of this study aim to contribute to the development of well-rounded construction professionals equipped to lead in an increasingly complex and competitive industry.

Historically, career trajectories in construction commence with a CM degree; traditionally, these have mostly focused on the technical competencies required for overseeing building projects. A conventional CM curriculum, aligned with the accreditation standards of the American Council for Construction Education (ACCE), is meant to equip students for positions centered on project supervision and project support. It is essential to acknowledge that project operations and business operations are interdependent; CM programs should educate and evaluate both domains.

As the industry transitions to data-driven decision-making, the business activities of construction firms will increasingly impact project execution and physical construction. As a result, there is an increasing demand for people who comprehend project operations and have a robust foundation in business competencies.

The motivation for this study is the perceived gap between the demand for greater inclusion of domain-specific business skills in CM curricula and the extent to which these topics are included. The authors aim to identify the most effective methods for teaching business competencies within CM education by using a case study of the NAHB Production Homes Competition—where students are engaged deeply in these topics—as a lens for analysis. The NAHB program requires proficiency in eight key competencies: three operations-focused skills (estimating, scheduling, and project management) and five business-oriented skills (market analysis, marketing, sales, finance, and risk management).

This analysis includes a detailed review of several accredited CM programs and their Student

Learning Outcomes (SLOs), combined with data collected from a student survey to explore the learning methods of core competencies. This study consists of three main objectives:

- Evaluate the role of business skills in accredited CM curricula,
- Evaluate the impact of participating in the NAHB student competition on business competency development, and
- Provide recommendations and improvements to SLOs related to business competencies.

CM EDUCATION AND THE ROLE OF BUSINESS SKILLS

Traditional CM education has focused predominantly on technical expertise while relegating business- and leadership-related competencies to supplementary or elective courses (Simmons et al. 2020; Singh 1992; Dietz 1983; Tatum 1987; Rokooei et al. 2017). CM programs are accredited either by the ACCE or the Accreditation Board for Engineering and Technology; ACCE is the accrediting body for the majority of CM programs.

Founded in 1974, the ACCE established itself as an accrediting body to better suit the needs of construction companies looking for engineers and contractors with management education in addition to their technical competencies (ACCE 2024). Today, the ACCE is responsible for accrediting over 100 CM programs. Its accreditation process is based on 17 key SLOs, as listed in Table 1.

While these SLOs are foundational for managing tangible aspects of construction projects, the narrow focus on technical expertise limits leadership and strategic decision-making skills (Tatum 1987; Toor & Ofori 2008). This technical focus reflects the industry's historical perception of construction as a task-oriented profession. Tatum (1987) argues that CM education, heavily rooted in engineering principles, often emphasizes problem-solving over leadership and manager development. This imbalance restricts graduates' ability to navigate the multifaceted challenges of the modern industry. Similarly, Toor and Ofori (2008) highlight that traditional CM education produces managers focused on routine operations, rather than leaders capable of engaging with the business operations of an organization. The lack of awareness of these competencies gives graduates a lesser understanding of the context of how individual projects fit into larger operations.

Stakeholders from both industry and academia express concern about the lack of leadership training in CM programs (Räisänen et al. 2015). As construction projects become more global and interdisciplinary, the need for leadership competencies teams becomes paramount. However, traditional curricula often fail to provide structured opportunities for leadership development, leaving students unprepared for mid- and senior-level management roles. Toor and Ofori (2008) also emphasize that traditional managers, limited by task-oriented mindsets, often struggle to lead teams effectively in the fast-paced, high-stakes environments demanded by construction.

Table 1. List of ACCE SLOs as of 2024-25

SLO No.	SLO Descriptions
1	Create written communications appropriate to the construction discipline.
2	Create oral presentations appropriate to the construction discipline.
3	Create a construction project safety plan.
4	Create construction project cost estimates.
5	Create construction project schedules.
6	Analyze professional decisions based on ethical principles.
7	Analyze methods, materials, and equipment used to construct projects.
8	Apply electronic-based technology to manage construction projects.
9	Apply basic surveying techniques for construction layout and control.
10	Understand different methods of project delivery and the roles and responsibilities of all constituents involved in the design and construction process.
11	Understand construction accounting and cost control.
12	Understand construction quality assurance and control.
13	Understand construction project control processes.
14	Understand the legal implications of contract, common, and regulatory law to manage a construction project.
15	Understand the basic principles of sustainable construction.
16	Understand the basic principles of structural behavior.
17	Understand the basic principles of mechanical, electrical and plumbing systems.

Note. These 17 SLOs are based on the ACCE requirements as of April 2024. At the time of writing, ACCE is considering further revisions to the numbers and titles of SLOs in the coming years.

Though leadership has been presented as an inherent personal quality, Chan et al. (2013) and Räisänen et al. (2015) stress that leadership is not an innate quality but a teachable skill that requires deliberate integration into academic programs. They argue that CM education must evolve to address broader professional competencies alongside technical training for graduates to have the capacity to develop stronger leadership skills. This perspective aligns with Tatum's (1987) call for curricula that balance technical knowledge with leadership and organizational skills, preparing students for both operational and strategic responsibilities.

Singh (1992) argues that part of this gap can be attributed to faculty members' lack of industry experience. Faculty often teach theoretical frameworks without connecting them to real-world applications, hindering students' ability to contextualize knowledge. This disconnect starts a cycle where graduates are unprepared to address the ethical, strategic, and interpersonal complexities of leadership roles. Singh argues that this lack of practical grounding undermines the relevance of CM programs and fails to meet industry expectations.

As the construction industry evolves, it increasingly demands professionals who can balance technical expertise with strategic thinking, leadership, and adaptability, making it essential for CM graduates to possess a broader skill set (Zheng et al. 2022; Lui et al. 2024). Murphy et al. (2019) introduced the concept of T-shaped professionals as a model for addressing the industry's

evolving demands. These individuals combine deep technical expertise in a specific area with broad professional competencies such as communication, collaboration, and leadership. Similarly, Zheng et al. (2022) emphasizes the emerging idea of ambidextrous leadership styles in modern construction projects. Ambidextrous leaders balance innovation with operational stability by equipping themselves with empowering leadership skills (which encourage team collaboration and risk-taking), along with directive leadership (which provides clear guidance and maintains alignment with project goals).

Though both methods of leadership can be effective, Du Plessis and Green (2013) highlight the importance of business acumen, particularly financial literacy and risk management. CM professionals must navigate complex financial environments, make informed decisions, and manage risks effectively each day. In a comprehensive study involving expertise elicitation and literature review, Pariafsai and Behzadan (2021) found that business-related topics (termed as "financial") were the eighth-most frequently cited skills for construction project management, behind technical and leadership skills (among others). The integration of business education into CM curricula equips students with the tools needed to comprehend and handle the financial and strategic aspects of CM beyond the scope of just one project. Fellows et al. (2013) and Murphy et al. (2019) also argue that CM programs must adapt to the industry's changing demands by integrating leadership and strategic thinking into curricula.

Business acumen is the foundation of effective decision-making in construction projects, encompassing financial literacy, risk assessment, and strategic planning. Du Plessis and Green (2013) emphasize the idea that financial literacy enables construction managers to allocate resources effectively, control costs, and improve overall project outcomes by having a more rounded understanding of financial implications within the larger organization. Without these skills, professionals risk making uninformed decisions that can jeopardize not only project success, but organizational success. Similarly, Dietz (1983) underscores the critical role of risk management in navigating the uncertainties inherent in construction, from fluctuating material costs to unforeseen delays. Strategic decision-making complements these competencies, equipping professionals to anticipate challenges and align project goals with broader organizational objectives.

Despite its importance, business education remains underrepresented in traditional CM programs. Singh (1992) critiques the lack of emphasis on financial and strategic training, noting that many CM faculty lack industry experience and are therefore unable to provide practical insights into decision-making processes. Kwon et al. (2012) echo this sentiment, reporting widespread dissatisfaction among industry stakeholders regarding the business preparedness of CM graduates. The emphasis on technical training at the expense of business acumen perpetuates a disconnect between academic preparation and industry expectations, hindering graduates' ability to thrive in leadership roles.

The lack of focus on business acumen in traditional CM curricula represents a critical gap in preparing students for leadership roles. Evidence from Du Plessis and Green (2013), Singh (1992), and Kwon et al. (2012) underscores the importance of financial and strategic training in enhancing project outcomes and career success. By adopting innovative teaching methods and fostering industry-academia collaboration, CM programs can address these gaps and better align educational outcomes with industry needs. Hegazy et al. (2013) advocate for applied learning methods such as case studies and hands-on exercises to develop these business skills. By simulating real-world

scenarios, students gain practical insights into financial and operational principles, bridging the gap between classroom theory and workplace reality.

NAHB COMPETITION AS A CASE STUDY AND ITS RELEVANCE

The integration of business acumen and leadership competencies into CM education often remains an aspiration, but the NAHB competition project provides a potential example of how applied learning can bridge competency gaps. By combining technical, business, and leadership training in a real-world simulation, the NAHB project demonstrates how CM curricula can align with the demands of the construction industry.

The NAHB project is a multidisciplinary, real-world simulation that immerses students in tasks that replicate the complexities of the construction industry. Participants are tasked with a simulation of a residential development on a chosen site with certain stipulations. Students engage in activities such as market analysis, site and product design, estimating, scheduling, financial planning, project management, and risk analysis, all within the framework of a hypothetical residential development. This hands-on approach integrates technical skills with team leadership and financial context, preparing students for the multifaceted challenges they will face as professionals.

One of the project's standout features is its emphasis on practical application. Unlike traditional classroom instruction, which often isolates technical and professional skills, the NAHB project brings these elements together in a collaborative environment. This combination fosters a deeper understanding of how leadership, technical knowledge, and strategic decision-making intersect in real-world construction projects (Zheng et al. 2022; Rokooei et al., 2017).

The multidisciplinary structure of the NAHB project reflects the collaborative nature of modern construction work. Students are required to work in teams, make decisions under pressure, and adapt to project requirements—skills essential for success in the field. As Simmons et al. (2020) argue, applied learning experiences such as the NAHB project not only enhance technical proficiency but also develop the interpersonal and strategic skills necessary for effective leadership. Moreover, the project's focus on applied learning aligns with the findings of Rokooei et al. (2017), who argue that simulation-based education fosters critical thinking, strategic planning, and problem-solving skills. By mirroring the complexities of professional practice, the NAHB project not only bridges competency gaps but also prepares students to excel in leadership roles.

The NAHB project addresses several key competency gaps identified in traditional CM education. This focus on applied learning directly supports the hypothesis that integrating business and leadership training into CM curricula better prepares students for leadership roles. The NAHB project provides a platform for students to develop and practice these competencies, making it a valuable case study for curriculum reform.

DATA COLLECTION

Researchers employed a mixed-methods approach to integrate quantitative and qualitative data to evaluate the educational significance of the competition and its accordance with business needs and student objectives. They organized the process into three primary components: curriculum SLO analysis, participant feedback, and data synthesis (Figure 1).

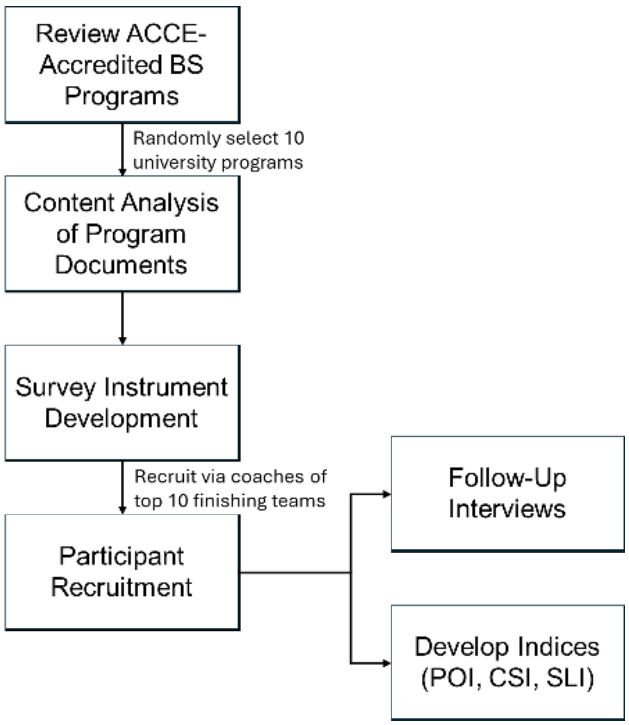


Figure 1. Research Methods

CM Curriculum and SLOs

The first component involved collection of publicly accessible data from 4-year CM programs accredited by the ACCE. Researchers randomly selected 10 ACCE-accredited university undergraduate programs from among the 70 programs with this status. The team reviewed, program outlines, ACCE public-facing program reports, and course syllabi from these 10 programs to understand the emphasis placed on different types of skills and how SLOs are satisfied. The primary focus was on identifying how business-related topics (finance, accounting, marketing, sales, and strategic planning) and traditional construction operations topics (estimating, scheduling, and project management) are integrated into the curriculum via a content analysis of the syllabi and ACCE accreditation public reports. This helped establish a baseline for comparing the educational impact of the NAHB competition.

NAHB Student Survey and Interviews

To assess the NAHB Production Home Competition's effectiveness in fostering business competencies, the research team surveyed and interviewed 25 former competition participants. At the time of data collection, 20 of these participants had graduated and were working in the construction industry while five were completing the last year of their degree program.

Survey Design

Past participants of the competition received a detailed survey consisting of both quantitative and open-ended questions. Participants were recruited through direct contact with coaches of teams who had regularly placed in the top 10 over the previous 10 years. Coaches in turn sent the survey

link to participants from the past ten years. The survey focused on eight key competencies divided into operations-based skills (estimating, scheduling, project management) and business-focused skills (market analysis, marketing, sales, finance, and risk management). These categories and questions emerged in response to findings from the content analysis of program documents.

Program Details

The survey prompted participants to provide descriptive information about their competition experience.

Learning Methods

The survey asked participants to report how they were exposed to various competencies through a matrix covering learning pathways such as an NAHB-project-specific classes, a major-required or elective course, industry training, or self-study. This information allowed for a deeper understanding of the longevity of skills created in certain contexts.

Perceived Performance

To understand the immediate outcomes of the competition, researchers asked participants to rate their perceived performance in each competency using a Likert-scale matrix table. The categories range from "Top 15%" to "Average" to "No idea," which enabled detailed comparisons across different competencies.

Current Skill Outcome

A second matrix assessed participants' self-reported current ability to perform key competencies. Skill levels included "Professional High-Quality," "Professional Mid-Quality," "Product Would Make Sense," "I Could Not Perform," or "No idea." This Likert-scale matrix table was meant to help researchers understand the loss, or lack thereof, of certain competencies across the competition.

FUTURE PLANS AND GOALS

THE SURVEY CONCLUDED WITH QUESTIONS ABOUT PARTICIPANTS' CAREER ASPIRATIONS AND THE IMPACT OF THE COMPETITION ON THEIR GOALS.

Follow-Up Interviews

The researchers selected participants for the interviews based on their survey responses, with an emphasis on capturing diverse perspectives across different institutions, roles within the competition, and reported confidence levels. The selection aimed to include individuals who represented a range of experiences, from those who excelled in the competition to those who reported challenges with certain competencies. The interviews followed a semi-structured format guided by a set of predefined questions, but allowed for open-ended discussion to explore emerging themes. Researchers designed the interview questions to better understand program attributes by:

- Identifying which aspects of the NAHB competition structure contributed most to their skill development and confidence.
- Exploring how participants perceived the long-term retention and applicability of the skills learned during the competition.
- Gathering perspectives on how the competition's focus on business and leadership

competencies compares to their core CM education.

- Understanding how well the competition prepared participants for real-world CM.

Interviewers conducted the interviews virtually via video conferencing to accommodate participants' schedules and geographical locations. Each session lasted approximately 30–45 minutes and was recorded with the participants' consent. Interview data was coded and analyzed thematically based on emerging themes.

DATA ANALYSIS

The final stage of the research was to synthesize findings from the curriculum analysis, survey responses, and follow-up interviews to provide a comprehensive evaluation of the NAHB Production Home Competition. The synthesis focused on understanding how the competition contributes to the development of competencies, identifying gaps in traditional CM curricula, and offering actionable recommendations for improvement (Jones 2024).

Quantitative Data Analysis

The research team analyzed the survey data using statistical methods to identify trends in skill development, retention, and confidence. They used descriptives to evaluate how students rate their perceived performance and current skill levels across key competencies. They also employed inferential statistics to compare responses across different participant groups (e.g., based on specialization, universities, or program structure). Key metrics calculated were:

Performance Outcome Index (POI)

The POI reflects participants' perceptions of their team's overall performance in mastering and applying key competencies during the competition. This measure provides insight into the immediate effectiveness of the competition as a learning experience and establishes a baseline for understanding skill retention over time.

Current Skill Index (CSI)

Participants used the CSI to report their current perceived confidence in real-world project management and business operations. Cross-referencing this index with SLI scores provides insights into how skill retention impacts participants' readiness for professional roles.

Skill Loss Index (SLI)

The SLI measures the degree of skill retention over time by comparing participants' post-competition skill levels with their current perceived ability to independently perform tasks. High SLI scores indicate significant skill decay, while low SLI represent higher retention of learned skills.

Qualitative Data Analysis

The qualitative findings helped reveal the underlying reasons behind trends in confidence and skill retention. Researchers thematically analyzed interview transcripts and open-ended survey responses, including three main focuses:

Program Attributes

Participants identified specific features of the NAHB competition that contributed to their learning.

Barriers to Retention

Recurring challenges include the lack of exposure to business skills post-competition or limited curriculum integration of these skills.

Real-World Preparedness

Interviews revealed mixed perceptions about the competition's ability to fully prepare participants industry roles.

RESULTS AND DISCUSSION

SLO Analysis and Findings

A review of SLOs from ten ACCE-accredited universities revealed notable variations in how CM programs define and emphasize learning outcomes. All ten programs followed the 17 ACCE SLOs, with significant discrepancies in additional learning outcomes. The 17 standardized SLOs fell into four categories based on their focuses (Table 2). This distribution highlights an over-emphasis on project operations, with minimal integration of business-focused skills into the standardized curriculum.

Table 2. ACCE SLOs Breakdown

SLO Focus	Total SLOs in each Focus (SLO numbers)
Business Operation	None
Project Operation	9 - *(SLOs 3, 4, 5, 7, 8, 9, 12, 16, 17)*
Both	7 - *(SLOs 1,2,6,10`,11,13,14)*
Specialty/Not Applicable	1 - *(SLO 15)*

Further analysis of the ten universities revealed that nine of the ten universities adhered strictly to the 17 ACCE SLOs. Six of these programs currently list three additional SLOs that were required by ACCE in 2023:

- SLO 18: Understand construction risk management.
- SLO 19: Analyze construction documents for planning and management of construction processes
- SLO 20: Understand construction management skills as an effective member of a multidisciplinary team

These additional SLOs somewhat align with prevalent industry demands for operational planning and risk management but fall short in addressing and assessing business-focused skills. The ACCE removed these three SLOs in their latest SLO update (2023-2024). This change highlights the continued oversight of these business and leadership skills. As these programs prepare to renew their accreditation, it is likely that they will also remove these three SLOs.

One program had the most comprehensive SLO package—including eight additional SLOs beyond the ACCE minimum, bringing the total to 25. These eight SLOs included the three SLOs from 2023-2024. The additional five SLOs emphasize leadership, cultural awareness, and social responsibility, positioning this program as a leader in holistic CM education.

- SLO 21: Understanding the societal role of construction managers.
- SLO 22: Emphasizing lifelong learning and continuing education.
- SLO 23: Developing key leadership characteristics for team building.
- SLO 24: Recognizing cultural differences and their influence on project success.
- SLO 25: Appreciating diversity within teams.

Though the implementation of SLOs into curricula is left to individual universities, SLOs serve as foundational guidance for skill development. This relationship between SLOs and competency development gives their verbiage an inherent influence across programs. Verbs such as "create," "analyze," and "apply" dominate project-operation-focused SLOs, as seen in SLO 5 ("Create construction project schedules"), SLO 7 ("Analyze methods, materials, and equipment used to construct projects"), and SLO 9 ("Apply basic surveying techniques for construction layout and control"). These active verbs emphasize higher cognitive domains, reinforcing the prioritization of technical skills in CM education (Englehart et al. 1956; Anderson et al. 2001).

In contrast, higher-level outcomes employ less action-oriented language, as seen in SLO 11 ("Understand construction accounting and cost control") and SLO 14 ("Understand the legal implications of contract law"). This passive phrasing represents lower cognitive domains, as identified by Englehart et al. (1956) and Anderson et al. (2001), and suggests lower expectations for mastery, potentially resulting in less rigorous instruction and assessment. Consequently, students may be underprepared for leadership roles that require broader strategic and interpersonal competencies.

Student Survey and Interview Analysis and Findings

The research team received a total of 25 responses from past participants in the NAHB Production Home Competition, representing six different universities across six states. These responses revealed stark differences in how competencies are introduced to students. As shown in Figure 3, skills traditionally associated with project execution—such as estimating, scheduling, and project management—were predominantly taught in required CM courses (72-80% of respondents). Conversely, broader skills critical for leadership and business strategy—such as market analysis, marketing, sales, finance, and risk management—were more likely to be learned through alternative methods such as NAHB-specific courses, self-study, or industry training (60-88% of respondents).

Figure 2 depicts CM-specific competencies that relate to SLOs (e.g., the "estimating" competency as it relates to SLO 4) and five learning methods identified in the survey (major-required class, NAHB-specific class, self-study, non-required class, and industry training/other). As illustrated in Figure 2, this bifurcation in how project execution and business/leadership topics are taught raises questions about the comprehensiveness of CM curricula and their ability to prepare students for leadership roles. The data revealed that the competition serves as a valuable learning tool, reinforcing core skills such as estimating, scheduling, and project management. Additionally, it

highlights the integration of certain business skills within the curriculum. Participants reported that finance strategy and risk strategy management were introduced in 36-40% of major-required courses. However, there remains some uncertainty about the depth to which these skills are taught and assessed. Despite these gaps, areas such as market analysis, marketing, and sales are predominantly introduced through either NAHB-specific classes or self-study initiatives. This indicates that the NAHB competition is a key catalyst for students to learn, practice, and simulate these critical business skills, providing an essential platform for their development.

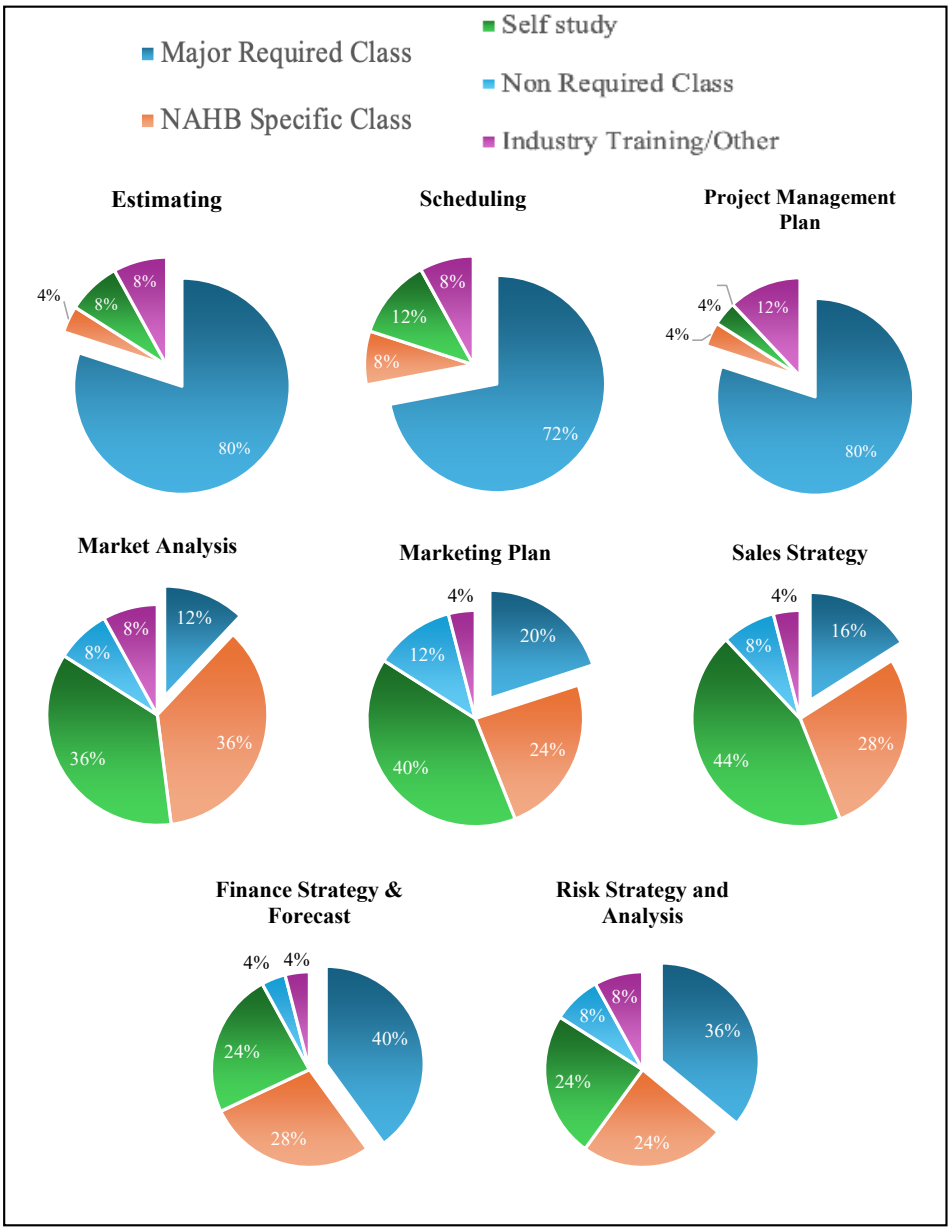


Figure 2. Competencies by Learning Method

Further analysis of NAHB surveys and interview data provided key metrics:

Performance Outcome Index (POI)

The next step is to understand participants' perceived performance in each competency during the

competition using a scale from 1 (lowest) to 4 (highest). Table 3 shows the results that indicate minimal differences in perceived performance across learning methods.

While major-required classes show the highest perceived outcomes for project-focused skills, the differences are negligent. This may be attributed to the collective nature of team performance: even if a student did not personally master a competency, their team's overall proficiency likely influenced their perceived success.

Current Skill Index (CSI)

Participants next assessed their current confidence in performing specific competencies, forming the CSI on a scale of 1-4, where 4 = Ability to produce a high-quality professional product; 3 = Ability to produce a professional product with a few questions; 2 = Ability to produce a product that made sense; and 1 = Inability to perform the competency.

The results in Table 4 reveal a stark divide between project-oriented and broader leadership or business skills. Project-focused competencies scored consistently higher, reflecting the emphasis placed on these skills during university education. In contrast, broader business and leadership skills, while addressed during the NAHB competition, showed lower CSI scores, suggesting limited retention or development outside the competition.

Table 3. Performance Outcome by Learning Method

Learned Competency	Primary Learning Method				
	Major-Required Class	NAHB-Specific Class	Self-study	Non-Required Class	Industry Training/ Other
Average	**3.1**	**2.8**	**2.5**	**2.3**	**2.9**
Estimating	3.2	3.0	1.0	-	3.0
Scheduling	3.1	4.0	1.7	-	3.0
Project Management Plan	3.3	2.0	3.0	-	3.7
Market Analysis	3.7	4.0	3.0	3.5	4.0
Marketing Plan	2.8	2.0	2.9	3.7	3.0
Sales Strategy	2.5	2.0	2.7	4.0	3.0
Finance Strategy & Forecast	3.1	2.0	2.5	4.0	1.0
Risk Strategy and Analysis	3.3	3.0	2.8	3.5	2.5

This differential presents the challenge of attributing current skill levels to the NAHB competition versus the participants' broader educational and professional experiences.

Skill Loss Index (SLI)

To better understand the retention of skills over time, the team calculated an SLI: the difference between the POI and CSI This analysis provides insights into how effectively different learning methods and the NAHB competition contribute to long-term competency development. While external factors may influence these outcomes, analyzing the interplay between CSI, SLI, and learning methods offers a clearer picture of the competition's impact (Table 5).

Table 4: Current Skill Index by Learning Method

Learned Competency		Primary Learning Method				
		Major Required Class	NAHB Specific Class	Self study	Non Required Class	Industry Training/Other
	Average	**3.0**	**2.7**	**2.6**	**1.7**	**2.8**
Estimating	**3.0**	3.1	3.0	2.0	0.0	3.5
Scheduling	**2.9**	3.0	3.0	2.7	0.0	2.5
Project Management Plan	**3.1**	3.0	2.0	4.0	0.0	3.7
Market Analysis	**3.1**	2.7	3.2	3.0	3.0	3.5
Marketing Plan	**2.7**	3.3	3.0	2.2	2.7	3.0
Sales Strategy	**2.3**	2.6	2.3	2.1	3.5	2.0
Finance Strategy & Forecast	**2.5**	3.1	2.3	2.0	2.0	2.0
Risk Strategy and Analysis	**2.8**	3.1	3.0	2.7	2.5	2.0

Table 5. Skill Loss Outcome and Learning Methods

Learned Competency		Primary Learning Method									
		Major Required Class		NAHB Specific Class		Self study		Non Required Class		Industry Training/Other	
	Average	-0.4		-1.0		-0.5		-0.4		-0.1	
Estimating	0.0	**80%**	**-0.1**	4%	0.0	8%	1.0	0%	0.0	8%	0.5
Scheduling	0.0	**72%**	**-0.1**	8%	-1.0	12%	1.0	0%	0.0	8%	-0.5
Project Management Plan	-0.2	**80%**	**-0.3**	4%	0.0	4%	1.0	0%	0.0	12%	0.0
Market Analysis	-0.2	12%	-1.0	**36%**	**0.0**	**36%**	**0.0**	8%	-0.5	8%	-0.5
Marketing Plan	-0.4	20%	0.5	**24%**	**-0.3**	**40%**	**-0.7**	12%	-1.0	4%	0.0
Sales Strategy	-0.7	16%	0.1	**28%**	**-1.4**	**44%**	**-0.6**	8%	-0.5	4%	-1.0
Finance Strategy & Forecast	-0.5	40%	0.0	**28%**	**-1.1**	**24%**	**-0.5**	4%	-2.0	4%	1.0
Risk Strategy and Analysis	-0.4	36%	-0.2	**24%**	**-0.5**	**24%**	**-0.2**	8%	-1.0	8%	-0.5

The findings support the theory that organizational and business skills are underrepresented in required CM programs. This disparity is evident in the teaching methods and further highlighted by the SLI. Skills taught primarily through NAHB-specific classes or self-study demonstrated a significantly higher SLI, as these topics were often covered less comprehensively and applied solely within the context of the competition.

Specialty Skills Analysis

Due to the total workload associated with the project, respondents identified their primary focus within their project team to better assess their skill development in specific areas including Construction, Business, Design, or Not Applicable. When the research team correlated this data with performance metrics, several key themes emerged:

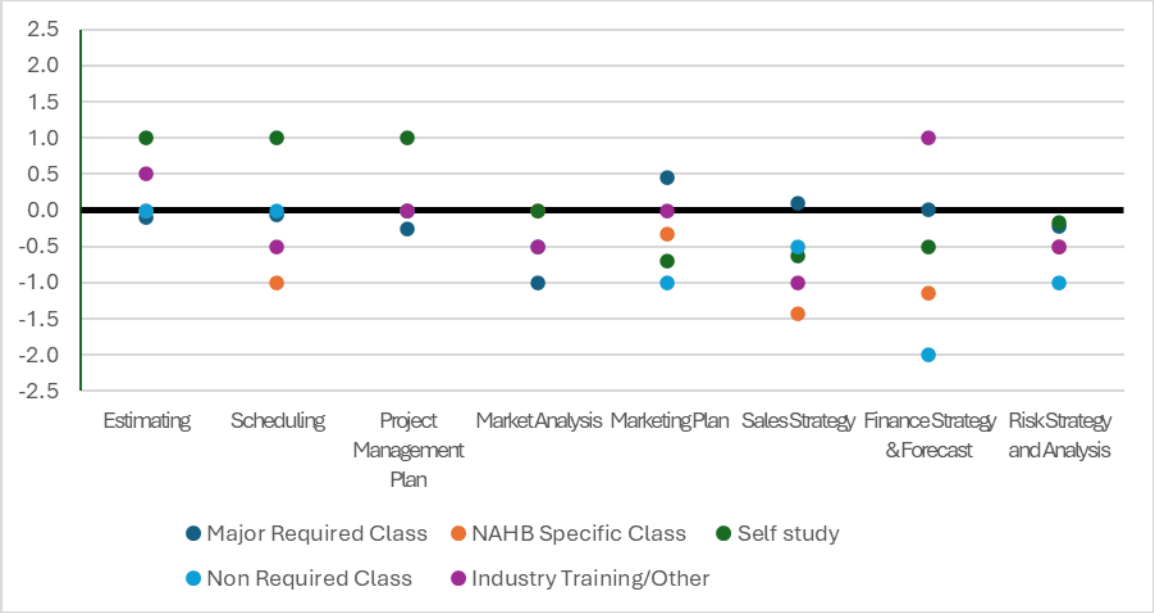


Figure 3. Skill Loss Index Scatterplot

Construction skills. Figure 4A illustrates that students focusing on construction-related skills such as estimating and scheduling exhibited minor retention deficiencies in these areas. Figures 4B and 3C reveal comparable outcomes. This trend is likely due to reinforcement from prior industry experience and the emphasis placed on these skills in education, even within the specific context of the NAHB competition.

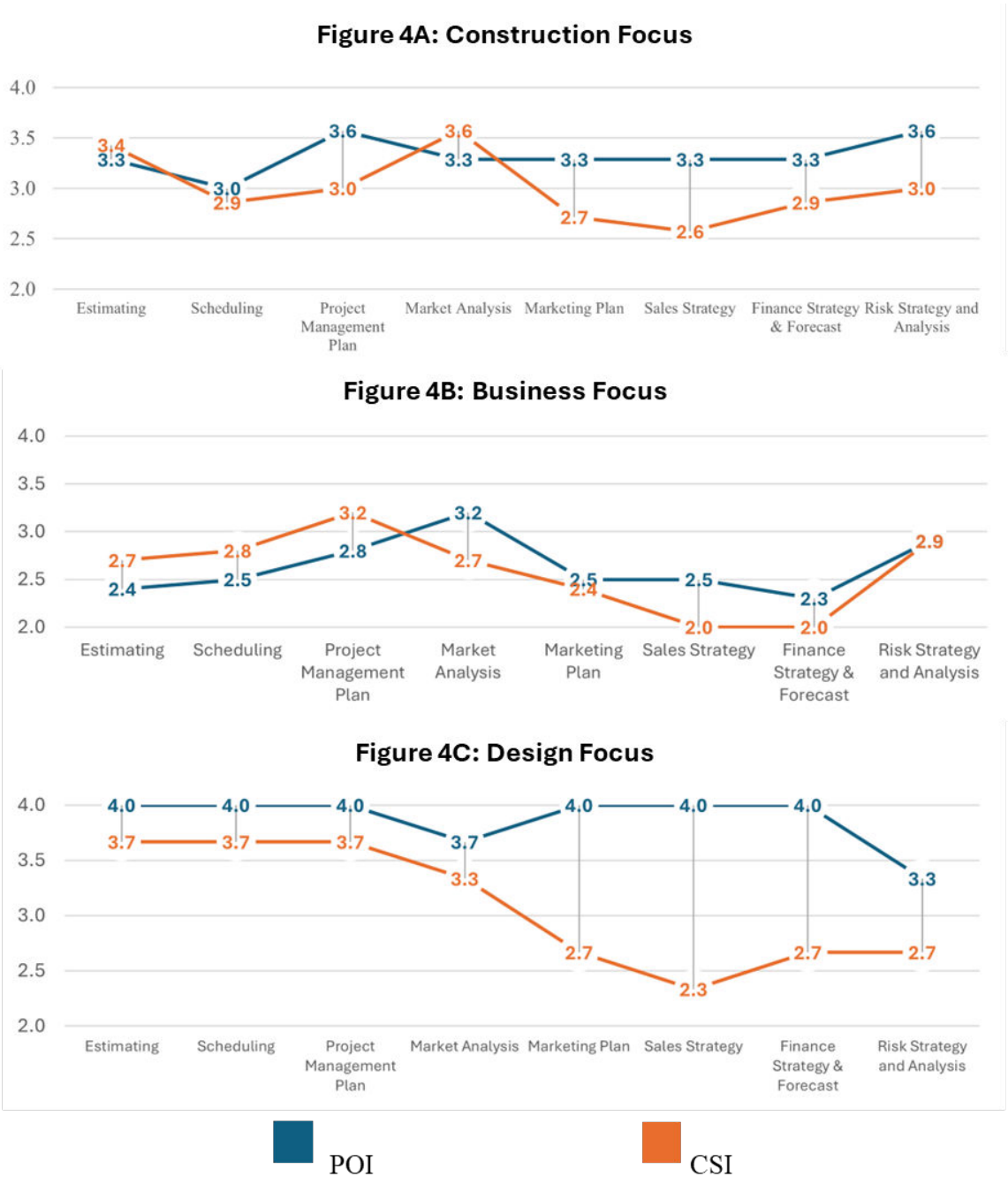
Business skills. Conversely, business-related skills—particularly Sales, Finance, and Risk—showed a broader decline in retention across participants. Figure 4A highlights a consistent loss of retention for students whose primary focus was Construction.

Design skills. Figure 4C indicates an even greater loss of retention for those concentrating on Design. However, Figure 4B demonstrates that students who focused on business-related attributes during the competition experienced a significantly smaller decline in retention of business skills. This outcome may be attributed to factors such as personal interest or prior exposure to these competencies. Additionally, it suggests that the NAHB competition may serve as an effective model for developing business-related skills in a practical, hands-on environment outside of a traditional classroom setting.

FUTURE PLANS AND GOALS

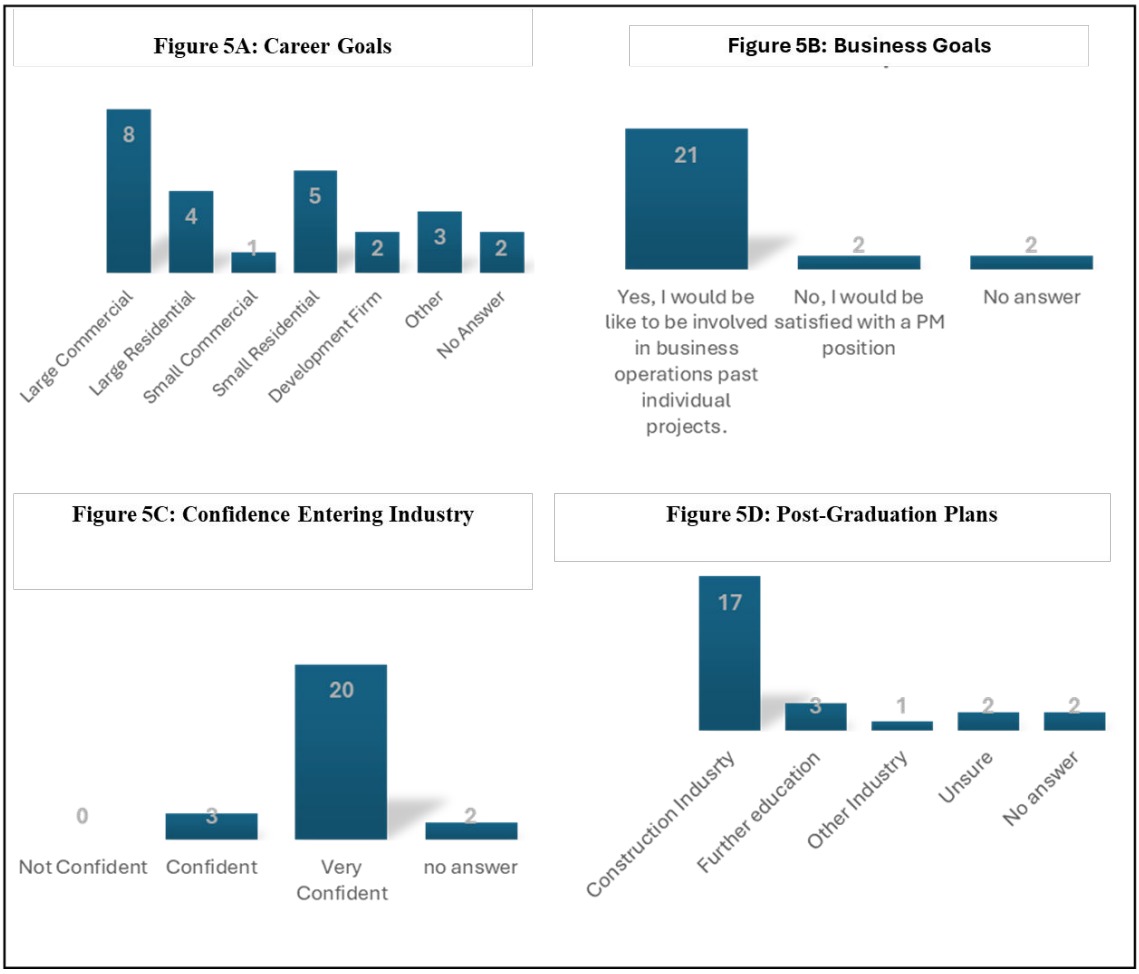
The final section of the survey focused on students' career goals, leadership aspirations, level of involvement they desired within their future roles, and confidence in entering the industry (Figures 5A-D).

The responses reveal that students are overwhelmingly confident about entering the construction industry. Most respondents indicated they feel well prepared to pursue their desired careers. Interestingly, the responses did not reveal a clear preference for company size or type, showcasing a wide range of interests in different areas of construction.



Figures 4 A, B, & C. Specialty Skills – Construction, Business and Design

However, Figure 5B highlights an even more significant finding: 80% of respondents expressed a strong desire to engage in business operations within construction companies, beyond involvement in individual projects. This indicates a growing interest in leadership and strategic roles within organizations. The NAHB competition aligns closely with this aspiration by fostering the development of future leaders equipped with the skills necessary to take on such roles.



Figures 5A, B, C, & D. Respondent Career Goals and Confidence

Recommendations

Based on the findings of this analysis of CM curricula and evaluation of student experiences when participating in the NAHB student competition, there are actionable steps to take to address the gaps in CM education and align academic outcomes with industry demands. These steps are essential to prepare graduates to succeed in leadership roles in an increasingly complex industry.

First, curriculum reform should focus on embedding business acumen and leadership training as core components of CM education. Revising SLOs to emphasize higher-order tasks, such as analyzing financial strategies or designing risk mitigation plans, can create a more robust learning framework. By transitioning from passive outcomes to more active, applied outcomes, educators can set clear, performance-oriented benchmarks that better prepare students for their careers. In addition, revising the language of current SLOs and adding new SLOs can set higher expectations for student performance and better align competencies with industry needs (Table 6).

Table 6. Recommended Changes to ACCE SLO Requirements

SLO Type	SLO Language
Current	**SLO 11:** Understand construction accounting and cost control.
Revised	Analyze construction accounting and cost control strategies.
Current	**SLO 14:** Understand the legal implications of contract law.
Revised	Analyze and apply contract law to construction project management.
Current	**SLO 10:** Understand different methods of project delivery and the roles and responsibilities of all constituents.
Revised	Evaluate and recommend project delivery methods based on stakeholder roles and project requirements.
New	1. Design and evaluate financial plans for construction projects, including cost forecasting and risk mitigation. 2. Develop marketing strategies tailored to construction services and client engagement. 3. Analyze market trends to guide construction organizations planning and development. 4. Plan and facilitate team collaboration to resolve conflicts and achieve project milestones. 5. Create and implement strategies to foster cultural competence and diversity in construction teams.

Integrating these advanced SLOs with experiential learning opportunities like the NAHB competition can reinforce their impact. This ensures that students are not only practicing these competencies in a realistic context but are also evaluated on their ability to meet industry-aligned standards. However, results from competition participant surveys indicate that many students lack foundational business skills before participating in the NAHB competition, which limits their ability to fully develop and retain these skills. To address this, programs should introduce prerequisite requirements focused on business competencies. This would ensure all participants have a baseline understanding of essential business concepts, creating a stronger foundation for the competition.

Programs should also be expanded to address broader market scenarios and challenges beyond residential construction. Developing contextual learning tools would enable participants to practice key competencies in diverse construction settings. For example, a simulation might challenge students to recommend adjustments to a project budget in response to labor shortages or material price fluctuations. These tools would not only broaden the context of these skills but would build on the practical application, further developing these competencies and resulting in better retention.

The study clearly demonstrates that while the NAHB competition is a valuable tool for learning, its full potential can only be realized through diverse learning methods. By implementing these recommendations, programs can turn the competition into a more comprehensive learning model that effectively bridges the gap between academic preparation and industry needs, ultimately preparing students for leadership roles in a dynamic and competitive construction industry.

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Construction Industry Preparedness for Generation Z and Millennials: Aligning Industry Characteristics with Workforce Job Preferences

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ABSTRACT

The construction industry in the United States suffers from workforce shortages, partly due to younger generations being hired more slowly than baby boomers retire. Generation Z's (Gen Z) lack of interest in joining the construction industry, coupled with the retirement of older workers, has amplified the problem. This paper investigates existing literature to identify the work and career preferences of Gen Z and Millennials and determine where the industry may focus efforts to attract these two generations. Through a systematic literature review, this study identified overlaps and gaps between the current construction industry workforce's perceptions of the industry and the preferences of Gen Z and Millennials. Seventeen key characteristics were identified as relevant for comparison. By increasing understanding of Gen Z and Millennials' career preferences, this study provides insights to help the industry enhance Gen Z motivation and retention.

Key Words: Workforce, Gen Z, Millennials, Career Preferences, Construction

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INTRODUCTION

The U.S. construction industry is experiencing a significant workforce shortage (Ashtab & Ryoo 2022; Sarihi et al. 2020), resulting in an economic crisis, because construction accounts for 13% of global GDP (Ghafari et al. 2023). This shortage is severe among the skilled trades, such as welders, pipefitters, and electricians (Albattah et al., 2015). The two significant factors contributing to the labor shortage are the retirement of baby boomers and not enough attraction from millennials and Gen Z to replace those baby boomers (Welfare et al. 2021). Millennials are those born between 1982-1994, whereas Gen Z individuals were born after 1995 (Schlee et al. 2020). Millennials comprise most U.S. employees (Stewart et al. 2017), whereas Gen Z has just entered the workforce over the last several years. Attracting and retaining these two generations of workers in the construction industry is critical to addressing the workforce shortages. However, strategies to attract and retain them are more challenging than those of previous generations (Bennett et al. 2012; Collisson et al. 2021).

Millennials' and Gen Z's lack of interest in the industry is having a dramatic impact on workforce availability (Liu et al. 2021). Contractors lose interest in bidding on jobs due to labor cost unpredictability (Kim et al. 2020). However, the construction industry needs to attract and retain the current and emerging workforce (Borg et al. 2021) to address this workforce shortage by finding a way to motivate Gen Z to pursue careers in the construction industry (Hatoum et al. 2022).

Several researchers have studied the potential impact of the workforce shortage. For instance, Karimi et al. (2018) and Kim et al. (2020) conclude that a labor shortage can bring substantial risk to a project with loss of productivity, increased cost, and schedule overruns. Karimi et al. (2018) propose bonuses, loyalty rewards, and higher salaries as solutions for motivating and retaining the workforce in the industry. Based on the analysis of existing literature, rewards such as competitive salaries and promotions are motivation factors that the construction industry uses to increase workforce satisfaction (Azeez et al. 2019). In addition to skilled labor, a workforce shortage is evident among construction management positions in various industry sectors (Bigelow et al. 2021; Gajjar et al. 2022). These studies conclude that salary, benefits, and career promotion opportunities are critical for professionals choosing a construction career.

Welfare et al. (2021) identify possible recruitment and retention strategies for the general workforce, such as increased wages, overseas recruitment, reformatting training requirements, increasing the workforce, and implementing a multi-skilled force. The effects of the pandemic will become more evident in the years ahead, as it significantly disrupted Millennials' and Gen Z's education, work, and daily activities. The imposition of social distancing requirements and isolation increased the complexities for Gen Z, who rely heavily on interpersonal skills (Becker 2021). The pandemic also disrupted opportunities for selecting and starting a career, as Gen Z had limited opportunities to explore career opportunities during the formative years of high school—when this decision typically takes place (Becker 2021; Centers for Disease Control and Prevention 2020). Many expect much of the Gen Z population to directly enter careers rather than begin post-secondary education (Collisson et al. 2021). Appropriate training and development opportunities to focus on resilience and career growth will be essential to help Gen Z sustain careers (Pichler et al. 2021).

PROBLEM

Attracting Gen Z and millennials to the construction industry could address the workforce problem in the construction industry. The preferences of the previous generation differ from those of the current generation, so there is a need for more research regarding the characteristics and preferences of Millennials and Gen Z and how this relates to choosing a career in the construction industry.

There is a current gap in the literature as to how the work preferences of Gen Z and Millennials align with current construction industry practices.

STUDY GOALS

The authors of this paper aim to highlight the extent to which workforce preferences for Gen Z and Millennials have been documented in the construction industry. They provide an overview of generational work characteristics and preferences, followed by a comparison to identify where generational preferences align with the document preferences in the construction industry.

The three objectives of this systematic literature review are:

- Identify the preferences and characteristics of Gen Z and Millennials when choosing a career.
- Identify current construction practices regarding workforce perception and satisfaction.
- Compare the preferences and characteristics of Millennials and Gen Z with current practices in the construction industry.

METHODOLOGY

The methodology for this study consists of two phases (Figure 1). In Phase 1, the researchers conducted a literature review and analysis to look at the generational preferences for work and job characteristics and compiled a matrix of characteristics and preferences. They also conducted a meta-analysis review of construction literature to assess current construction practices, current workforce perceptions, and satisfaction levels, creating a second matrix of characteristics and preferences. Phase 2 involved a comparative analysis to identify alignment between generational preferences, industry practices, and workforce perceptions. Thus, the researchers identified areas of alignment, focusing on the extent of alignment between Gen Z and Millennials and current worker satisfaction with specific job characteristics and preferences.

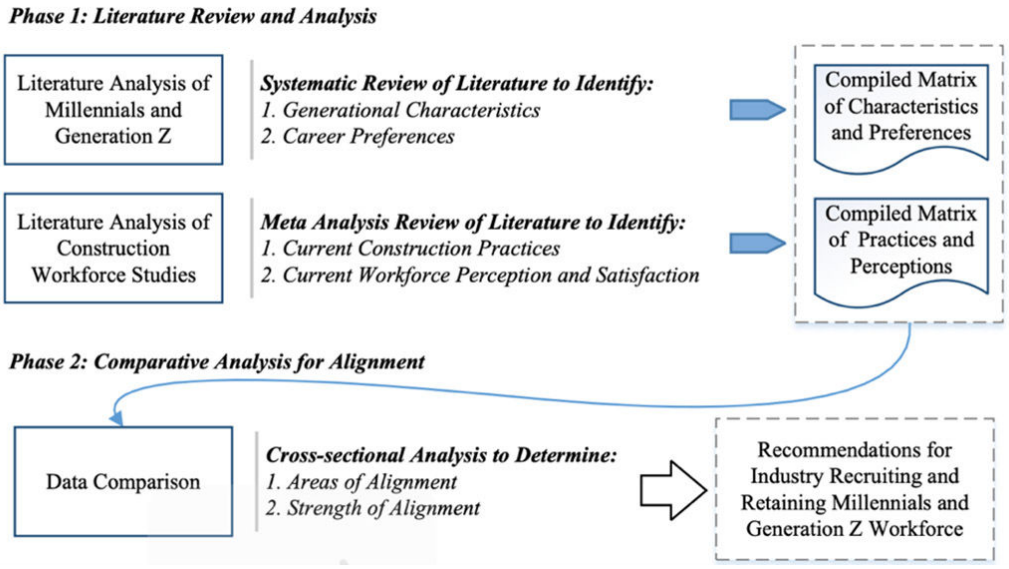

Figure 1. Study Methodology

Phase 1: Literature Review and Analysis

The researchers conducted a systematic literature review of the generational characteristics and work preferences of Millennials and Gen Z. They identified keywords relevant to the study, such as "Gen Z Characteristic," "Gen Z Work Preferences," "Gen Z Work Satisfaction," "Young Talent Career Value," "Gen Z Career Value," "Millennial Characteristic," "Millennial Work Preferences," Millennial Work Satisfaction," and "Millennial Career Value." They conducted another systematic literature review of current construction practices regarding workforce perception, satisfaction and construction industry characteristics, identifying relevant keywords such as "Construction Attraction," "Construction Retention," "Construction Satisfaction," "Construction Talent, "Construction Career Value," "Construction Millennials," "Construction Work Preferences," and "Construction Gen Z."

The team searched for the keywords in the Applied Science & Technology, ASCE library, Compendex, Engineering Village, ICONDA, and Science Direct databases and selected only blind, peer-reviewed publications. The inclusion criteria for this phase were:

- the type of publication (peer reviewed),
- published after 2010,
- articles that focused on the discussion of Gen Z and Millennials.

The team reviewed the extracted papers using the keywords and inclusion criteria, starting with the titles and the abstracts. Then, they further examined the content of the selected papers to identify peer-reviewed publications that match the study's aims. They identified a total of 19 peer-reviewed articles that spoke to the characteristics and preferences of Gen Z and Millennials and a total of 24 peer-reviewed articles that provided information about the construction industry workforce perception and satisfaction.

Phase 2: Cross-Sectional Analysis

Based on the preferences and characteristics defined in Phase 1, the research team mapped Gen Z and Millennials' characteristics and work preferences to the construction industry characteristics and workforce perceptions identified in peer-reviewed studies. They created a matrix to compare construction workforce studies with the identified characteristics and preferences of Gen Z and Millennials. Using this matrix, they investigated positive and negative perceptions within the construction workforce for the identified characteristics and preferences of Gen Z (indicating whether the construction industry is doing well in that area). Additionally, they identified gaps in the literature where specific characteristics or preferences were not evaluated.

PHASE 1 RESULTS AND FINDINGS

Literature Analysis of Millennials and Gen Z Characteristics and Preferences

The data from the literature review did not identify any significant differences between the characteristics and preferences among Millennials and Gen Z. They identified a total of 17 unique characteristics and preferences (Table 1) and compiled

A matrix in Table 1 shows the characteristics and work preferences identified for Millennials and Gen Z. Tech savvy was the most critical characteristic for Millennials and Gen Z; 13 out of 19 published articles (68%) identified the use of technology in their desired workplace as a

characteristic. From the work preference perspective, work-life balance was important for Gen Z and Millennials when considering a career path, 12 out of 19 published articles (63%) indicated the importance of balancing personal life and professional work. Nine out of 19 published articles (47%) identified a collaborative or friendly group-oriented work environment as an essential characteristic and personal and professional development and reward as a vital work preference for Millennials and Gen Z. Interestingly, only 3 out of 19 published articles (15%) identified the characteristic of educated and job safety by Millennials and Gen Z.

Table 1. Gen Z and Millennial Characteristics & Preferences

Studies	*Characteristics*									*Preferences*							
	Tech Savvy	*Self-Reliant*	*Desires Feedback*	*Collaborative*	*Open To Diversity*	*Entrepreneurial*	*Fast Paced*	*Anxious*	*Educated*	*Work-Life Balance*	*Growth/Development*	*Reward*	*Work Satisfaction*	*Personal Impact*	*Challenging Work*	*Job Security*	*Job Safety*
(Hoxha et al. 2020)	X	X	X	X	X	X		X	X	X	X		X				
(Becker 2021)		X															
(Raoufi et al. 2018)		X															
(Seibert et al. 2016)											X						
(DiMattioet al. 2020)	X	X	X		X	X	X	X		X							
(Collisson et al. 2021)	X		X		X		X	X									
(Pichler et al. 2021)	X	X	X	X	X			X									
(Baghdasarin 2020)	X						X										
(A. Buzzetto-Hollywood et al. 2018)	X	X															
(Bennett et al. 2012)	X				X				X	X	X	X					
(Egerová et al. 2021)	X			X		X				X		X					
(Abbas Saeed et al. 2018)	X			X		X				X		X					
(O'Hara et al. 2019)				X		X			X	X							
(Ng et al. 2010)				X		X	X			X	X	X	X	X	X	X	
(Maloni et al. 2019a)	X	X	X	X	X	X				X	X	X				X	X
(Song et al. 2020)		X	X	X						X	X	X	X	X	X		X
(Ayodele et al. 2020)	X			X						X	X	X	X	X	X	X	X
(Isabel Sánchez-Hernández et al. 2019)	X	X	X		X					X	X	X	X		X	X	
(Arora et al. 2019)	X		X	X			X			X	X	X		X	X		
Total	13	9	8	9	7	7	5	4	3	12	9	9	5	4	5	4	3

Existing literature identifies Gen Z as self-reliant with individualistic character (Hoxha et al. 2020), creative, and followers of a self-directed learning approach (Becker 2021). At the same time, Gen Z appreciates open feedback and considers the exchange of feedback a valuable work characteristic (DiMattio et al. 2020). They have grown up with technology (Bennett et al. 2012) and are the most diverse generation ever, making them open to adaptability and diversity (Pichler et al. 2021). For Millennials, teamwork contributes to their work satisfaction, and they want to work with good people in a nurturing environment (O'Hara et al. 2019). They have adopted technology and are a less diverse generation than Gen Z. They look for entrepreneurial career opportunities, can gather information quickly, and are fast paced (Pichler et al. 2021).

Literature Analysis of Construction Workforce Preferences and Characteristics

A total of 24 published articles (Table 2) identified current construction workforce preferences and characteristics. The research team extracted 17 characteristics and work preferences of Gen Z and Millennials from the reviewed studies and compared them to the construction characteristics and workforce perception studies. Table 2 identifies overlaps between the groups of studies. The chart in Table 2 displays the construction workforce perspective studies along the Y-axis and the Gen Z and Millennial characteristics and work preferences on the X-axis. Table 2 shows:

- A matrix comprising construction workforce studies along the Y-axis and Gen Z and Millennial characteristics and work preferences on the top X-axis.
- Preferences and characteristics denoted as P (positive), N (negative), or NC (not considered).
- A P indicates a positive perception by the construction workforce for the identified study for that preference and characteristic (indicating that the construction industry is doing well in that area).
- An N represents a negative perception by the construction workforce for the identified study for that preference and characteristic (indicating that the construction industry is not doing well in that area).
- NC means that the study did not evaluate the specific characteristic or preference.

Table 2 summarizes the perceptions of various characteristics and preferences of Gen Z and Millennials from the point of view of studies related to the construction workforce. The characteristics include being tech-savvy, self-reliant, eager for feedback, collaborative or group-oriented, open to diversity and change, entrepreneurial, fast-paced, anxious, and educated, with strong preferences for work-life balance, personal and professional development, reward, work satisfaction, personal impact, challenging work, job security, and job safety.

Out of the 24 studies analyzed, some showed positive perceptions for certain characteristics of the younger generation, such as tech-savvy (5 positive), feedback (3 positive), collaborative or friendly/group-oriented (3 positive), work-life balance (3 positive), personal and professional development (3 positive), and reward (9 positive). However, there were also notable negative perceptions for some characteristics, such as work-life balance (9 negative), personal and professional development (11 negative), reward (3 negative), and job safety (11 negative). Many characteristics—such as self-reliant, entrepreneurial, and fast-paced—did not appear or were not considered in several studies, indicating gaps in the research. The overall trends highlight areas where the construction industry is perceived positively and negatively by its workforce, suggesting opportunities for improvement in addressing workforce needs and preferences.

Table 2: Construction Workforce Preferences and Characteristics

Studies	Characteristics									Preferences							
	Tech Savvy	*Self-Reliant*	*Feedback*	*Collaborative Or Friendly/Group Oriented*	*Open To Diversity and Change*	*Entrepreneurial*	*Fast Paced*	*Anxious*	*Educated*	*Work Life Balance*	*Personal and Professional Development*	*Reward*	*Work Satisfaction*	*Personal Impact*	*Challenging Work*	*Job Security*	*Job Safety*
(Shan et al. 2017)	NC	NC	NC	NC	NC	NC	NC	P	NC	N	N	N	N	N	N	N	N
(Azeez et al. 2019)	NC	NC	NC	NC	NC	NC	NC	NC	NC	N	N	P	N	N	N	NC	NC
(Chan et al. 2020)	N	NC	NC	N	NC	NC	NC	P	N	N	N	P	N	N		N	N
(Welfare et al. 2021)	NC	NC	NC	P	P	NC	NC	N	NC	N	P	P	P	P	P	NC	N
(Karakhan et al. 2020)	NC	NC	NC	NC	NC	NC	NC	N	NC	N	N	NC	N	N	NC	NC	N
(Metro et al. 2021)	NC	NC	NC	NC	N	NC	NC	N	NC	N	N	P	N	N		N	N
(Minooei et al. 2020)	NC	NC	NC	NC	NC	NC	NC	N	NC	N	N	P	N	NC	NC	N	N
(Alwasel et al. 2017)	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	N
(Albattah et al. 2015)	NC	NC	NC	NC	NC	NC	NC	NC	N	NC	N	N	NC	NC	NC	N	N
(Bigelow et al. 2021)	NC	NC	P	P	NC	NC	NC	NC	NC	P	P	P	NC	P	P	NC	P
(Bigelow et al. 2019)	NC	NC	P	P	NC	NC	NC	NC	NC	P	P	P	NC	P	P	NC	P
(Sokas et al. 2019)	NC	NC	N	N	NC	NC	NC	NC	NC	N	N		NC	NC	NC	NC	N
(Perrenoud et al. 2020)	NC	NC	P	N	NC	NC	NC	NC	NC	N	N	N	NC	NC	NC	N	N
(Gajjar et al. 2022)	NC	NC	NC	NC	P	NC	NC	NC	NC	P	N	P	NC	NC	NC	P	NC
(Karimi et al. 2018)	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	P	NC	NC	NC	NC	NC
(Sedighi et al. 2012)	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	N	NC	NC	NC	NC	NC	NC
(Ofori 2015)	P	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
(Laforet 2013)	N	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	N
(Al-Bayati et al. 2017)	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
(Bademosi & Issa 2021)	P	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
(Assaad et al. 2020)	P	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
(Mésároš et al. 2021)	P	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
(Zaychenko et al. 2018)	P	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
(Lee et al. 2020)	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
Positive	5	0	3	3	1	0	0	2	0	3	3	9	1	3	3	1	2
Negative	2	0	1	3	2	0	0	4	2	9	11	3	6	5	2	6	11
Not Considered	17	24	20	18	21	0	0	18	22	12	10	12	17	16	19	17	11
Studies	Characteristics									Preferences							

Comparing the construction workforce's preferences and characteristics with those of Gen Z reveals notable misalignments. Gen Z typically values tech-savviness, work-life balance, opportunities for personal and professional development, and diversity, reflecting their desire for modern, inclusive, and flexible work environments. However, the construction workforce's perceptions indicate negative views on work-life balance, personal and professional development, and job safety, areas highly valued by Gen Z. This comparison highlights a gap in which the construction industry needs to adapt to attract and retain Gen Z workers by improving areas has been perceived negatively.

PHASE 2 RESULTS AND FINDINGS

Comparative Analysis Between Gen Z/Millennial and Construction Workforce Perception

This study examines both the skilled trades and management within the construction industry. Past research typically focuses on construction workers in general and less on trades like plumbing and masonry (Sarihi et al. 2020). For instance, Chan et al. (2020) link work-life balance for trade workers to factors such as income, poor safety, long hours, and organizational support, which do not tell the whole story.

Work-life balance was an essential preference for Gen Z and Millennials, identified by 12 out of 19 (63%) publications. Twelve of 24 (50%) publications in the construction industry measured work-life balance as a factor when examining workforce perceptions. However, nine out of 12 (75%) publications related to the construction industry viewed this factor as unfavorable or non-existent. When addressed by the studies, work-life balance was not well perceived within the industry and is an area that requires further study. Studies have yet to examine diversity and openness to change, suggesting that the industry may overlook these qualities. Work-life balance, diversity, and openness are some of the most important factors for Gen Z and Millennials in choosing a career, so more research is necessary in this area in relation to construction if the industry wants to attract workers from these generations.

Construction is one of the most hazardous industries (Al-Bayati et al. 2017). The physical nature of the industry is challenging and demands physical strength (Shan et al. 2017b). Those in the industry must lift heavy loads, operate heavy equipment, face work-related health problems (Jafari et al. 2023), and work in extreme weather conditions (Welfare et al. 2021); all these factors influence the labor shortage problem. Some studies point out that the construction industry is changing its nature, from a field that caused many physical injuries to a safer and better-managed environment. Since the 1990s, organizations such as the Center to Protect Workers' Rights, the Construction Industry Institute, and the National Institute for Occupational Safety and Health (NIOSH) have all initiated new best practices to protect workers' health and improve work safety (Alwasel et al. 2017).

The most mentioned characteristic within the studies, mentioned by 72% of the publications, was that Gen Z and Millennials are tech savvy. This characteristic aligns with the construction framework, which increasingly demands technologically skilled employees (Ofori 2015). Implementing high-technology inventions is usually seen more often in large construction companies, the pioneers in the industry (Laforet 2013). Robotics and automation technology have been part of the industry since their introduction in the 1960s and are growing in different categories, such as the production physical construction products, sensor data acquisition and processing, virtual reality, augmented reality and 3D printings (Bademosi et al. 2021), and building information modeling (BIM)—which has been one of the most prominent technological advancements and become prevalent in 2007, seeing rapid growth after 2012 (Assaad et al. 2020; Mésároš et al. 2021). Drones (Zaychenko et al. 2018) and virtual design and construction (Lee et al. 2020) are other examples that show that the

industry is changing with the introduction of new technology.

Collaborative or friendly/group-oriented workspace is another crucial factor for Gen Z and Millennials, as identified by nine out of 19 (47%) publications. However, only six out of 24 (25%) construction-related publications measured collaborative or friendly/group-oriented workspace as a factor in understanding workforce perception, and so was labeled a negative factor. However, three out of six (50%) of the publications within construction did not consider collaborative or friendly/group-oriented workspace as a factor in understanding workforce satisfaction. The construction industry may include having a bond, closer community, or friendly environment among employee as part of their construction business. The very nature of the work requires collaboration and teamwork to succeed and profit. Even though the studies do not explore satisfaction of current workers in how they work in a collaborative environment in depth, the nature of the environment aligns with Gen Z and Millennials' preferences for a career that offers collaborative, group-oriented workspaces.

Reward is another crucial factor for Gen Z and Millennials, identified by nine out of 19 (47%) publications. Twelve out of 24 (50%) construction industry publications measured worker perception. Nine of the 12 (75%) articles measuring this characteristic addressed reward as positively viewed, meaning that the industry does well in this area. The construction industry needs to ensure that salaries and raises are comparable to other sectors and that the benefits offered are appropriate, comprehensive, and affordable, with financial bonuses.

Personal and professional development is another critical factor for Gen Z and Millennials, identified by nine out of 19 (47%) publications about those generations. Fourteen out of 24 publications (58%) about the construction industry measured this factor. However, most publications point out that the industry needs to do better in providing personal and professional development opportunities. The construction industry needs to plan for personal skill development, opportunities for growth, career development, and training as part of the business. Five out of 19 (26%) publications about Gen Z and Millennials identify challenging work as necessary for workers from those generations; five out of 24 (20%) publications about the construction industry addressed challenging work.

Four of 19 (21%) publications about Gen Z and Millennials identified personal impact and job security as essential workplace characteristics. Eight out of 24 publications (33%) in the construction industry measured personal impact, and four out of 24(33%) measured workers' perceptions of job security. However, most publications pointed out that the industry could be doing better in relation to these two factors.

Five out of 19 (26%) publications about Gen Z and Millennials also identified work satisfaction as a necessary career characteristic. However, only seven out of 24 publications (29%) in the construction industry measured overall work satisfaction. The studies indicate that workers negatively perceive how the industry is doing in this area. More than half of the publications within construction (80%) did not consider overall work satisfaction. However, some evaluated sub-factors of satisfaction—such as financial rewards—which the team investigated separately.

Publications related to generational characteristics also identified self-reliance (nine of 19, 47%), entrepreneurship (seven of 19, 36%), and fast pace (five of 19, 26%) as other characteristics of Gen Z and Millennials. However, no publication out of twenty-four publications in the construction industry measured these three characteristics, exposing a need for more study in these aspects of the industry.

The literature review reveals that the construction industry underperforms in most areas and characteristics valued by Gen Z and Millennials. Initially, the team identified Gen Z's preferences

and characteristics; then, they analyzed workforce preferences and characteristics from construction industry publications. They conducted a comparative analysis to identify alignments between Gen Z/Millennials and the construction industry. Table 3 highlights the preferences and characteristics most valued by Gen Z/Millennials and the current construction workforce, as well as the factors overlooked by the industry that require attention. The first column in Table 3 (Gen Z's Preferences and Characteristics) shows the percentage of publications on Gen Z's preferences and characteristics that discuss the specific factors. The team calculated this value by dividing the number of publications referring to each factor by the total number of publications reviewed. The second column shows the percentage of construction industry publications studying each specific preference and characteristic within the workforce. This percentage was calculated by dividing the number of construction industry publications discussing each factor by the total number of publications discussing construction workforce preferences and characteristics. The third column shows the percentage of construction industry publications that overlooked the identified preference or characteristic. The percentage for each factor was calculated by dividing the number of construction industry publications that overlook each factor by the total number of construction industry publications reviewed.

Table 3 Comparative Analysis for Alignment Between Gen Z/Millennial and Construction

Gen Z's Preferences and Characteristics	Gen Z's Preferences and Characteristics Discussed (%)	Construction Industry Publication - Workforce Preferences and Characteristics Discussed (%)	Construction Industry Publication Percentage Overlooking Factors (%)
Work-life balance	63	50	75
Personal and Professional Development	47	58	78
Reward	47	50	25
Work Satisfaction	26	29	80
Personal Impact	21	33	62
Challenging Work	26	20	40
Job Security	21	28	80
Job Safety	15	54	84
Tech-Savvy	68	28	25
Self-Reliant	47	0	0
Feedback	42	16	25
Collaborative Or Friendly/Group Oriented	47	25	50
Open To Diversity and Change	36	12	66
Entrepreneurial	36	0	0
Fast Paced	26	0	0
Anxious	21	25	66
Educated	15	8	100

The ease with which Gen Z uses technology and their desire for a work-life balance are the work characteristics most referred to in publications related to Gen Z. Where the use of technology and how technology can impact the construction industry is widely covered, work-life balance is only examined in a few studies about the construction industry—and often in a negative light. This suggests that work-life balance in the industry requires more research. Another area that could

use some further study is personal and professional development. Gen Z favors opportunities for development, and this preference shows up in close to half of the studies about the generation but very few industry studies.

DISCUSSION

This study contributes to the growing body of literature that addresses workforce shortages in the construction industry by focusing specifically on the preferences and characteristics of Millennials and Gen Z. Through a comprehensive literature review and comparative analysis, the authors identified several key findings that align with, add to, and sometimes challenge existing research.

Moreover, this literature review highlights the critical preferences and characteristics of Millennials and Gen Z and contrasts these with the current practices and perceptions within the construction industry. The findings indicate several misalignments that the industry must address to effectively attract and retain younger workers. For example, both this paper and existing research highlight preferences for work-life balance, a collaborative work environment, and opportunities for personal and professional development (Becker 2021; DiMattio et al. 2020).

Both Millennials and Gen Z are characterized by their tech-savviness, with a high demand for workplaces that integrate modern technology. The construction industry has made strides in this area with the adoption of BIM, drones, robotics, and other advanced technologies. However, there is still a need for widespread implementation across all sectors of the industry. Training programs that focus on upskilling employees in these technologies could attract younger workers and improve job satisfaction by aligning with their preference for technologically advanced work environments.

A collaborative or friendly work environment is another significant preference for Millennials and Gen Z. However, the construction industry often falls short in fostering such an environment. The nature of construction work, which often involves long hours and physically demanding tasks, can create a stressful and isolating environment. To address this, the industry should promote team-building activities, team-oriented work environments, and open communication channels that encourage collaboration and support among workers. Creating a positive work culture where employees feel valued and connected can improve job satisfaction and retention rates.

Competitive salaries, benefits, and recognition are crucial for motivating and retaining the Gen Z workforce. The construction industry does reasonably well in this area, but there is room for improvement. Transparent and merit-based reward systems, opportunities for career advancement, and comprehensive benefits packages are essential. Additionally, offering financial incentives—such as bonuses and loyalty rewards—can further motivate employees. Regularly reviewing and updating compensation packages to remain competitive with other industries is also vital.

While Millennials and Gen Z value opportunities for personal and professional development, the construction industry has yet to place greater emphasis on providing clear career pathways, ongoing training, and development opportunities. The industry should invest in employee development, career growth opportunities, and training to align with the desires of these generations While certain aspects of work satisfaction appeared in the reviewed literature, the overall perception of work satisfaction in the construction industry is negative. Identifying the root causes of dissatisfaction and investing in the workforce's continuous development will not only enhance job satisfaction, but build a more skilled and adaptable workforce.

The construction industry often has a poor public image, seen as dangerous, dirty, and not supportive of work-life balance. This negative perception deters younger generations from pursuing careers in construction. To change this, the industry needs to rebrand itself. Highlighting improvements in safety, utilizing modern technology, and offering meaningful, well-paying careers can help improve the industry's image. Implementing outreach programs in schools and colleges, showcasing successful careers, and using social media to promote a positive image could attract young talent.

Furthermore, the challenging nature of construction work, which includes physical tasks and complex projects, may appeal to Gen Z and Millennials. Traits like self-reliance, entrepreneurship, and a fast-paced environment also align with their preferences but have not been thoroughly studied in relation to the construction industry. Exploring and promoting these aspects could attract young workers looking for stimulating tasks. The industry should find ways to emphasize these traits to draw in new talent.

One of the most critical preferences for both Millennials and Gen Z is work-life balance. The literature review reveals that while this balance is paramount for these generations, the construction industry often neglects this aspect. This oversight is problematic, as it not only impacts job satisfaction but also overall workforce retention. The construction industry must adopt more flexible work schedules and provide a supportive environment that prioritizes employees' personal lives. Implementing policies that allow for remote work (where feasible), offering paid time off, and encouraging a culture that respects personal time can significantly enhance work-life balance in the industry. Studying work-life balance in the construction sector is the first step, but the authors also recommend studying how the construction industry sets its strategies and policies in relation to work-life balance and attracting and retaining new employees. In addition, further research should focus on defining and prioritizing work-life balance based on the new generation entering the industry. With more research, specific challenges of and tailored solutions to work-life balance will emerge for further study.

In conclusion, improved alignment between the construction industry and the preferences of Gen Z and Millennials is crucial for attracting and retaining the next generation of construction workers. By addressing the areas requiring improvement and continuing to excel in areas of alignment, the construction sector can position itself as an attractive and sustainable career choice for Gen Z while acknowledging its existing workforce challenges. The industry must address the evolving needs and expectations of tomorrow's workforce through outreach and education to highlight why a construction career is a good fit for the younger generations. Through this outreach and improved awareness, construction could become a valid career option and, in doing so, shrink the space between current differing preferences and current perspectives of work in the industry. Table 4 summarizes the implications for both the industry and academia.

CONCLUSION

The workforce plays a critical role in the construction industry's success. The construction industry in the United States is suffering from a labor shortage and should take significant steps to overcome the challenge. Learning more about the current and potential workforce (Millennials and Gen Z) is one of the first steps toward fighting against the labor shortage and motivating Gen Z and Millennials to join the construction industry. This paper focuses on the intersection of Gen Z and Millennials' work preferences and characteristics and the construction industry's approach to these characteristics. Knowing their perception of Gen Z and Millennials' preferences is critical to attracting and retaining these two generations in the construction industry. Also, the authors discovered that very few studies about current workforce perception and satisfaction have been published since 2010.

Table 4. Industry and Academia Implications

Key Characteristics and Preferences of Gen Z	How Construction Could Address	How Construction Education Could Assist
Work-life balance	Adopt flexible work schedules, offer remote work options where feasible, and promote a culture that respects personal time.	Educate the incoming workforce on the work environment in the construction industry.
Tech-savviness	Integrate advanced technologies like BIM, drones, and robotics more widely across all sectors; provide training opportunities.	Implement training programs for the younger workforce that align with their preferences.
Collaborative or friendly/group-oriented work environment	Foster team-building activities, create supportive team-oriented work environments, and improve communication channels.	Create team-building activities that promote collaborative learning.
Competitive salaries and benefits	Improve transparency in reward systems, career advancement opportunities, and comprehensive benefits package.	Present the information to future students.
Personal and professional development opportunities	Provide clear career pathways, ongoing training, and development opportunities to align with personal growth goals.	Identify the root causes of dissatisfaction and invest in the workforce's continuous development.
Workplace safety and positive image	Rebrand the industry by highlighting improvements in safety, modern technology, and opportunities for career advancement.	Promote the positive aspects of construction careers through outreach programs, partnerships with schools, and social media.
Challenging and stimulating work environment	Emphasize the complex and entrepreneurial aspects of construction work, highlighting the dynamic nature of projects.	Teach students how to handle complex, fast-paced projects and instill an entrepreneurial mindset.

Based on the compiled matrix of characteristics and preferences of Gen Z and Millennials, it is clear that work-life balance, collaborative or friendly group-oriented work environment, and professional and personal development in the workplace are most preferred by Gen Z and Millennials. This study also concludes that the industry focuses more on using rewards as motivation and retention factors. However, the construction industry overlooks work-life balance, work satisfaction, and personal professional development, all of which Gen Z and Millennials prefer. Furthermore, the paper's findings suggest that diversity and openness to change are factors that the industry has ignored. However, previous research indicates that there is more creativity in the workplace that exhibits diversity, and this could improve motivation among workers. The study's findings imply that the construction industry should focus on the areas it has overlooked and initiate a new implementation strategy in its human resource management.

One area for improvement may be the exploration and adoption of new technologies, such as augmented reality and virtual reality; these technologies might enhance training and engagement for younger workers. Incorporating these and other technologies into the workflow and workers'

responsibilities can provide an outlet for the generation that grew up in a tech-filled world. Incorporating and further exploring automation and robotics and adopting these for use on the job site may also attract a wider range of workers.

It could be valuable to evaluate career development programs—such as mentorship initiatives—for their effectiveness in meeting the professional growth needs of Millennials and Gen Z and influencing job satisfaction and retention rates. Research into specific work-life balance initiatives, like flexible hours and mental health support, could identify the most effective strategies to implement in the industry. Furthermore, examining the industry's commitment to sustainability and social responsibility might reveal how these factors influence the career choices of younger generations. Research in these areas could provide valuable insights into how the construction industry can better attract, motivate, and retain Millennial and Gen Z workers, ultimately minimizing the labor shortage.

FUTURE WORK AND LIMITATIONS

This literature review aims to provide insights into Gen Z work preferences and how they align with the construction industry's practices, but there some limitations. The authors used a systematic method to analyze peer-reviewed journal articles, ensuring consistency but possibly missing important contributions from other sources (like books and reports). Future reviews could include these broader perspectives. Additionally, the keyword search covered many identified aspects of workforce characteristics and Gen Z preferences; this ensured a thorough capture of relevant literature, but it is possible that some relevant articles were inadvertently overlooked. Future reviews could expand keyword variations to address different terms and phrases.

Finally, relying on one primary reviewer might introduce biases, though the review followed strict protocols and was validated by coauthors. These coauthors specialize in the same industry, but collaborative reviews with interdisciplinary teams could further improve the analysis. Despite these constraints, this review offers a strong synthesis of key themes in how Gen Z workforce preferences align with those of the construction industry; this research should guide future research and practice.

Future research should delve into several of this paper's findings to highlight the insights, such as evaluating the findings from this study within the context of the construction companies.

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