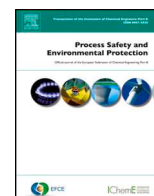




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Safety and health management response to COVID-19 in the construction industry: A perspective of fieldworkers



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ABSTRACT

The COVID-19 outbreak has significantly impacted the construction industry. The pandemic can exacerbate an already dire safety and health situation in the industry and negatively impact construction employees and employers. The present study investigates the safety and health measures implemented by construction firms in the United States (US), their effectiveness and usefulness, and workers' satisfaction with these COVID-19 measures. A questionnaire survey was developed and distributed to construction fieldworkers in the US to collect their perspectives on the implemented COVID-19 measures in the construction industry. A total of 187 valid responses were received and analyzed to achieve the aim of the study. Results revealed that strategies implemented to increase social distance and minimize group gathering to 10 persons in certain workstations were perceived to be substantially more effective than job-site screening strategies. Furthermore, smaller contractors implemented fewer safety measures and perceived them to be significantly less effective than those used by medium- and large-sized contractors. Fieldworkers were favorably disposed toward using technologies, such as video-conferencing apps and wearable sensing devices, to slow the spread of COVID-19 on construction job sites. The present study contributes to the body of knowledge by identifying safety and health measures to mitigate the spread of COVID-19 in construction. Practically, the study findings provide valuable insights to inform the successful implementation of safety strategies in the construction industry during a pandemic. The results are crucial for industry practitioners responsible for developing and revising pre- and post-pandemic safety and health plans.

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1. Introduction

Coronavirus disease 2019 (COVID-19) is a respiratory disease caused by the SARS-CoV-2 virus, initially discovered in December 2019. The virus primarily spreads from person to person through respiratory droplets produced from infected people when they cough, sneeze, or talk [Centers for Disease Control and Prevention CDC (2020)]. The World Health Organization (WHO) declared COVID-19 a global pandemic on March 11, 2020 (WHO, 2020a, 2020b). As of December 2021, confirmed cases were approximately 50 million confirmed cases and 808,000 deaths recorded in the United States (US). Work-based restrictions, such as complete lockdowns and implementing social distancing practices, were put in

place to respond to the pandemic, which impacted most industries globally, including the construction industry (Alsharaf et al., 2021).

The construction industry plays a significant role in developing the economy (Rasheed, 2015; Associated General Contractors (AGC) (AGC, 2021), which accounted for 4.2% of the gross domestic product in the US in 2020 (Bureau of Economic Analysis (BEA), 2020). In November 2021, more than seven-million employers were in the construction industry in the US (Bureau of Labor Statistics BLS, 2021). The construction industry is vulnerable to the COVID-19 crisis because most construction activities must be performed on-site, limiting the number of workers that can work remotely (del Rio-Chanona et al., 2020). Furthermore, multiple employees working close to one another is a must when performing several construction activities, such as working in a confined space.

While construction is already considered an industry with significant health and safety risks (Kamas et al., 2019), the introduction of COVID-19 provides an additional risk that could drastically impact the safety and health of workers in the construction industry. As a

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once-in-a-century event, numerous unprecedented measures have been taken to curb the spread of COVID-19 across the industry and mitigate its effects on the progress of the industry and the workforce altogether (Alsharef et al., 2021; Stiles et al., 2020). In response to the pandemic and the gradual economic re-opening, the CDC and Occupational Safety and Health Administration (OSHA) proposed and enacted multiple measures and regulations. The objective of these measures and regulations was to keep construction employees safe. However, several reports suggest a mixed feeling within the construction community regarding the feasibility and effectiveness of these measures and regulations. For instance, OSHA cited multiple companies for lack of compliance (enforcement) with the enacted COVID-19 regulations (Occupational Safety and Health Administration OSHA, 2021). In some instances, top management approved the application of COVID-19 measures, believing that they were effective and easy to implement. However, workers sometimes intentionally or unintentionally ignore these measures and regulations because they add additional restrictions, making workers less productive (Alsharef et al., 2021; Amoah and Simpeh, 2020). Organizations must work closely with frontline workers to ensure their recommendations are accommodated in the decision-making process and reduce the potential of failed implementation. Few studies have investigated fieldworkers' perceptions of the effectiveness of safety and health practices and strategies in the construction industry in response to a pandemic (Alsharef et al., 2021). Bridging this gap in knowledge is essential to efficient COVID-19 risk mitigation given that an employee's perceptions about an organization's practices, and not the actual effect of organization's planned practices, directly influence the employee's behavior and performance (Jiang et al., 2017; Liao et al., 2009).

As with most regulations and safety measures, awareness and implementation are typically influenced by organizational demographic factors, such as company type, size, and location (Lin and Mills, 2001; Cunningham et al., 2018). Previous research has suggested that these demographic factors could impact stakeholders' perception toward factors that influence the implementation of safety solutions (Chen and Jin, 2013; Nnaji et al., 2019). For instance, (Awwad et al., 2016) posited that large contractors are more invested in developing safety management programs than smaller contractors. Furthermore, a recent report released by Dodge Data and Analytics and CDC indicates that, although 96% of large employees have developed a written policy to protect job site safety, only 57% of small contractors have a written plan in place (SmartMarket Report, 2021).

Given the dynamic nature of the COVID-19 pandemic and the need to support effective strategy implementation during and post pandemic, assessing fieldworkers' perception toward COVID-19-related strategies implemented by the construction industry is important. This assessment should account for the potential differences across key organization demographic factors. However, insight on fieldworkers' perspectives on safety and health interventions introduced in response to a pandemic, such as COVID-19, is limited. The goal of the present study is to fill this gap in research and practice by achieving the following:

- a. Provide insights on the implemented COVID-19 related measures in the US construction industry and their perceived effectiveness from the perspective of fieldworkers, and
- b. Provide context-based recommendations to promote the use of practical solutions for improving worker safety and health during a pandemic.

2. Background

The following section provides a review of the impact of COVID-19 on the construction industry. It describes the different strategies

recommended by OSHA and CDC to mitigate the spread of COVID-19 in construction job sites.

2.1. Impact of COVID-19 on the construction industry

Construction projects across the US and other countries experience suspension, delays, stoppage, or increasing safety and health concerns because of the COVID-19 pandemic (Becker et al., 2021; Ogunnusi et al., 2020; Al Amri and Marey-Pérez, 2020; Zamani et al., 2021; Gamil and Alhagar, 2020). In the meantime, the pandemic also causes a considerable financial impact on construction projects. For example, expenses for additional materials and equipment, such as installing handwashing stations to decrease the spread of the COVID-19 virus and protect workers on-site, can exceed the planned budget of the project. Paying additional labor costs because of labor shortage and project management for double shifts, staggered shifts, and remote work and experiencing substantial loss of productivity compared with normal operations are frequently encountered by employers and contractors (Becker et al., 2021). As summarized by Assaad and El-adaway (2021), the short- and long-term impacts posed by the COVID-19 virus on the construction industry include (1) workforce-related issues, such as worker shortages because of infections and preventive quarantines and worker layoffs caused by project cancellations and delays; (2) project and workplace considerations, such as implementing new workplace practices and policies; (3) procurement and supply chain implications, such as the restrictions and closures in the international exchange markets; and (4) contractual, legal, and insurance aspects, such as issues regarding the applicability of the force majeure clause. The construction industry must develop and implement effective strategies to tackle these challenges. Consistently, researchers have highlighted the need to prioritize worker safety, health, and wellbeing during this challenging time to reduce the projected workforce crisis in the construction industry (Ogunnusi et al., 2020; Alsharef et al., 2021; Assaad and El-adaway, 2021).

2.2. Industry Responses and safety and health challenges faced by fieldworkers

In the US, resources from federal, state, and local agencies and professional societies, such as the American Society of Civil Engineers, Association of General Contractors, and Associated Builders and Contractors, provide guidelines and best practices to help engineers and contractors continue construction work amid the COVID-19 pandemic. The federal guidelines place a large focus on eight aspects for construction employers: (1) hazard assessment; (2) controlling and prevention; (3) promoting social distancing and face masks; (4) cleaning, disinfection, and hand hygiene; (5) managing sick workers; (6) return to work after worker exposure to COVID-19; (7) provide education, training, and communication; and (8) mental health and wellbeing considerations (CDC, 2020). Therefore, most construction organizations implement social distancing and face masking guidelines, enhance cleaning and disinfection on sites, and facilitate the appropriate use of remote work to help prevent and slow the spread of COVID-19.

Furthermore, companies increasingly rely on technologies as critical elements in implementing these guidelines (Nnaji and Karakhan, 2020). For instance, the use of virtual meeting applications, such as Zoom, Skype, and Microsoft Team, notably increased during the pandemic. These technologies are used to promote social distance, provide the required training, and limit worker exposure to hazards. Furthermore, a combination of cameras and wearable sensing devices (WSDs) are being used to keep workers socially distanced on the job site and enhance contact tracing if needed (Shubina et al., 2020; Magesh et al., 2020). WSDs are small devices that workers can attach to their body and outfits as accessories to

Table 1
COVID-19 Safety and Health Measures.

Covid-19 Strategy Category	Specific Strategy	Source (s)
Increase Social Distance	Shift work (increase social distance) Staggered breaks and lunches Separated project offices (employees are spread-out when working in door) Remote work, where possible Project area isolation (employee performs tasks alone)	Alsharef et al. (2021); Amoah and Simpeh (2020); Zheng et al. (2020); Centers for Disease Control and Prevention (CDC), 2020; Centers for Disease Control and Prevention (CDC), 2021; (Quezon and Ibanez, 2021); Simpeh and Amoah (2021); Koshy et al. (2021); Cirrincione et al. (2020); Pradhan et al. (2020); Hollingsworth (2020); Occupational Safety and Health Administration (OSHA), 2016; Occupational Safety and Health Administration (OSHA), 2020
Minimize Group Gathering Size to 10 Persons	Wearable technologies for tracking location Shift work (minimize large groups) Separate work areas isolated via barriers Use of technologies (e.g., using Skype and Zoom for meetings) Increased use of remote worksite for prefabrication	
Job-site screening	Job site health questionnaire for all workers (pre-job health check surveys) Temperature / fever checks using thermometers Travel questionnaires to verify exposure to high-risk locations COVID-19 tests Workers physically examined for exposure conditions	
Cleaning supplies	Screening using onsite cameras Hand sanitizer Wash stations greater than normal 3rd party cleaners Hourly sanitization of key high touch areas such as elevator keys, door handles, etc. UV sanitation Fog atomizers	
PPE	Latex gloves Respiratory N95 and others Face shields	

monitor their health and safety performances on-site (e.g., assess physical workload, level of fatigue, and mental status) (Awolusi et al., 2018; Karakhan and Alsaffar, 2019; Ahn et al., 2019; Nnaji and Karakhan, 2020)). This class of technology is typically built into or attached to personal protective equipment (PPE) (Ahn et al., 2019), belt clips (Nnaji et al., 2021), or worn directly on workers' body (Awolusi et al., 2018). Although such technology is promising, several studies have highlighted the slow adoption rate of WSDs in the construction industry (Choi et al., 2017; Nnaji et al., 2020). Regardless, WSDs have the potential to play a vital role in keeping workers safe and healthy during the pandemic. Table 1 lists different strategies currently implemented in the construction industry, as discussed in previous COVID-19 related publications.

As mentioned earlier, while most organizations responded to COVID-19 by providing considerable safety resources to workers, the actual implementation and enforcement was suboptimal, leading to several OSHA citations. Previous studies have highlighted that successfully implementing safety interventions in the construction industry is problematic given the poor safety culture and climate throughout the construction industry (Seo et al., 2015; Chen and Jin, 2013; Fang and Wu, 2013; Meng et al., 2021). In some instances, organizations put strict punitive measures, such as strikeout policies, to influence worker safety behavior and attitude (Meng et al., 2021).

In addition to enforcement concerns associated with worker behavior, other concerns have been highlighted by researchers. Amoah and Simpeh (2020) investigated the COVID-19 safety program implementation challenges at construction sites in South Africa by conducting interviews with 19 construction professionals participating in ongoing projects. The findings of the study reveal that the inadequate supply of PPEs, the lack of compliance with worker health and safety regulations/guidance (particularly complying with social distancing), the difficulty in sharing tools and

equipment and sanitizing all materials, and public transport usage by workers are the primary safety management challenges during the pandemic (Amoah and Simpeh, 2020). Similarly, Alsharef et al. (2021) interviewed 34 construction managers in the US, and reported the adopted several safety measures, such as social distancing protocols, staggering of construction operations, and COVID-19-related training. However, the study's sample size was limited and focused only on management-related personnel as opposed to fieldworkers. Another study placed emphasis on investigating the construction practitioners' knowledge, attitudes, and practices regarding the transmissions and preventions of COVID-19 in China (Zheng et al., 2020). Zheng et al. (2020) revealed that the study participants were generally satisfied with the countermeasures (e.g., wearing masks, temperature measurement, and regular disinfections) taken by their employers in preventing the spread of the virus. However, the study of Zheng et al. was conducted in China and did not focus on workers with the highest level of exposure to COVID-19 on the job site (i.e., fieldworkers).

Given the severe consequences of the spread of COVID-19 on the construction industry in the US, the implementation and effectiveness of COVID-19 countermeasures must be investigated. Investigating the implementation and perceived effectiveness of COVID-19 helps address the current gap in COVID-19 response by providing implications to industry practitioners to minimize the spread of the disease during the pandemic (Assaad and El-adaway, 2021), thereby ensuring the safety and health of construction workers is maximized. Limited studies provide a thorough investigation of the US construction industry's safety and health measures in response to COVID-19. The present study aims to investigate the health and safety measures taken by the construction firms in the US during the COVID-19 crisis, as well as the perceived effectiveness and satisfaction of the implemented COVID-19 countermeasures in practice on construction job sites. Specifically, this

study answers the following research questions from the perspective of construction fieldworkers:

- I. What are the frequent COVID-19 preventive safety measures used on construction projects?
- II. Are fieldworkers satisfied with preventive measures provided by their employers?
- III. Does information on the use and effect of COVID-19 preventive measures differ based on demographic characteristics?

It is important to note that while the focus on “perceived effectiveness” and not the “actual/objective effectiveness” of COVID-19 safety and health control measures could introduce some subjectivity and bias, previous studies have proven that perception, not reality, has the most impact on individual behavior (Duncan et al., 2011; Gaskin et al., 2013).

3. Research methodology

The present study utilized a quantitative research method relying on a questionnaire survey. Working with researchers and practitioners, the research team developed and distributed a questionnaire to construction fieldworkers in the US to capture critical insights needed to answer the previously mentioned research questions.

3.1. Survey development

The survey consisted of two primary sections. The first section focused on collecting demographic information from the participants. The demographics questions selected in this study were informed by previous studies (Alsharif et al., 2021; Stiles et al., 2020; Zheng et al., 2020). The second section of the questionnaire asked the participants to respond to six sets of questions related to the level and quality of safety training provided; safety and health practices used to increase social distance; safety and health practices to minimize group gathering size to 10 persons; safety and health practices used in job site screening; cleaning, disinfection, and hand hygiene practices; availability of PPE; and overall assessment of COVID-19 response by their organizations. The survey design, especially the questions asked in the second section of the questionnaire, was influenced by OSHA and CDC materials/guidelines Centers for Disease Control and Prevention (CDC), 2020; Centers for Disease Control and Prevention (CDC), 2021; Occupational Safety and Health Administration (OSHA), 2020 and discussions with construction practitioners actively working in the industry. Specifically, the research team, working with a risk management consulting firm, developed and modified the content of a previous questionnaire distributed earlier by the organization. Utilizing a similar questionnaire helped ensure the internal and external validity of the survey instrument (Al-Saffar, 2020). Information related to the perceived effectiveness of safety measures was obtained from ratings based on a five-point Likert scale (ranging from “1” = “strongly disagree” to “5” = “strongly agree”). Finally, the participants were asked to rate on a scale of “zero” to “100” the level of preparedness of their employer in mitigating COVID-19 infection on their projects, where “0” is “not prepared at all” and “100” is “highly prepared.”

3.2. Survey distribution

The survey was designed and distributed in Qualtrics, a widely used survey design and distribution platform. The scope of the study was limited to fieldworkers. Thus, the survey was distributed to fieldworkers through the US construction industry. Qualtrics identified and distributed the survey to potential participants through their partnership with worker unions and other employees related to organizations in the construction industry. The research team

opted to use a third-party platform to ensure that participants could be recruited across several regions in the US. Furthermore, given that the study was launched in the middle of a shutdown (from August 1 to October 25, 2020), distributing the survey using traditional means (e.g., paper surveys and construction site visits) was infeasible. The number of participants necessary to establish statistical significance was calculated using Eq. (1).

$$S_s = \frac{Z_{\alpha/2}^2 \times P \times (1 - P) \times D}{e^2} \quad (1)$$

where S_s represents the sample size, $Z_{\alpha/2}$ is the z-value that represents the confidence level in the data, P is the sample proportion, D is the design effect, and e is the sampling error.

The margin of error for this survey study was 10%, the standard deviation ($Z_{\alpha/2}$) for a two-tailed alternate hypothesis at $\alpha = 0.05$ was 1.96, and the sample proportion was 50% for a simple random sampling where $D = 1$ (Suresh and Chandrashekar, 2012). Therefore, a sample size above 96 was required to examine the perceived effectiveness of COVID-19 practices. To improve generalizability of the results across the wider population, and improve group-based comparisons, the researchers attempted to double the estimated sample size.

Approximately 1200 construction fieldworkers were contacted, of which 300 fieldworkers agreed to participate. However, only 187 participants met the study requirements (fieldworkers, 18 years and older, and currently active in the construction industry) and passed the survey quality checks put in place by the researchers to ensure high-quality responses. First, attention check questions were included in the online survey [e.g., “select the first option (“strongly disagree”) for this question]. Participants who failed the attention check questions were dropped from the survey. Then, speeders were flagged based on completion time. Responses with completion times that are more than one standard deviation away from the median completion time were flagged. Finally, participants who choose one option throughout the questionnaire (straight liners), regardless of the question asked, were flagged and dropped from the study. The average time to complete the questionnaire was approximately 8 min, and the participants that completed the survey were given a reward of \$10 for their time and participation in the study. This reward was distributed by Qualtrics, not the research team itself.

3.3. Statistical analysis

The present study utilized a combination of descriptive and inferential statistical approaches to answer the key research questions described previously. First, the research team conducted a descriptive analysis to identify counts, mean, median, and standard deviation. This information was used to determine the rate of COVID-19 prevention measures implementation and the perceived effectiveness of preventive measures. The present study considered five demographic characteristics (job title, sector, organizational type, organization location, and organizational size) and their impact on the perception of fieldworkers regarding their organization preparedness and response to the spread of COVID-19. Proportion and Pearson Chi-Square analysis were then used to analyze the difference in the level of COVID-19 prevention interventions across the five demographic factors. The null hypothesis for the proportion analysis was that *the proportions of companies implementing safety and health measures for the groups based on their five demographic characteristics are equal*.

The researchers utilized non-parametric inferential statistical approaches to assess the potential difference in workers' perception of COVID-19 measures effectiveness because of demographic characteristics. Mann-Whitney U-test (two-samples) and Kruskal-Wallis test (more than two samples) were used to conduct the analysis. The

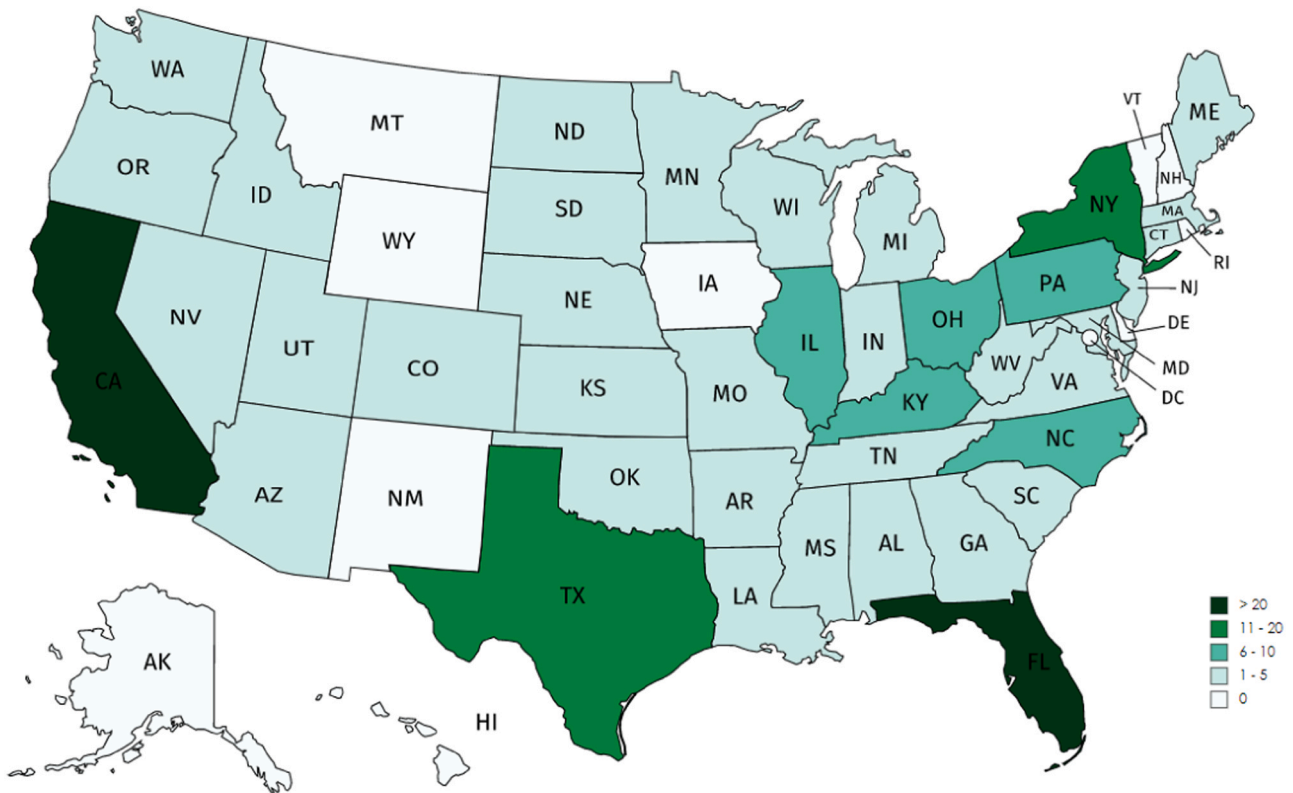


Fig. 1. Location of Survey Participants by State (n = 187).

reason to use non-parametric analysis is that the data collected when examined violated the equal variance and normality assumptions needed to perform parametric analysis. Dunn-Bonferroni post hoc was used to identify the comparison that significantly differs. The null hypothesis for these tests is as follows: *The distributions of the groups under investigation have the same median.* A multiple proportion z-test analysis was used to determine whether demographic factors impacted the implementation of COVID-19 safety measures. The null hypothesis is as follows: *The proportions of companies implementing safety and health practices for the groups (demographic characteristics) are equal.*

Furthermore, the researchers conducted a one-sample Wilcoxon signed rank test to assess the perceived level of the overall effectiveness of safety procedures put in place by construction organizations (Meke et al., 2018). Following previous research (Karakhan et al., 2020; Al-Saffar, 2020), a perceived effectiveness rating significantly above the midpoint/neutral choice of the scale (three on a five-point Likert scale) was considered evidence of the effectiveness of the safety procedure. The null hypothesis for the one-sample test is as follows: *The population median effectiveness rating (η) is less than or equal to hypothesized median rating (η_0).*

4. Results

This section presents the results gathered from the questionnaire survey and insights extracted from data analysis.

4.1. Participants demography

A total of 187 respondents who currently work in the construction industry throughout the US completed the survey and passed the quality checks set by the research team to ensure high-quality responses. Participant's response to the question "How do you best define the location of the majority of your company's operations?" is

mapped in Fig. 1. Most organizations were located regionally, with only 14 (7.5%) executing projects throughout the country (in more than one region), eight (4.3%) in Mid-Atlantic, and five (2.7%) internationally distributed outside the US.

The participants were mostly from the residential construction sector (63.6%), followed by 27.3% from the commercial construction sector. In terms of organization types, more than half (56.7%) of the participants work for general contractors, and approximately one-fifth (18.7%) of the participants work for sub-contractors. As for company size (by the number of direct-hire employees), the majority of the participants (61.5%) are from relatively small companies with less than 100 employees. This company size sample distribution is representative of what is obtained in the construction industry (U.S. Census Bureau, 2020). Carpenters, foremen, superintendents, equipment operators, electricians, and other fieldworkers or trade persons contributed 87.2% of the responses received. The vast majority of the participants (88.2%) have more than five years of professional experience, and nearly half of the participants (46%) held an associate degree or above. Table 2 summarizes the background information of the participants.

4.2. COVID-19 training

In terms of training related to COVID-19, more than 60% of the participants (113) indicated that their employers provided additional training for operations during the pandemic. Approximately 97% of the study sample have participated in additional safety training during the pandemic, indicating that their employer provided a detailed guideline for implementing new COVID-19 related practices, including, but not limited to, social distancing, hand washing, and the use of face mask/covering. The participants indicated that their employer also described potential hazards and safety risks that fieldworkers may be exposed to during the pandemic as part of the training. When asked whether the participants' level of

Table 2
Background information of participants (n = 187).

Category	Demography	Count	%
Industry Sector	Residential	119	63.6
	Non-residential	68	36.4
Organization Type	General Contractor	106	56.7
	Sub-contractor/Specialty Contractor	35	18.7
	Owner Agency/ Client (e.g., State DOT, etc.)	34	18.2
Size of Company	Small (Less than 100 Employees)	115	61.5
	Medium (101 – 500 Employees)	37	19.8
	Large (Above 501 Employees)	35	18.7
Job Title	Frontline worker (Carpenter, plumber etc.)	129	69.0
	Supervisor (Superintendent and Foreman)	58	31.0
Region	Northeast	33	17.6
	Southeast	45	24.1
	Midwest	34	18.2
	Southwest	21	11.2
	West	27	14.4
	National/International	27	14.4

understanding was verified through objective assessments (e.g., test questions after the provided training), more than 70% of the participants (77%) said “yes.” The survey responses also revealed that the vast majority of the surveyed participants (93.8%) agreed that all company fieldworkers must complete COVID-19 related safety training.

4.3. Availability and use of PPE, cleaning, disinfection, and hand hygiene

The study participants were asked whether additional cleaning tools and hand washing areas (e.g., hand sanitizer, wash stations greater than normal, and UV sanitation), and access to sanitization materials and PPE (e.g., latex gloves, face shields, respiratory N95, and others) were provided by their employers on sites during the COVID-19 pandemic and whether such suppliers or designated washing areas made them feel somehow safer (i.e., protected from or less exposed to the virus). Fig. 2 presents the response results on the availability of the cleaning solutions on sites and whether the participants felt safer with such cleaning solutions available on site. Only participants who used this preventive measure were asked if it made them feel safer. As shown in Fig. 2, more than three-quarters of the participants (77%) indicated that their employers/organizations provided hand sanitizer stations. About 75% of the participants who had access to hand sanitization stations felt safer because of this washing supply. Other practices related to disinfection and hygiene included a policy preventing sharing of tools and equipment on-site using clean gloves throughout the workday and ensuring ventilation systems on-site are fully operational. Furthermore, as for access to

sanitization materials and PPE, the participants were asked whether they had access to latex gloves, respiratory N95, face shields, hand sanitizers, and handwashing stations. The most accessible sanitization materials and PPE accessible on-site were hand sanitizers (86%), latex gloves (81%), and respiratory N95 (70%).

4.4. Use of wearable devices for COVID-19 management

Concerning the use of WSDs on construction sites to protect worker safety and health during the pandemic, approximately 30% of participants indicated that they use WSDs sensors themselves for safety and health management purposes. Approximately 59% of the participants indicated that they are willing to use WSDs and share location-based information with their supervisors and safety personnel as part of COVID-19 preventive measures if this data can positively influence their health and safety, whereas 61% of fieldworkers surveyed indicated a willingness to share additional personal information (e.g., temperature, heart rate, and hydration) conditioned that such a data would be used to protect the workforce, not other purposes that involve productivity improvement.

4.5. Controlling and prevention

The study participants were asked to indicate whether their organization implemented the listed safety measures on-site, and based on their perceptions, whether the implemented safety measures were found to be effective or made them feel more protected from contracting the COVID-19 virus. Table 3 summarizes the responses of specific safety measures that were implemented to reduce the spread of COVID-19 on construction job sites. Table 3 shows that top safety measures used in practice to increase distance during the pandemic are staggered breaks and lunches, remote work, separated project offices, project area isolation, and shift work.

Based on the average ratings received on the perceived effectiveness of the safety measures to increase social distance, staggered breaks and lunches, remote work, and project area isolation were rated as the most effective measures. Only participants who selected “Yes” when asked if the practice was implemented on their project by their employer were given the option to rate the perceived effectiveness of that practice. Results from the one-sample t-test indicate that the participants believe that the measures implemented by their employers for enhancing social distance are statistically effective and make them feel safer on the job site (p-value < 0.01).

Regarding safety measures used to minimize group gathering size to 10 individuals or less, more than half of the participants indicated that they implemented separate work areas isolated via barriers, shift work, increased use of remote worksite for pre-fabrication, and use of technologies, such as using Skype/Zoom for meetings to achieve this goal. The participants were also asked to

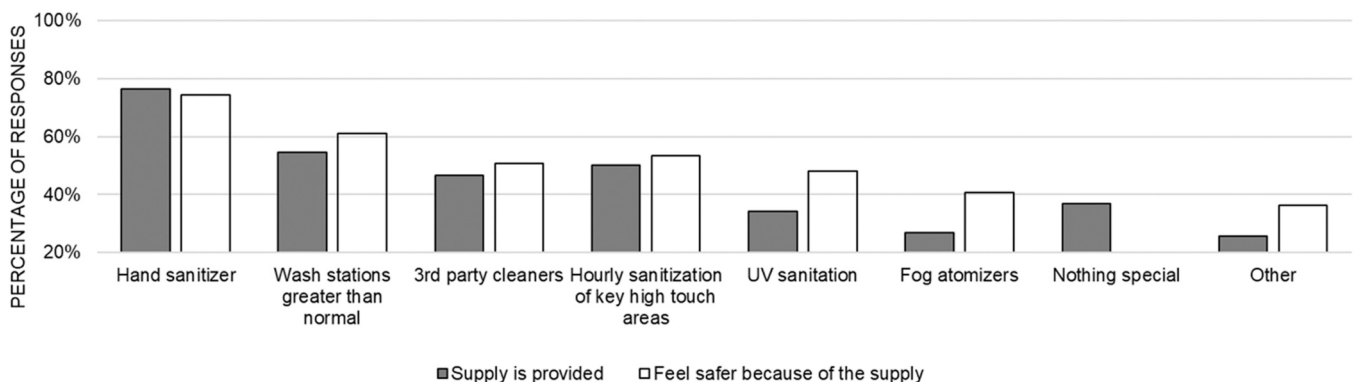


Fig. 2. Cleaning Supplies and Hand Washing Areas Provided on Sites.

Table 3
Safety and Health Practices Used on Construction Jobsite.

Practices	Implemented? (n = 187)		Effective (felt safer)? (n [*])				
	Yes	No	Min	Max	Mean**	SD	p-value
Safety and Health Practices Used to Increase Social Distance							
Shift work (increase social distance)	105	82	1	5	3.63	1.16	<0.01
Staggered breaks and lunches	111	76	1	5	3.71	1.11	<0.01
Separated project offices	108	79	1	5	3.66	1.09	<0.01
Remote work, where possible	109	78	1	5	3.7	1.1	<0.01
Project area isolation	107	80	1	5	3.7	1.11	<0.01
Safety and Health Practices Minimize Group Gathering Size to 10 Persons							
Shift work (Size to 10 Persons)	104	83	1	5	3.49	1.2	<0.01
Separate work areas isolated via barriers	108	79	1	5	3.58	1.16	<0.01
Use of technologies (e.g., using Skype and Zoom for meetings)	100	87	1	5	3.58	1.13	<0.01
Increased use of remote worksite for prefabrication	102	85	1	5	3.59	1.15	<0.01
Safety and Health Practices Used in Job Site Screening							
Job site health questionnaire for all workers	96	91	1	5	2.88	1.5	0.139
Temperature / fever checks	100	87	1	5	3.05	1.39	0.808
Travel questionnaires	83	104	1	5	2.98	1.40	0.733
COVID-19 tests	67	120	1	5	2.99	1.49	0.876
Workers physically examined for exposure conditions	78	109	1	5	3.01	1.47	0.892
Screening using onsite cameras	64	123	1	5	2.85	1.51	0.115

* n for each practice is equal the number of participants that selected "Yes" to the question about Implemented

** Were 1 = strongly disagree; 3 = neither agree nor disagree; 5 = strongly agree

identify whether certain COVID-19 safety measures were implemented in job site screening. Temperature/fever checks were identified as the most frequently used COVID-19 specific safety measure used in job site screening, followed by job site health questionnaire for all employees and travel questionnaires.

Table 4 summarizes the results from the Proportion and Pearson Chi-Square analyzes. Results found no statistical evidence of an association between the perception of fieldworkers regarding the implementation of their organization COVID-19 plan and three demographic characteristics (job title, company sector, and location). The proportion of the participants whose companies implemented COVID-19 measures are about the same regardless of the above-mentioned three demographic characteristics. However, implementation levels statistically differed in a significant manner across organization types and company sizes. Smaller companies and subcontractors reported significantly lower implementation proportions than medium- and large-sized companies. Similarly, general contractors reported higher implementation proportions compared with owner representative firms and sub-contractors.

As for the perceived effectiveness of the implemented safety measures, increased use of remote worksite, separate work areas isolated via barriers, and use of technologies were rated as the top

three most effective safety measures in terms of perceived effectiveness to prevent COVID-19 related illnesses. Furthermore, the participants believe that the strategies implemented to minimize group gatherings were statistically effective on a one-sample t-test (p-value < 0.01). Temperature/fever checks were rated as the safest approach to conduct job site screening from the perspective of fieldworkers. Workers physically examined for exposure conditions was the second safest, followed by COVID-19 tests and travel questionnaires. However, job screening strategies were not significant measures for preventing the spread of COVID-19 based on the data collected (p-value ranged from 0.115 to 0.892).

Similar to the results from assessing the level of COVID-19 safety and health measures implementation, only company type and size had a statistically proven impact on the perception of fieldworkers regarding the effectiveness of implemented COVID measures by their organizations (median value within the sub-groups substantially differed). To be specific, general contractors were found to implement more effective prevention measures than sub-contractors according to the study participants' perception.

Post-hoc analysis shows the significance of subgroups of the demographic characteristics that were found to have a statistically significant impact on the perception of fieldworkers (company type

Table 4
Results from demographic characteristics analysis.

COVID Prevention Measures	Implementation (p-value)					Effectiveness (p-value)				
	Job title	Sector	Org. Type	Location	Size	Job Title	Sector	Org. Type	Location	Size
Increase Social Distance										
Shift work (increase social distance)	0.6	0.38	<0.01*	0.608	<0.01*	0.73	0.59	<0.01*	0.19	<0.01*
Staggered breaks and lunches	0.14	0.46	<0.01*	0.647	0.01*	0.09	0.85	<0.01*	0.24	0.03*
Separated project offices	0.63	0.69	<0.01*	0.350	0.01*	0.37	0.91	<0.01*	0.11	<0.01*
Remote work, where possible	0.48	0.30	<0.01*	0.245	<0.01*	0.33	0.25	<0.01*	0.95	0.01*
Project area isolation	0.79	0.78	0.133	0.337	0.078	0.58	0.73	0.01*	0.14	0.01*
Minimize Group Gathering Size to 10 Persons										
Shift work (Size to 10 Persons)	0.93	0.50	<0.01*	0.32	<0.01*	0.31	0.17	<0.01*	0.26	<0.01*
Separate work areas isolating via barriers	0.87	0.59	0.02*	0.39	0.01*	0.30	0.20	<0.01*	0.64	0.02*
Use of technologies (e.g., using Skype and Zoom for meetings)	0.34	0.91	0.0*	0.13	0.00*	0.10	0.33	<0.01*	0.16	0.02*
Increased use of remote worksite for prefabrication	0.40	0.56	<0.01*	0.12	<0.01*	0.34	0.10	<0.01*	0.83	0.00*
Job Site Screening										
Job site health questionnaire for all workers	<0.01*	0.21	<0.01*	0.53	<0.01*	0.41	0.12	0.112	0.11	0.32
Temperature / fever checks	0.20	0.42	<0.01*	0.66	<0.01*	0.22	0.61	0.02*	0.55	0.47
Travel questionnaires	0.93	0.57	0.03*	0.38	<0.01*	0.61	0.50	0.08	0.12	0.21
COVID-19 tests	0.28	0.90	<0.01*	0.76	<0.01*	0.23	0.97	0.04*	0.12	0.08
Workers physically examined for exposure conditions	0.22	0.61	0.01*	0.48	<0.01*	0.60	0.47	0.04*	0.09	<0.01*
Screening using onsite cameras	0.77	0.58	<0.01*	0.84	<0.01*	0.27	0.46	0.01*	0.11	0.16

Table 5
Post-hoc analysis of COVID-19 safety measure perceived effectiveness.

COVID Prevention Measures	Organization Type			Company Size		
	Sub-GC	Sub-owner	GC-owner	Small-large	Small-medium	Large-medium
Increase Social Distance						
Shift work (increase social distance)	<0.01*	<0.01*	0.20	<0.01*	<0.01*	0.95
Staggered breaks and lunches	<0.01*	<0.01*	0.53	0.01*	<0.01*	0.90
Separated project offices	<0.01*	<0.01*	0.27	<0.01*	0.01*	0.47
Remote work, where possible	<0.01*	<0.01*	0.43	0.01	<0.01	0.59
Project area isolation	<0.01*	<0.01*	0.39	0.01*	0.09	0.14
Minimize Group Gathering Size to 10 Persons						
< 0.01 *	<0.01*	<0.01*	0.18	<0.01*	<0.01*	0.78
Separate work areas isolated via barriers	<0.01*	<0.01*	0.99	0.09	0.02*	0.78
Use of technologies (e.g., using Skype and Zoom for meetings)	<0.01*	<0.01*	0.28	0.02*	0.02*	0.97
Increased use of remote worksite for prefabrication	<0.01*	<0.01*	0.28	<0.01*	<0.01*	0.54
Job Site Screening						
Job site health questionnaire for all workers	0.11	–	–	0.32	–	–
Temperature / fever checks	0.02*	0.18	0.43	0.28	–	–
Travel questionnaires	0.94	<0.01*	0.15	0.35	–	–
COVID-19 tests	0.04*	<0.01*	0.14	<0.01*	–	–
Workers physically examined for exposure conditions	0.05*	<0.01*	0.08	0.03*	0.03*	0.88
Screening using onsite cameras	<0.01*	<0.01*	0.14	0.19	–	–

Note: GC stands for general contractor

and size) regarding the effectiveness of implemented measures on the spread of COVID-19 in construction, is shown in Table 5.

4.6. Fieldworker satisfaction with organizational preparedness

Regarding worker satisfaction, approximately 52% of the study participants stated that the information presented to them on COVID-19 by their employers was not specifically related to the construction industry and their specific tasks and, therefore, felt somehow irrelevant to their situation. Similarly, 23% of the participants stated that the COVID-19 information presented to them was excessive (i.e., too much in quantity), and 12% of the participants indicated that the information was complex (i.e., not easy to follow and understand). Furthermore, six participants (3%) indicated that they needed the materials in other languages, and such materials were not translated to them in their preferred language.

Finally, participants indicated their perception toward their employers' overall COVID-19 safety and health risk mitigation preparedness using a 0–100 scale. This scale was used to assess fieldworkers' overall satisfaction with their employee's management of COVID-19. After collecting and analyzing the responses, the average score was found to be 63.1, with a standard deviation of 29.6.

5. Discussion of results

5.1. COVID-19 safety and health measures at construction sites

Concerning safety and health measures for controlling and preventing the spread of COVID-19, the most frequent measures used in practice included staggered breaks and lunches, remote work, and separated project offices to reduce the number of workers on-site at a time and increase the social distance of fieldworkers on sites. Given that the virus could be transmitted by touching a contaminated surface or an object, hand sanitizers, wash stations, and hourly disinfection were frequently provided to fieldworkers by over half of the surveyed employers. Most fieldworkers surveyed had access to latex gloves, N95 masks, and other masks needed to prevent COVID-19 infection. The abovementioned findings are similar to recent studies conducted in South Africa (Amoah and Simpeh, 2020), the UK (Jallow et al., 2020), and China (Zheng et al., 2020). Nevertheless, based on the findings of this study, the current safety and health measures taken on sites could not be viewed as adequate protection to the fieldworkers from the virus. As shown in Table 2 and Fig. 2, none of the identified measures were provided by all or

nearly all the investigated construction companies. At the time of the study, construction fieldworkers are still exposed to high-risk levels related to COVID-19 infection in their workplaces, and a construction worker remains likely to come in contact with the virus if significant prevention measures were not taken.

Results from the present study (see Table 4) suggest no statistical difference regarding the implementation of COVID-19 safety measures when assessing three demographic characteristics: the job title of the participants, company sector, and location of where the company operates. However, implementation level statistically differed significantly across organization types and company sizes (smaller companies and subcontractors reported significantly lower implementation proportions). Previous studies indicate that smaller firms are more susceptible to injuries and fatalities and struggle to implement effective safety measures (Lin and Mills, 2001; Cunningham et al., 2018). This susceptibility and struggle are mainly due to limited financial resources, fewer employees to engage in activities such as safety committees, and poor attitude toward safety compared with productivity (Sinclair and Cunningham, 2014). Given this antecedent, general contractors must pay close attention to sub-contractors working on their projects and set the proper safety culture on projects. General contractors should consider including clauses in their contracts with sub-contractors that require the sub-contractors to, at the minimum, adopt and implement the strategies implemented by the general contractors.

Furthermore, the client (through their representative) and the general contractor should prioritize safety-leading indicators when selecting sub-contractors (Karakhan et al., 2018; Al-Saffar, 2020). Leading indicators provide the client and general contractor with more effective and proactive metrics to measure the preparedness and culture of a sub-contractor toward worker safety. Furthermore, general contractors should support and closely collaborate with sub-contractors to develop their safety capability. As mentioned previously, most sub-contractors have a limited budget and resources to invest in safety management, and such collaboration is critical to achieving desired safety outcomes. This collaboration could be established through providing project-based training, mutually reviewing site-specific safety plans, and involving sub-contractors in safety minutes. General contractors should create an environment and a culture that welcomes employee participation and feedback regarding all aspects, especially workplace safety. Effective and open communication with employees regarding implemented safety measures could minimize resistance to the implemented safety measures and encourage employees to adhere to the safety plan.

5.2. Perceived effectiveness and worker satisfaction of the implemented measures

Results from the study indicate that participants believe that staggered breaks and lunches, remote work, project area isolation, remote worksite of prefabrication, and technologies for meetings were the most effective measures in increasing social distance and minimizing group gathering size to 10 persons. These approaches provide flexible worksites by only having essential field crews on sites, keeping unessential workers away from hazards, and establishing flexible work hours to limit the number of workers on-site at the same time. It is important to note that recent empirical studies indicate that increasing social distance and minimizing gathering sizes have proven to reduce infection rates in occupational settings (Oksanen et al., 2020; Knoll et al., 2020). Regarding jobsite screening, the results from temperature/fever checks, physical examinations for exposure conditions, and COVID-19 tests were found to make fieldworkers feel safer compared with other subjective, self-reported assessment methods. On average, job screening strategies were the least implemented and the least effective from the perspective of the study participants in the three categories (measures used to increase social distance, minimize group gathering size to 10 persons, and job site screening) of COVID-19 measures. Interestingly, previous surveillance studies on the effectiveness of temperature/fever screening have reported mixed conclusion. While Facente et al. (2021) concluded that temperature screening did not detect majority of potential infectious individuals, Chen et al. (2020) posits that temperature checks are a useful tool for monitoring and controlling COVID-19 spread.

Regardless of these results, some organizations implemented this strategy which suggest that they believe it is an effective tool for managing workplace health and safety and mitigating the spread of COVID-19 on job sites. This result suggests a possible divergence between the perception of fieldworkers and top management personnel toward safety and health measures related to COVID-19. Typically, top management implements strategies that are believed to be cost effective and that could keep fieldworkers safe. It is important to note that at the time of the study, the strategies evaluated were recommended strategies and not required by CDC and/or OSHA (Occupational Safety and Health Administration OSHA, 2021). Given that successful implementation of safety intervention in the construction industry is highly dependent on fieldworker's buy-in, including fieldworkers in the decision-making process would go a long way to towards increasing workers' compliance. Moreover, interacting with fieldworkers would provide top management the opportunity to demystify certain concerns about efficacy that fieldworkers might have, thereby increasing their perception of intervention effectiveness.

The participants indicated that they were not satisfied with the information provided, citing issues such as materials lacking construction-specific information, long trainings and excessive information, and the complexity of the information provided. Thus, as the level of information on COVID-19 has increased compared with what organizations were aware of in 2020, construction organizations should provide concise, up-to-date, and industry-specific COVID-19-related information to fieldworkers on the job sites. The information should be focused on how to identify, measure, and prevent/control the spread of COVID-19 infection on construction job sites. Considering non-native English employees, construction companies should provide training or share materials in other languages to ensure that all employees, including non-native English speakers, are safe and supported during the COVID-19 crisis.

Only company type and size had a statistically proven impact on the perception of fieldworkers regarding the effectiveness of implemented COVID measures. This finding is likely because general contractors are often more capable than sub-contractors in multiple

aspects, including their budget, human and non-human resources, and their connections with professional associations/unions. This capability provides more flexibility in terms of planning and managing employee health and safety on the job site. Hinze and Gambatese (2003) studied factors impacting the safety of sub-contractors in the construction industry and found that, compared with general contractors, subcontractors typically have fewer safety incentives and rewards, fewer on-site safety inspections, fewer training opportunities, and higher employee turnover rates – all of which could impact the safety of workers in the job site negatively. With regards to company size, there are contradicting findings in the existing literature; some studies have found that large-sized companies have higher injury rates than small- and medium-sized companies, whereas others found that small- and medium-sized companies may encounter fewer injuries and fatalities because of the limited number of people on-site and higher levels of connection among the workforce (Hinze, 2006; Hinze and Gambatese, 2003; Holte et al., 2015). That being said, almost all studies agree that larger companies have theoretically higher capabilities (e.g., money and resources) compared with smaller companies that make them more advanced in terms of managing workplace safety and mitigating potential on-site hazards (Hinze and Gambatese, 2003; Huang et al., 2011; Holte et al., 2015).

There was no statistically significant evidence that job title, sector, and location where the company operates has an impact on the perception of the participants regarding the effectiveness of implemented measures to prevent the spread of COVID-19 on construction jobsites. This finding makes sense given that COVID-19, and its various variants, has spread across the US and there is no territory, throughout the US, with no illness whatsoever. Furthermore, all construction sectors have a similar work environments and work procedures. Therefore, such a sector is not expected to implement different measures to prevent the spread of the virus than other sectors. The main goal of all construction job sites in all sectors is to provide necessary PPEs and enforce social distancing to prevent contact between employees, significantly minimizing exposure to the virus. Findings from the present study suggest that some measures are perceived to be more effective in preventing the spread of COVID-19. These findings allow companies to implement measures that are perceived by fieldworkers to be effective for optimizing occupational safety and health during the COVID crisis. Construction companies are also encouraged to test other interventions not reported in the present study and evaluate their validity in dealing with the spread of COVID-19 in construction. The use of safety measures and interventions should not end with the end of COVID-19. Instead, in the post-COVID-19 era, construction companies should continue to use some of these practical measures and find effective ways to accommodate these strategies within their safety management system. Using this approach will ensure a high level of preparedness when encountering another pandemic or other unrepresented safety and health hazards.

The participants were asked whether they use any WSDs to track their proximity/location and collect physiological data related to their health and wellbeing on their projects. The relatively low WSD implementation level (approximately 30%) is not surprising given that previous studies reported low WSD adoption and implementation (ranged from 5%–20%) in the construction industry (Nnaji et al., 2020; Choi et al., 2017; SmartMarket Report, 2017). As mentioned earlier, 61% of participants indicated a willingness to share more personal information (e.g., temperature, heart rate, and hydration), which is a sharp divergence when contrasted with previous studies that posit more resistance to sharing personal/physiological information (Ahn et al., 2019; Awolusi et al., 2018; Choi et al., 2017). Furthermore, the physiological information that could be collected, such as body temperature, can serve as initial measures for COVID-19 detection (Lan et al., 2020). Detecting COVID patients

early helps prevent the spread of the virus to follow employees throughout the construction site.

The use of WSDs provides continuous tracking of workers' temperature and screening that could be used to prevent the COVID-19 infection on the job sites, which is a more effective way than temperature checks using temperature guns or scanners (Whitelaw et al., 2020). Furthermore, workers' temperature and screening could be critically important for contact tracing such a COVID case is detected on-site (Whitelaw et al., 2020). More than half of the participants do not mind their employer collecting personal and physiological information related to their temperature and heart rate when WSDs are used as long as the information collected would contribute to improving their health and safety on-site. Such information can be directly used to prevent exposure of fieldworkers to COVID-19. For instance, physiological metrics such as resting heart rate, temperature, sleep, stress, or activity level, collected via WSDs could be used to detect COVID-19 infection on the job site (Gadaleta et al., 2021; Seshadri et al., 2020). Moreover, the physical distances between two or more workers acquired by WSDs could be used to determine whether workers comply with the social distance guidelines (staying 6 feet apart). These metrics are captured by several commercially available wearable devices such as Apple Watch, Biostrap, Empatica, Fitbit, Garmin, VivaLNK Vital Scout, WHOOP Strap, and Zephyr BioHarness (Seshadri et al., 2020). It is important to note that while these devices are commercially available, additional research on the level of accuracy in correctly detecting distance between workers in different work configurations (avoiding false positives when workers a closer than 6 feet but separated by a wall, for instance) is required.

In summary, the attitude of the study participants toward the use of WSDs and the perception regarding the effectiveness of WSDs on improving worker safety and health in construction are encouraging, which suggests that fieldworkers are open to using WSDs as part of safety management plans. Prior to COVID-19, fieldworkers were critical to the use of such devices as they may invade their privacy and personal space (Nnaji et al., 2021). The present study seems to assure that fieldworkers may be open to the use of WSDs as long as their use is solely for safety and health purposes.

6. Conclusions, limitations, and future studies

The present study provides a thorough investigation of the implementation of safety and health measures to mitigate COVID-19 risk in the US construction industry. This study contributes to practice by informing construction firms on the usage and perceived effectiveness of COVID-19 countermeasures and identifying opportunities for improvement in approaches used to mitigate the spread of the virus among construction fieldworkers. The study extends current knowledge by highlighting the need for continued advocacy aimed at smaller construction companies that have limited resources for occupational health and safety management. The findings indicate that the fieldworkers are slightly satisfied with the safety and health measures implemented by their companies to control, prevent, and mitigate the spread of COVID-19 on construction job sites. However, the study participants highlighted some issues with their organizations' preparedness to deal with the pandemic. The messaging and dissemination of information were a concern. However, this concern, which was not germane to construction, was largely due to the evolving nature of the virus. The present study provided recommendations on how to mitigate these issues in the future and to ensure that all construction companies have a rigorous health and safety management plan that prioritizes the health and safety of employees and reduces any potential exposure to deadly viruses.

The outcome of this investigation is anticipated to provide much-needed information for practitioners interested in assigning effective

COVID-19 safety and health measures into their regular health and safety management plan and help them adopt measures that fieldworkers perceive to be effective. Adopting health and safety measures perceived to be effective by employees reduces employee resistance to the implementation of such measures and encourage them to participate in and adhere to the safety plan. Contractors could utilize the findings of this study to integrate multiple practices and technologies within their existing safety programs to improve the effectiveness of their programs and prevent the spread of infectious diseases, such as COVID-19 on their projects. Going forward, construction companies should develop a thorough safety and health plan that include an infectious disease training program, a policy for information collection and sharing, and training to encourage technology adoption and implementation for safety and health management.

Despite the useful and practical insights provided in the study, the present study has a few limitations. First, the study focused on fieldworkers in the US construction industry only. Future studies could assess the perception from the perspective of top management and contrast results with that of the fieldworkers. Such an assessment and contrast would provide a complete picture that considers all construction teams. Second, the effectiveness of the safety and health measures are determined based on the perceptions of the survey participants. This reliance on the study participants' perception may introduce some subjectivity to the findings, given that the findings were not determined in a purely objective manner, such as experiments. The study participants were carefully selected using a third-party platform to minimize any potential subjectivity. Furthermore, quality checks were used to remove responses that were not of high quality. Future studies should empirically investigate the effectiveness of the identified safety and health measures for COVID-19 in construction using a more objective method, such as a case-control study or a longitudinal study. Finally, it is important to note that in certain cases, general contractors set the safety culture and requirements, and sub-contractors are required to implement certain safety programs. The present study did not ask sub-contractors if the strategies implemented on their projects were required by the general contractor or their direct line employer (sub/specialty contractor). Knowing if certain strategies were enforced by the general contractor (or their direct employer) could shed additional insights on their perception towards these strategies. Finally, the present study classified small organizations as organizations employing less than 100 workers. Future studies could assess the perception of workers employed by micro-organizations (less than 10 employees) towards COVID-19 safety and health measures. It is possible that micro-organizations may have a different perception regarding effective measures to mitigate the spread of COVID-19.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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