# Individual and Organizational Factors Influencing Technology Adoption for Construction Safety

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## Abstract

Individual and Organizational Factors Influencing
Technology Adoption for Construction Safety

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Nowadays, providing a safer and zero-injury jobsite is an objective of many construction companies. Nevertheless, construction industry has not achieved a satisfactory level of safety, and is still considered to be one of the most dangerous occupations. Currently, there are several studies addressing the technology applications for construction safety but many of them are limited to research studies and are not really adopted by construction companies. Reviewing

the past researches in this context shows that cultural, individual and organizational factors have a great impact on the technology adoption for construction safety. This study aims to investigate where the construction industry stands right now in the way of using technologies for safety. In addition, it identifies the contributing factors as well as barriers affecting employees' and employers' opinions to apply/refuse a new technology for safety. Finally, the potential solutions and recommendations are discussed to address the current barriers.

The methodology of this research includes the following two main parts: a web-based survey and key informant interviews. Our results demonstrate that in the studied population (all from the Puget Sound area), companies started applying new technologies (in their current condition) for safety almost 7 years ago and the trend has been accelerated in the past 2-3 years. Currently, about 83% of participants apply at least one type of technologies for construction safety. The top three technologies that are used mostly by construction companies are safety-specific software applications, ICT devices, and BIM, respectively. On the contrary, wearable technologies are completely new to the construction industry and are least used among the studied technologies. In general, this study reports that according to the construction experts, safety inspection, safety training, and safety planning are the top three phases that can benefit more from applying new technologies. Also, safety communication is mentioned as an area that may be influenced positively by the applications of new technologies. During this research, the most significant barriers for technology adoption were identified, including: complexity to use; uncertainty about practicality and benefits of applying a new technology; time needed for additional training; cost, and leadership support. In terms of potential recommendations to overcome the technology adoption barriers, some solutions are provided to construction companies (users) as well as technology developers including "Enhance the overall safety culture", "Have practical expectations", "Look from users' perspective" and "Be flexible in technology features".

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# 1. Introduction

Nowadays, providing a safer and zero-injury jobsite is a vision of many construction companies. Over the last few years, safety in construction has been taken more seriously and many in construction are looking for new innovations to keep their employees safer (Baker 2014). Nevertheless, construction industry has not achieved a satisfactory level of safety, and is still considered to be one of the most dangerous occupations. Every year hundreds of workers are injured and/or killed on construction jobsites, which cause millions of dollars of financial loss (OSHA).

Common strategies used by many construction companies include behavior-based interventions, hands-on safety training and conducting regular inspections. In addition to those strategies, new innovations and technologies are also being introduced to the industry to promote safety. Despite the accelerated advancement of these innovations and technologies, only certain types of them are actually applied in construction projects for safety purposes. Past researches suggested that the factors involving in the success of a new technology are not limited to the technological aspects but they also highly depend on an end user's behaviors, work environments and his/her employer's approaches toward innovative solutions. Currently, there are different types of technologies in the market, all with the claim that they can improve safety on construction jobsites. Past studies also suggested the using new technologies for construction safety.

This study aimed to investigate where the construction industry stands right now in the way of using technologies for safety. In addition, it identifies the contributing factors as well as barriers affecting employees' and employers' opinions to apply/refuse a new technology for safety. Finally, the potential solutions and recommendations are discussed to address the current barriers. The studied population in this research is limited to the construction and safety experts from medium to large-size construction companies in the Puget Sound Area.

Different sections of the thesis are organized as that follows:

- Section 2, Literature Review: This section gives a summary of different types of technologies that were studied in past researches as well as their benefits for construction safety. The section provides the background on what were available and why, and introduces potential barriers companies may face while adopting new technologies.
- Section 3, Methodology: This section explains the methodology of this study which is mainly composed of survey and interview. The terms and definitions used in the survey

and interview questions are defined. In addition, the section also explains how the survey and interview questions were designed to satisfy the research inquiry.

- Section 4, Data Analysis and Discussion: The results of data analysis are categorized and discussed in the following four themes: “demographic information”, “current practices of applying technologies”, “individual and organizational/managerial factors” and “recommendations and solutions”.
- Section 5, Conclusion: The last section includes a summary of the research questions and their corresponding results. In addition, the limitation of this study, the research findings, and potential future research extensions are explained in this section.

# 2. Literature Review

This section gives a summary of different types of technologies that were studied in past researches, as well as their benefits for construction safety. In addition, it generally introduces safety technologies, talks about how they can benefit safety, and points out potential barriers companies may face while adopting new technologies.

## 2.1. Technologies for Construction Safety

In the past decade, the construction industry has changed dramatically due to innovative technologies. Building information modeling (BIM), GPS, and ICT (Information and Communication Technologies) devices are among the ones which have been applied in construction projects. Although the application of new technologies in construction has increased in the last few years, this industry still is considered reluctant regarding the adoption and implementation of innovations. (Lin et al. 2014). Adopting technology in construction industry is slow in comparison to many other industry sectors (Teizer et al. 2013). Because construction safety faces this slow technology adoption even more than other parts of the industry, construction safety has remained largely unchanged for many years (Friedman 2015).

Although, nowadays the safety considerations are taken more seriously by construction companies, the safety performance is still far away from approaching an acceptable level. The accident statistics indicate that the construction industry is considered as one of the most dangerous occupations. According to OSHA, 874 construction workers died on the job in 2014 and that is about 20.5% of the worker fatalities in the private industry. (OSHA)

Given the current construction safety practice and performance, it seems that this field needs a new trend to improve safety management as well as safety performance. An inner look at the current safety practice in construction reveals some potential areas that may benefit noticeably from application of new technologies.

## 2.2. Types of New Technologies

**BIM**

Building Information Modeling (BIM) is currently widely applied within the construction industry. BIM as a tool is defined as a digital representation of physical and functional characteristics of a facility. (Anumba 2010). Applying BIM may benefit a construction project in design, pre-

construction and construction phases. In terms of safety, BIM generally benefits construction projects by carrying out risk assessment and identifying safety hazards (Zhang et al. 2012, Zhou et al. 2013). It also enhances safety planning and communication by increasing the overall knowledge of safety issues before the site exists (Ganah et al. 2014). Several studies have been conducted regarding developing specific uses of BIM for safety enhancement. For instance, Zhang et al. (2012) provide an automated safety-rule checking platform in BIM. This platform identifies potential safety hazards automatically so that corresponding prevention methods can be applied in an automated approach.

There are also some examples of integrating BIM with different sensing technologies. A study performed by Riaz et al. (2014) suggests a solution that integrates BIM with oxygen and temperature sensors to facilitate intelligent monitoring of confined spaces through real-time sensor data to avoid time sensitive emergency situations. “Dynamic virtual fences” is another example of combining BIM and sensing devices for improving workers’ safety. In this case, a 3D model is developed and upon which dynamic virtual fences are generated. Workers are protected by virtually fencing dangerous area and sending them alerts in real time when they approach those areas. In the physical jobsite, tags are attached to physical fences and workers on-site to track their precise locations to avoid potential collisions. Also, the physical barriers are checked automatically to ensure that safety measures are installed at the proper locations with proper dimensions according to the regulations (Zhang et al. 2012). Figure 1 indicates an example of applying BIM to identify and address fall hazard in safety planning.

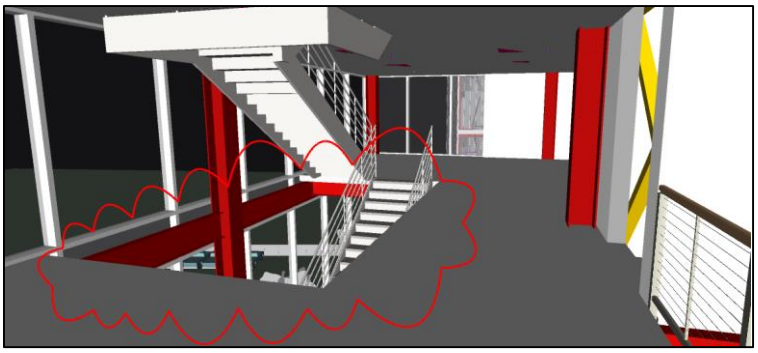

*Figure 1: Example of Applying BIM for Safety Planning*

**Drone**

As a brief definition, drone is an unmanned aircraft that can fly autonomously, that is, without a human in control (Villasenor 2012). Drone is formally known as unmanned aerial vehicles (UAV). Essentially, a drone is a flying robot which may be remotely controlled or can fly through software-

controlled flight plans in their embedded systems working in conjunction with GPS (Rouse 2015). Figure 2 indicates an example of drone.


*Figure 2: Drone*

Drone can be used for safety inspection. It is controlled by supervisor through iPhone/ iPad to gathering data from jobsite, providing real-time hazards identification, visually verifying the steps in work, and viewing potentially hard to reach areas. (Grayson 2014; Harris 2015; Friedman 2015)

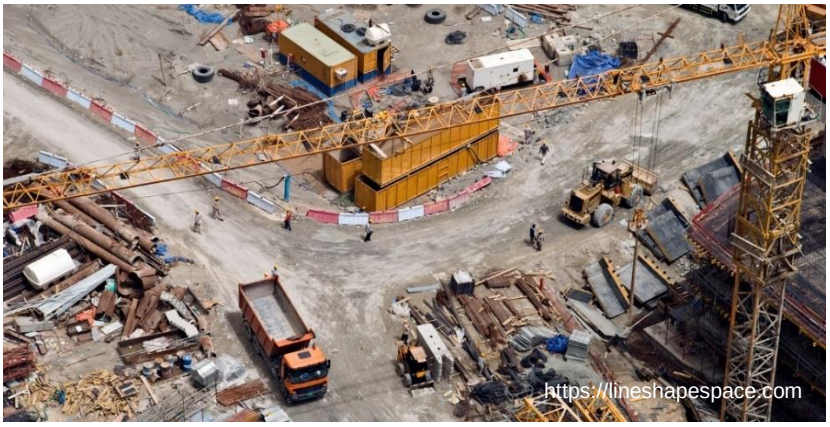


*Figure 3: Example of Using Drone for Safety Inspection*

In addition, drone allows for real-time communication on the site through live video or radio connection between workers in the field and the safety manager that leads to higher communication and on-time response efficiency (Harris 2015). Figure 3 indicates a photo of a construction site that captured by a drone.

**RFID Tags**

Radio frequency identification (RFID) is based upon the usage of radio signals for data transfer. A tag is attached to an item and can be scanned when needed by a stationary or mobile reader using radio waves. A tag usually has a unique code, which permits tagged items to be individually identified (Dyevakov 2007). Previous studies suggest that RFID tags including passive and active tags are a potential solution to improve safety on the site. RFID tags can be attached to personal protective equipment (PPE), as it is indicated in the figure 4, and be carried by the workers. These

tags can help the supervisor to identify real-time location of workers and warn them when they enter dangerous areas (Hong Kong RFID Ltd. 2007). Another research study (Kelm et al 2013, Zhou et al. 2013) discussed using passive RFID tags embedded or attached to PPE for automatic controlling of site access as well as time recording.


*Figure 4: RFID Tag Attached to a Hard Hat*

**Wearable technologies**

Wearable technologies refer to any small electronic devices and clothes (e.g. smart watches, glasses, and hard hat) that are worn by construction workers and transfer their critical real time data to a hardware that is managed by a supervisor or a safety manager (the figure 5 shows a smart watch and smart glass). Wearable technologies can measure worker's biometric information such as body temperature, heart rate, blood gas saturation levels, repetitive motion, and velocity of movement. Then, the supervisor will receive alerts if a worker's vitals are at dangerous levels or if a worker falls (Gatti 2011, Baker 2014). Not only can wearable technologies provide real-time monitoring of construction workers' vitals but they can also provide safety alarms and location-based alerts to the workers. For instance, a smartwatch could warn a worker to put on his protective smart clothing when the worker is nearing or operating certain machinery (Friedman, 2015)

The real time data allow a supervisor to identify every worker on site visually or virtually at all times (Baker, 2014); track workers' location and communicate with them if they enter or are about to enter a potential hazard zone; and also view whether or not they are in the correct zones and performing the assigned tasks. (Raymond, 2014)


*Figure 5: Examples of Wearable Technologies*

**ICT devices and software apps**

ICT stands for Information and Communication Technologies and it includes the range of hardware and software devices such as personal computers, assistive technology, scanners, digital cameras, image editing software, database and spreadsheet programs (NCCA, 2008). Currently, there are a wide variety of safety specific software and mobile applications that are tried in field by construction practitioners. Generally, proper tracking of information (Johnson2012) is essential for identifying safety hazards and avoiding accidents on construction jobsites. Various types of safety information can be collected or transferred and documented by aid of ICT devices and safety specific applications. This information includes but not limited to pictures and mark-ups of unsafe working conditions, safety materials, standards and data sheets, job hazard analysis, safety reports, and materials for on-site training (Johnson 2012). Having access to this information allows people on site to collaborate and communicate safety issues on time (Writer 2015) and facilitate cooperative decision making (Mitchell et al. 2006).

Using applications for safety inspection enhances the collection and analysis of safety information and identifies risk patterns that leads to predict an accident before it happens. Lin et al. (2014) provides a user-centered design approach to develop and evaluate a safety application that aims to address the drawbacks of current inspection approach and improve safety management.

Monitoring unsafe working conditions and unsafe behaviors on construction sites is a key point for predicting accidents and taking proactive actions (Seo et al, 2015). The other study conducted by Moon et al. (2015) discusses using multiple ICT developments such as sensors, wireless networking, and safety monitoring applications in order to monitor safety for concrete formwork structures. In this research, when an abnormal deformation of concrete formwork is indicated by sensors, a warning signals is sent to the safety manager to stop the operation of formwork. In addition, the safety manager can have access to a web application and track the safety condition of concrete formwork execution.

Developing a computer vision-based safety and health monitoring is another example of applying ICT that provides the automated and continuous monitoring at construction sites by taking images or videos. (Seo et al, 2015). Nevertheless, the efficiency of these approaches is questioned in practice due to intervention with workers' privacy and technical challenges in technology application. (Seo et al, 2015)

## 2.3. Benefits of New Technologies

This section discusses the potential benefits that new technologies may bring to construction safety.

An efficient safety plan needs a precise and holistic view of the project which leads to a better risk assessment. In this regard, building information modeling (BIM), as well as 3D and 4D visualization can help with health and safety throughout the construction process. Providing a big picture of the project may facilitate the process of project review for safety purposes and help to determine potential risks and predict accidents. (Zhang et al. 2012, Zhou et al. 2012)

Although a comprehensive and careful planning is required for a good safety performance, it is not enough to ensure project safe on site. As a matter of fact, construction projects and the workforce change radically, not only with each project but also during each project (Usrey, 2007). This characteristic of construction raises the importance of efficient safety inspections as well as safety monitoring throughout the project. Currently, a typical safety inspection is carried out by a safety specialist through looking for violations and unsafe situations on site and taking notes to record observed issues (Lin et al. 2014). Nevertheless, the current approach of inspection is an obstacle when it comes to providing a detailed and standard observation report, because inspection notes taken by different safety specialists may vary greatly for the same type of issues (Lin et al. 2014). Applying technologies such as safety specific software for field inspections allows inspectors to prepare and implement standard inspection checklists. Such practice can be extremely beneficial in improving poor safety performance and in addition making applicable safety standards available on site and during inspection (Johnson, 2012)

The safety inspection not only benefits the jobsite by identifying and revising unsafe practices, but also may improve safety performance through recording detailed observations and using them for safety planning and training. In many cases a terrible accident happens because when observing at-risk conditions, no proactive action is taken by management (Usrey, 2011). While by recording the observations, this information can be addressed in safety meetings for precautionary actions and avoiding probable accidents. Past research suggests that safety

professionals who use technology to record detailed observations can use the information to identify where observations occur – not just by location, but also regarding who and what was observed. In addition, technologies may assist tracking observations, and makes it easier to track and trend a subcontractor. (Usrey 2011)

Besides safety inspection, safety monitoring plays a significant role in preventing accidents or minimizing the extent of injuries on the jobsite. An effective monitoring raises the awareness of the people as well as equipment on site for timely actions when necessary. Applying innovative technologies helps safety monitoring with providing information in a short time or real time. Past research has shown that using innovative technologies for timely detection and correction of errors is a feasible way to finally avoid various accidents (Zhou et al. 2012). Currently, in many instances, when workers are exposed to a hazardous situation, managers fail to identify and correct the situation or warn workers about the risk at the right time. Similarly, sometimes when an accident occurs, the time taken to identify and take care of injured person may increase the negative consequences.

The best way of avoiding accidents and injuries is taking proactive instead of reactive actions, i.e. being anticipating and preventing accidents before they take place. With that in mind, real-time information is the key instrument for proactive safety management (Zhou et al. 2012). New technologies such as RFID tags as well as wearable technologies provide the opportunity to track on site activities by both workers as well as equipment, aiming to identify hazardous situations and predict potential risk. Past research has shown that predicting potential risk situations calls for real-time intelligent site monitoring and the ability to react when the level of risk increases (Carbonari et al. 2011).

Some types of new technologies can be applied to obtain safety-related information from the field and send it to the relevant parties to inform timely decisions. Given that on construction sites there is still a large proportion of work that is done manually, technologies which do not require a user's hands when being applied are easier to use and do not distract people from their tasks. This results in the benefit of the technology having a higher chance to be accepted by users. Wearable technologies benefit safety monitoring and increase situational awareness on site (Bansal, 2010, Green et al. 2012). For instance, equipment worn by workers or installed in the cab of an operating equipment is designed to alert the presence of potential hazards, and particularly for heavy equipment to reduce the percentage of struck-by incidents (Green et al. 2012). In addition, given that many jobsite locations as well as individual assignments change frequently in construction projects (Friedman, 2015), it may be an obstacle to apply technologies which need to be affixed

to specific locations in order to work properly. In this case, wearable technologies are suitable alternatives since they are designed to be attached to the workers or equipment, and have the significant advantage to increases their domains of use.

Besides the points articulated in the previous sections, safety-related technologies may be applied for other purposes such as facilitating communication on site. Construction sites are noisy and busy. Site conditions such as loading noises as well as workers being in the hard-to-access locations make communication difficult among workers, as well as between workers and supervisors. Applying technologies can help safety professionals have a better access to timely communication (Usrey, 2011). For instance, safety professionals and field workers can communicate through live video or radio connection (Harris 2015). Also, in some cases different types of sensing technologies may make the real-time communication easier by sending an alerts and notifications to safety manager to take necessary actions (Riaz et al. 2014). In addition, technologies can benefit on-site communication by informing off-site supervisor with real-time information.

The data gathered and shared by different types of technology may be utilized by safety teams to provide necessary resources such as training and coaching (Usrey, 2011). For instance, safety specialists can gather inspection and monitoring data, analyze them and prepare safety reports to address safety-related issues in meetings and trainings. In general, safety technologies, if could be properly integrated with current construction practices, potentially increase the efficiency of safety management tasks as well as raise the overall safety awareness in construction projects.

Although, all the discussed advantages for innovation technologies benefit safety in construction projects noticeably, many of these technology applications are limited to research studies and are not really applied by construction companies. Therefore, there is a need for researchers and practitioners to focus more on technology transition, i.e. how to go from research into practice (Zhou et al. 2013). To investigate the reasons of failure in technology transition when it comes to construction safety, the factors considered to be the barriers of technology adoption and application for construction safety will be discussed in the next section.

## 2.4. Barriers of Applying Technologies for Construction Safety

Using technologies for construction safety potentially improves the efficiency of safety activities and leads to a safer jobsite. The construction industry is considered to be reluctant to change (Friedman, 2015). In addition, there is a common view by construction workers that those who don't perform the tasks directly on the jobsite don't understand the nature of the work. (Ursey, 2011). This view may cause a resistance towards new innovations and methods that need to change the traditional way of work. So the general resistance to change and technology in the construction industry remains an additional barrier of technology application (Lin et al. 2014). This general view about the construction industry suggests that there are some individual and organizational factors in construction that prevent practitioners from adopting and accepting innovative technologies.

### 2.4.1. Culture of the Construction Industry

The construction industry is highly competitive; therefore, productivity is a determinant factor (Welch et al. 2015) for decision- making by companies when it comes to applying technologies. In addition, despite an organization's decision to adopt an innovation, its actual usage depends on how employees implement an innovation (Talukder 2012). So understanding the factors that can influence an individual's intention to utilize technology can assist managers to implement strategies to increase and improve the uptake of technologies and improve the innovation adoption process (Sargent et al. 2012).

Recent studies have demonstrated several reasons for failure of technology adoption for construction safety. Besides the general resistance to change in construction, uncertainty about practicality and benefits of new technologies are considered to be a challenge that impedes the introduction and development of innovative technologies in construction (Lin et al. 2014). In general, time, energy and cost are critical factors for successful completion of construction projects. Hence, to motivate the utilization of new technologies, their benefits should justify the investment of time and energy required for their application (Sargent et al. 2012). In addition, it is important to examine the adoption of innovations by employees within organizations because a successful adoption of technology depends on its acceptance among users; otherwise the expected benefits cannot be obtained and the technology may eventually be given up by the company. To increase the chance of technology adoption by construction companies, it is essential to convince people that they can benefit directly from their application (Talukder 2012).

As it mentioned before, construction people when being compared to other industries are considered as late-adopters of innovations (Smith 2015). As a result, when the benefits of new technologies are still unproven, such risks present an obstacle for technology adoption. When the cost of some existing innovations are not affordable for small to medium-sized companies, the uncertainty for obtaining benefits from these innovations makes people doubt about their investment on new technologies. Some studies argued that the companies' economic condition affects significantly the technology adoption process (Jacobsson et al. 2010).

### 2.4.2. Individual Factors

As a definition, the individual factors refer to individuals' cognitive interpretations of innovation and themselves (Talukder 2012). In this study, individual factors represent users' opinion on a new technology and it's impacts on his/her work. For instance, it refers to the extent to which a participant is enthusiastic to adopt new technologies for safety, or the extent to which a participant believes that he/she can benefit from applying safety technologies in his/her own work.

Adopting new tools can result in unintended changes in the way tasks are performed. These changes can impact work organization, workplace culture, and productivity (Welch et al. 2015). The past research indicates that the extent to which users need to change their current methods and procedure to integrate the new tool, affects directly on their tendency to apply the tool (Sargent et al. 2012). For instance, a study which investigated applying ICT to improve safety inspection indicates that one safety specialist who participated in the field evaluation decided to stop using the research prototype because the integration was an additional workload for him (Lin et al. 2014). In fact, the more innovation technologies require radical departure from the current way the tasks are carried out, the less chance they have to be utilized by the construction people (Welch et al. 2015). The level of training that people need to upgrade their skills and learn how to adopt and use new technologies may also be an obstacle for technology application. In some instances, experienced employees are very keen to adopt innovative solutions, but the burden to acquire skills to successfully adopt these innovative solutions causes barriers to the adoption itself (Abrahamse et al. 2011).

Previous studies conducted in the field of technology adoption indicate that the level of technology complexity impacts directly on the rate of its implementation. In fact, users' perception of easiness of applying a technology plays a significant role in technology adoption and implementation (Sargent et al. 2012). Furthermore, people's knowledge and skills of applying innovation increase their intention to use a technology and accelerate the adoption process (Sargent et al. 2012,

Adriaanse et al. 2010). The other factor affecting users' perception of ease of use as well as technology advantage is their previous experience of using the technology (Talukder 2012, Davis et al. 1989). Past researches demonstrated that users' experience of applying a new technology can affect both positively and negatively the future adoption of that technology. (Abrahamse et al, 2011 Venkatesh et al. 2000)

Besides the barriers mentioned above, the social factors have also impacts upon human intention to utilize new technologies. The social influence is defined as the extent to which members of a social group influence one another's behavior in adoption. The social factors include the influence of peers and social network (Talukder, 2012) that affect individuals' beliefs about the need of technology application to improve their work. The social network plays a significant role in technology diffusion across the construction industry. A number of empirical studies have found that personal communication and networking are among the most important factors for successful technology transfer (Welch et al. 2015). The effect of social factors can work both as a barrier, as well as a driver for technology adoption. The social network can encourage people to apply a new technology, or be dissuasive for new users when they see that the others in the industry do not apply the technology. For instance, a previous study about applying wearable technologies in construction suggests that many people do not believe they desperately need wearable technologies in their work, nor are they willing to switch over to technologies that their usual partners are not using (Sargent et al. 2012, Friedman 2015). When a company does adopt a new method that is advantageous, it is possible that the company keeps the innovation as a competitive advantage and does not spread the word. (Welch et al. 2015)

In general, to a successful technology adoption in an organization, there should be an effective support system and a general tendency to both invest in new technologies, as well as provide required training to upgrade users' skills. Therefore, top management support influences significantly the trend of an organization's decision for technology transfer, as well as its users' intention to apply new technologies (Sargent et al. 2012, Abrahamse et al. 2011, Venkatesh et al. 2003). As discussed before, new technology applications need an effective delivery method and training to facilitate the process of integration of new tools with current methods and procedures. Figure 6 summarizes the potential barriers for adopting technologies discussed above.

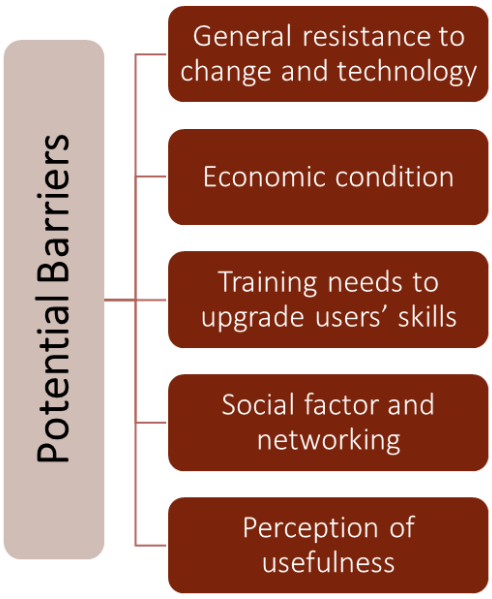


*Figure 6: Examples of potential barriers for technology adoption*

Although, the technical aspects of technology application may be challenging for some users, the past researches suggested that the main attributer to technology adoption are organizational and cultural, rather than technical. Therefore, a successful technology adoption needs not only address the technical knowledge in training sessions, but also needs to focus on technology application in daily operation (Talukder 2012). It should be noted that, providing training for users may be a challenging task for construction companies, because in many cases, their people are in a broad range of knowledge and experience that makes it difficult to provide an effective training for everyone.

In general, reviewing the past researches in this context shows that individual and organizational factors have a great impact on the technology adoption for construction safety. The culture of a construction company affects significantly the organization's decision making, as well as people's attitude toward applying safety innovations (Welch et al. 2015). Since a successful technology adoption depends on both organization's as well as users' intention, an investigation about the determinant factors affecting technology application in construction can assist managers to implement strategies to accelerate and improve the innovation adoption process (Sargent et al. 2012).

## 2.5. Research Questions

Based on the past researches the two most important groups of barrier factors preventing construction industry from applying safety technologies are considered to individual, as well as

organizational and managerial factors. So to promote the adoption of safety technologies in the industry, the most significant cultural barriers including both individual as well as organizational factors should be identified. In addition, given that currently there is a gap between research and practice regarding the technology adoption for construction safety, the current application of safety technologies needs to be investigated. Consequently, the research questions of this study are defined as follows:

1. What is the current practices of technology adoption in construction safety?
2. What are the most significant individual and organizational factors for adoption of technology in construction safety?
3. What are the possible solutions for the barriers to accelerate and improve new technologies adoption for construction safety?

# 3. Methodology

The methodology of this research include the following two main parts: a web-based survey and face-to-face interviews. The first phase of the study is an investigation of the current application of technology in construction companies as well as identifying the most significant barriers of technology adoption for construction safety. Aimed to this purpose, a web-based survey was developed with Catalyst web tools. The survey has been distributed via email to a list of 164 contacts who are occupied in the construction industry. The survey became first accessible on 02/12/2016 and stayed open for two months. The Total number of submitted results was 31 that indicates the maximum 19% of participation rate. Based on the results of the survey, some questions were identified as unexpected results or not specific trends, as well as, some new questions were raised from the survey findings. Therefore, a key informant interview was designed to investigate the questions that need to be studied more deeply.

To develop the questions, the results of the literature review have been utilized to identify and categorize the innovative technologies may currently be applied for construction safety and their purpose of use. Based on the results, the technologies applied for construction safety are classified based on their purpose of use into the following groups:

- Safety inspection
- Safety communication
- Safety planning
- Safety monitoring
- Incident investigation
- Safety training
- Emergency responses
- Physical (work) improvement

The dictionary meaning of technology is “The practice, description, and terminology of any or all of the applied sciences which have practical value and/or industrial use” (Walker 1999) or “systematic application of knowledge to practical tasks in industry” (Hornby 2006). In this study, the term of technology refers to any kind of innovative tools, applications or devices applied in construction safety management to improve efficiency, quality and productivity.

Currently there are various types of technology applied in the field of safety, the results of past researches are categorized in the following table (table 1) including the various aspects of safety management and the types of technologies associated with each group.

*Table 1: Types of Technologies Used in Different Safety Phases*

| | Safety inspection | safety communication | safety planning | Safety monitoring | Incident investigation | Safety training | Physical improvement |
|---|---|---|---|---|---|---|---|
| BIM | X | X | X | | | | X |
| ICT devices | X | X | X | X | X | X | |
| Drone | X | X | | X | | | X |
| Software Apps | X | X | X | | | X | |
| GPS | | | | X | | | |
| Wearable technologies | | X | | X | | | |
| Laser scanning | | | | X | | | |
| Game technology | | | | | | X | |
| 3D visualization | | | X | | | | |
| RFID | | | | X | X | X | |
| Virtual reality | | | X | | | | |
| Others: Halo light, Inverted Drill press, Concrete Drill jig | | | | | | | X |

Among these information, those types of technologies (shown in the figure 7) as well as the types of safety purposes that are more common in the industry are identified to being asked. The selected types are as follows:

- Safety technologies: BIM (Zhang et al. 2012, Riaz et al. 2014, Ganah et al. 2014, Zhou et al. 2013), drone (Grayson 2014; Harris 2015; Friedman 2015), ICT (Lin et al. 2014, Adriaanse et al. 2010, Johnson 2012, Riaz et al. 2006, Moon et al, 2015), RFID tags (Teizer et al. 2010, Kelm et al. 2013, Dyevakov 2007), wearable technologies (Gatti et al.

2011, Baker 2014, Friedman 2015, Raymond, 2014), software applications (Johnson, 2012, Moon et al. 2015, Mitchell et al. 2006 ), and GPS (Riaz et al. 2006, Ku et al. 2013)

- Safety purpose: safety inspection, safety monitoring, safety planning, safety communication, and physical improvement


*Figure 7: Types of Technologies*[1]

The following terminologies were used in the survey and interview as different phases and activities of safety practice in a regular construction project.

- Safety inspection: spot check or prearranged visit that examines the workplace and work equipment with acceptable standards to ensure that a given environment falls within acceptable safety limits. (Topic guide 16.7 Health and safety inspection, monitoring and review)
- Safety communication: Safety communication includes communication among project participants, among workers, and between workers and managers about safety issues, giving safety-related feedback, and conducting timely communication throughout the jobsite.
- Safety planning: Outline how safety will be managed on the project including roles and responsibilities of project participants, resources available, hazard analysis, hazard prevention solution, training requirement, and safety equipment needs.

[1] Pictures' sources: BIM (http://www.vcam-bim.com/), RFID Tags (http://www.piicomm.ca/rfid-solutions/), Wearable Techs (http://www.designersofthings.com/sanjose/cfa/)

- Safety monitoring: observing normal practices or tracking project entities e.g. how people working on site to assess whether they are safe. The main purpose of safety monitoring is acquiring real-time information on construction site to recognize and warn employees of potential hazards.
- Physical (work) improvement: Modify or improve the task or work environment to facilitate physical working conditions, and worker's limitation to mitigate hazardous activities.

To develop the survey questions, the safety terms have been linked to the questions to avoid any confusion in the terms definition and its impact on reliability of the results (in the web based survey, participants could click on each term and see its definition in a new web page).

## 3.1. Survey Questions

In the first part of the survey the participants are asked about their demographic information including their age, their job title, the years in construction and the size of company. This information is gathered and analyzed to provide a glance of the population as well as to investigate if there is a meaningful difference in technology adoption between companies with different sizes, or between old and new generation of managers. Table 2 indicates how the demographic information questions have been designed.

*Table 2: Demographic Information obtained by the Survey Questions*

| | |
|---|---|
| Age | 20-30 |
| | 31-40 |
| | 41-50 |
| | > 50 |
| Job title | Safety manager |
| | Project manager |
| | Other |
| Years in construction | 1-5 |
| | 6-10 |
| | 11-15 |
| | > 15 |
| Size of company | < 20 |
| | 20-50 |
| | 51-200 |
| | > 200 |

The rest of the survey questions are categorized in three main groups. The second group are the questions that are answered by the all participants (called common section). The questions in Part A are answered by the participants who do not have experience using technologies for construction safety. And questions in part B are answered by whom have experience using technologies for construction safety. After the first 15 questions, the rest of the questions have been divided into part A and B to allow ask more in-depth questions based on the participants' experience.

The first and second questions of the common section ask about participants' experience in using technologies for general use in their company as well as for safety purposes. The goal of these questions are to identify both the most applied innovative technologies by construction companies and to compare the technology application for general use with their use for safety purposes.

In the section of common questions, the question number 3 to the end of the question 15 have been designed in the form of 5-likert scale with 1 being "strongly disagree" and 5 "strongly agree". The questions in this part address two main issues including individual factors which means the way a participant as a technology user believes about the safety technologies, and organizational or managerial factors which means how a construction company as an organization and determinant sector behaves toward applying safety technologies. For instance, the questions related to the individual factors investigate the extent to which a participant is enthusiastic to adopt new technologies for safety, or the extent to which a participant believes that he/she can benefit from applying safety technologies in his/her own work. The questions ask about organizational factors include but not limited to the following examples: "Q3: Your company believes that using new technologies for safety brings long-term benefits to the company", or "Q13: The most significant barrier to employees training when applying new safety technologies is that our people are in broad phases of knowledge and experience". In these examples, the questions are asked aimed to see firstly, if construction companies believe that they may obtain long-term benefit by applying new technologies, and secondly to investigate if they are ready to invest on safety technologies to obtain long-term benefit.

In addition, in the question 5 the participants are asked about their opinion regarding the most significant barriers for safety technologies adoption in their company. Some of the answer options are the factors that are suggested by the lit review. The providing options for this question are shown below.

- Cost

- Complexity to use
- Time needed to learn and adopt the tool
- Need for additional training
- Need for changes in routine methods/process of doing tasks
- Uncertainty in obtaining benefits
- Additional initial setup of the tech
- Lack of organizational and top management support
- Lack of technical infrastructure support

Similarly, to the previous section, the part A with the total of six questions addresses the both aspects of individual and organizational factors preventing people in the industry from applying the safety technologies. The questions Q17-A and Q18-A are considered to the individual factors and the question Q16-A, Q19-A, Q20-A, and Q21-A are considered to the organizational and managerial factors respectively.

The last part of the survey is answered by the people who have experience using technologies for safety. This section includes the total of seven questions are designed to investigate the current application of safety technologies as well as barriers for technology adoption that are resulted from negative previous experiences of applying safety technologies. Given that one reason of failure in technology adoption is focusing only on technical knowledge rather than training people how to apply technologies in the daily function, the mentioned issue is addressed in the part B to see the extent to which the majority of the industry emphasize on applying technologies in an integration with the current approaches. The question Q18-B, Q19-B and Q20-B are a series of question asking about the participants' experience of failure of safety technologies adoption. These questions ask about the type of the failed technology, the reason of the failure, and the time that users give to a safety tech to be adopted in their company. The Q21-B in this section studies when the participants start using a new technology for safety in their projects to see if there is a specific trend of applying safety technologies for construction safety.

## 3.2. Interview Questions

The interviews were conducted in face-to-face meetings with safety experts in construction who have experienced applying safety technologies in their companies. To find the interviewees, an infographic of the survey results was prepared and sent with an invitation email to a list of industry contacts. The interview includes 19 questions that address the safety experts' experiences of

applying technologies in their company, as well as ask about their comments and recommendations on technology adoption in construction projects.

According to the table 3 the interview questions can be divided into four different areas.

*Table 3: Survey Questions Are Divided into Four Areas*

| | Question Areas | | | |
|---|---|---|---|---|
| Questions | Demographic Information | Current Practices in applying Techs | Most Significant Barriers | Recommendations & solutions |
| Q1 | X | | | |
| Q2 | | X | | |
| Q3 | | X | | |
| Q4 | | X | | |
| Q5 | | X | | |
| Q6 | | | X | |
| Q7 | | X | X | |
| Q8 | | | X | |
| Q9 | | | X | |
| Q10 | | X | X | |
| Q11 | | | X | |
| Q12 | | | X | |
| Q13 | | X | | X |
| Q14 | | X | | X |
| Q15 | | | | X |
| Q16 | | X | X | |
| Q17 | | X | X | |
| Q18 | | X | X | |
| Q19 | | | X | X |

The first area similar to the survey, asking about demographic information of the interviewees that contains the information about age, job title, years in construction, size of the companies, and the types of construction projects they perform in their companies. The second area's questions address the current practice of applying safety technologies in construction companies. In these questions, the respondents were asked to elaborate what types of technologies are currently used in their projects, and how they benefit safety in their companies. The third area studies the most significant barriers for technology adoption. These questions are answered based on the respondents' experience and their overall knowledge of the characteristics and demands in the

construction industry. Finally, the fourth area of questions are designed to investigate safety experts' recommendations and solutions for facilitating safety technologies' adoption in construction projects. Figure 8 indicates each steps of the general research workflow.


*Figure 8: The Research Workflow*

# 4. Data Analysis & Discussion

In this section, the results obtained from the survey and interview will be discussed in four main categories including demographic information, current practice of technology adoption, the main barriers facing technology adoption for safety, and solutions/recommendations for facilitating successful technology transitions.

## 4.1. Demographic Information

The Link of the survey was sent to a list of industry contacts. In total, 164 individuals have received the survey and 31 persons equal to 19% have responded to it. Figure 9 indicates the demographics of the survey participants.

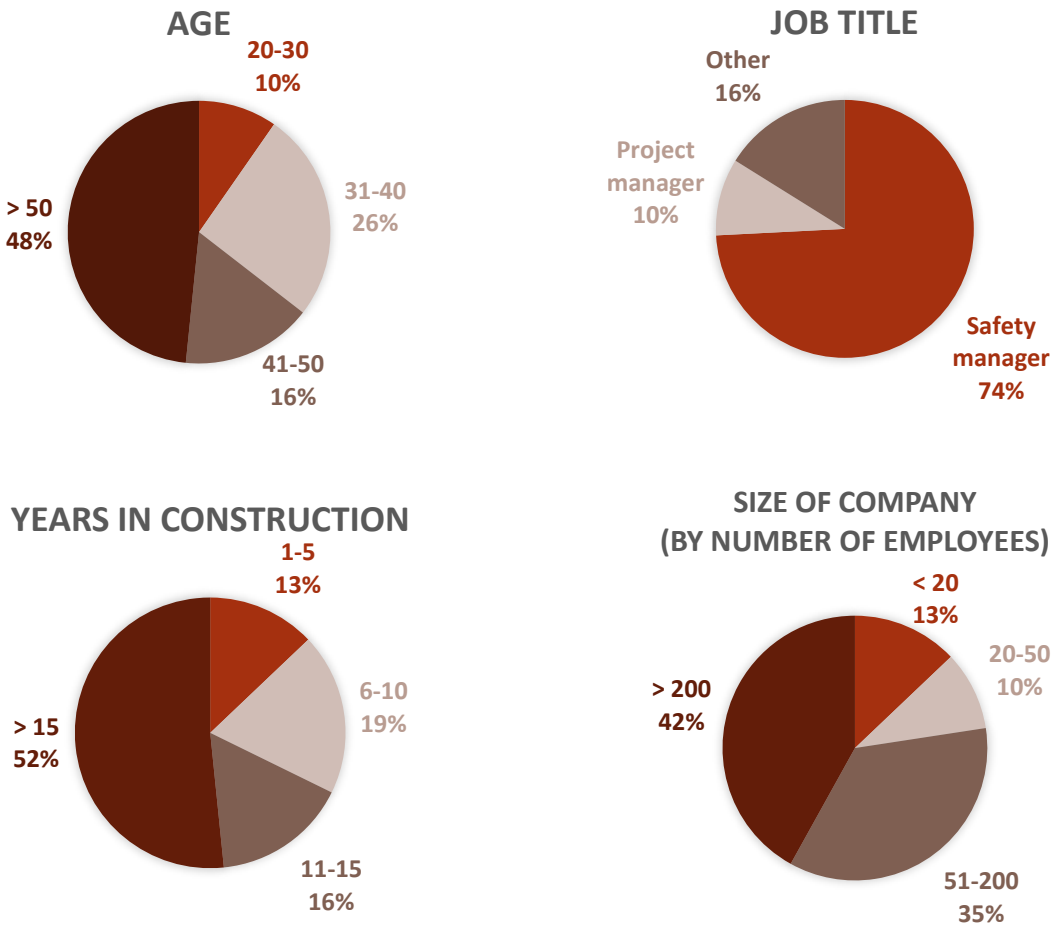


*Figure 9: Demographic Information of the Survey Participants*

As shown in the above charts, around half of the participants are older than 50 years old and they are occupied in the field of construction safety with over 15 years' experience. Also, the most of the participants are from medium to large-size of companies.

For the second phase of the research, 6 interviews were conducted with experts in construction. The interviewees include 4 safety managers, one construction manager and one safety inspector. Four of the interviewees are from the top Puget Sound general contractors, one from subcontractor, one from a federal organization, and one interviewee works as an owner representative for capital projects for a public university. Most of the participants are older than 40 years old with more than 12 years' experience in large size organizations or construction companies.

## 4.2. Current Practice of Applying Technologies

During the survey participants were asked to explain what types of technologies they use in their companies for general purposes, as well as for safety purposes. The following chart (Figure 10) indicates a comparison based on percentage of use between applying different types of technologies for general vs. safety purposes.

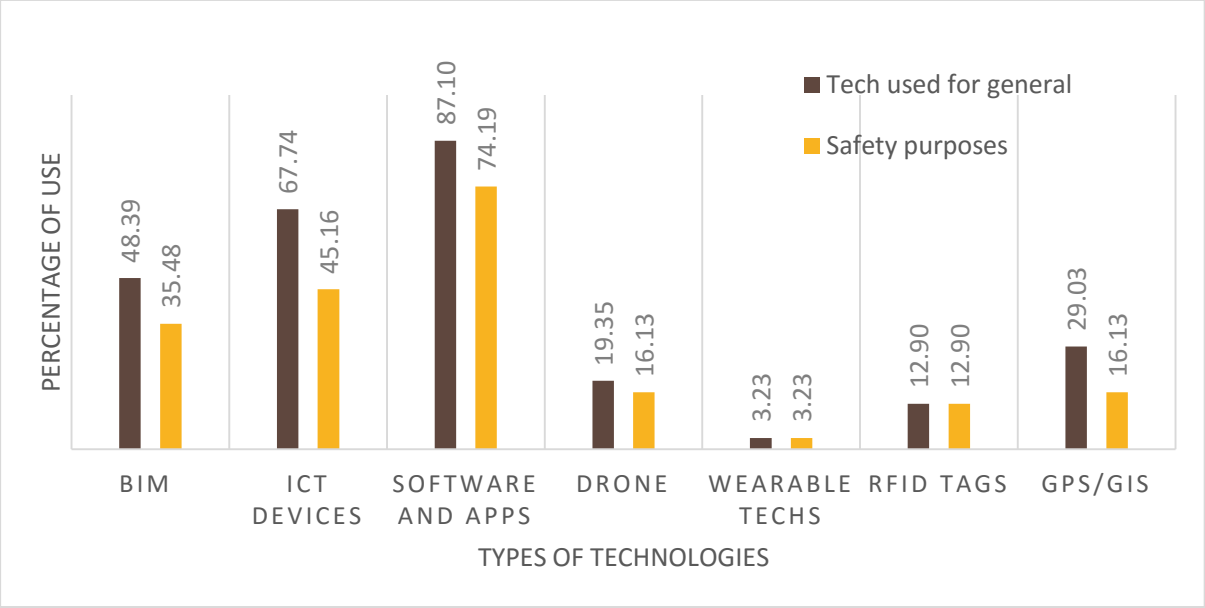


*Figure 10: Technologies used for General Vs. Safety Purposes*

The above chart shows that software applications, ICT devices, and BIM are the top three technologies that are currently applied by construction companies for both general and safety purposes. Also for approximately all types of technologies, the results indicate a higher

percentage of use for general vs. safety purposes. The lowest usage percentage belongs to the wearable technologies with only 3.23% that indicates wearable technology is still considered to be new and is not be adopted by construction companies.

For more in-depth study in this regard, the interviewees were asked to elaborate how they apply new technologies in their companies. The beginning of applying safety technologies by the participants averagely back to 7 years ago, however the use of technology in its current condition started since 2-3 years ago. The survey data analysis also shows that almost 65% of respondents started applying safety technologies since less than 3years ago. The main changes in the industry during the last few years caused by upgrading and developing new software, as well as developing new uses of BIM in construction projects. In general, according to a safety manager use of BIM in their company back to 8 years ago, CAD and other technologies were being in used before that. In addition, in terms of safety purposes, DB12 (similar to a little tiny laptop with a pen) was one of the first technologies that was being used for safety inspection. Another safety inspector mentioned that IPhone was the first ICT device that he used in his job for safety purposes.

**BIM**

According to the interviewees, BIM is currently used by most of the construction companies in various phases. BIM is applied generally for project management, they create 3D and 4D models for visualization and coordination, as well as use the model for logistic planning and scheduling. The layout points can be generated in the model and a robotic total station is being used to do layout in the field. BIM also benefits construction projects by applying it for estimating, the 3D model is used to understand the project pull quantity and cost model trending, as well as for tracking the changes and their cost effects. In terms of safety use, the BIM is used for planning ahead, or reviewing what the site is going to look like before the site exits. BIM enables the project team to model the site logistic and review the safety plan ahead of time. Also, they can plan the site out in great details including safety precautions and identify hazards in the model e.g. identifying a tie-off point of harnesses and showing how it supposed to be in a proper way. The level of details includes the structural model, but some safety elements such as safety railing zones can be also identified and modeled in 3D. The building model can be used by the safety people through their ICT devices on the jobsite.

The results of the interviews reveal that however BIM is doing a great job as a model for looking at the structure, and identifying hazards and conflicts, it hasn't fully come together with safety yet. Right now, safety people have limited involvement in creating a model, the only way they

are getting involved is when they are asked questions like “do we need guardrails here? Or that must be a confined space, is that can be an issue?” a safety manager said. So, there is still a disconnection between safety people and BIM coordinators in terms of applying BIM for safety purposes.

**Drone**

The results of the survey and interviews indicate that drone is used in construction projects in limited ways. Almost 19% of the survey respondents use drone for general purposes, this number for safety purposes is around 16%. It needs to be mentioned that the difference between general percentage and safety percentage might be higher in practice, since these results comes from the survey respondents who are mostly occupied in safety fields and they answer the questions based on their knowledge and experience.

According to the interviewees, drone is mostly applied in construction projects for reviewing the constructability. There has been recently some limitation for using drone in terms of privacy issues but it looks like the rules are being revised. The drone enables the project team to perform a quality/safety inspection specially for the unreachable or unsafe locations, as well as to monitor the people location on the jobsite. The other use of drone is for area photography of jobsite; the quick photos drone takes are used for logistic services. Also images help to better understand the construction, so the project team can see how they are going to approach the work, and providing safer approaching strategy.

**Wearable technologies**

According to the survey results, the wearable tech is the least used among the studied technologies. During the interview, one subcontractor reported that they use wearable technologies such as smartwatches generally in their health program. However, it seems that wearable technologies considered to be completely new to the construction people so that most of the participants are not using this type of technology or they’re not even aware of the current options of wearable technologies in the market.

**RFID tags**

The data collection indicates that RFID tags are applied for organizing and quickly access lots of information on the jobsite. For instance, barcodes can be used for preparing punch list, also they can be incorporate with 3D model so that people can scan off barcodes and they take them to that spot with 3D coordination model. Also, RFID tags can be applied for maintaining jobsite security and safety, for instance a construction manager mentioned that they use RFID tags in

identification cards for controlling the site access. However, the results show that RFID tags are not widely applied in construction projects. According to a safety manager, technical problem can be a reason of this limited usage. Some kinds of tags get destroyed in the field, they exposed to chemicals and they get broken, so they don't work properly and there is no real cost advantage to them.

**GPS**

According to the survey results GPS is applied by 29% of the respondents for general purposes compared to 16% for safety purposes. However, in terms of safety, the interviewees didn't mention any specific usage of GPS. As it mentioned earlier in the BIM section, the GPS is generally used in survey equipment in combination with BIM 3D models for laying out the works on jobsite. In addition, GPS is used for navigation including locating the vehicle position on the site and tracking vehicle speeds.

**ICT devises / software applications**

Software applications and ICT devices with respectively 74% and 45% percentage of use are the two top type of technologies that are used for construction safety. Currently there are wide variety of software applications and mobile applications in the market that can be purchased or free downloaded by users. In addition, ICT devices like iPhones and iPads are more acceptable by construction people because of their user friendly interface and various fixture like photo capturing option they provide.

The results of interviews indicate that 100% of interviewees apply at least one type of specific safety software applications. In general, ICT devices and software applications are used for the following five purposes:

1. Calling & messaging
2. Inspection and audit
3. Access to Data
4. Data analysis and reporting
5. Training

Some larger companies develop their own in-house software to customize it based on their unique objectives and combine different purposes in one application.

The Interviewees reported different benefits and uses of ICT and applications. For instance, safety inspection applications are applied to gather observational data from jobsite, so if they have a

safety issue in one site they can find a trend and see if there is a similar problem in another one. So it gives them a heads up to look for things and take a more proactive approach instead of reactive, and predict accidents before they happen. Also, gathering the data, tracking them and generating safety reports can benefit project team to evaluate their performance on site and identify areas where improvements or more focus is needed. One interviewee mentioned that construction team can significantly benefit from accessing 3D and 4D models on jobsite which bridge the gap between design and actual construction. Receiving most updated information of site condition and reviewing most recent work changes leads to a significant reduce in reworks and demolition activities and ultimately decrease the number of injuries and safety issues on the construction site.

Although, the results of the survey and interviews demonstrate a high percentage of use for safety specific applications, applying inspection application hasn't been received favorably. Currently, some companies apply safety specific applications in combination with paper. For example, they gather observational data with paper form and enter the data into the software for managing and analysis purposes. Although, this is not the way that the software was designed to be used, this is still a feasible and easier method for taking advantage from the software and reduce paperwork.

A common format of inspection application has several safety categories that are scored with an easy to follow yes or no grade and all categories are scored with color coding green for yes and red for no. Housekeeping is also rated based on a score between 1-10. However, some of the interviewees reported disadvantages for this format. In particular, using the yes/no check boxes could be confusing in the case that several data sample of the same type are gathered. For example, a safety manager explained that if you are on a jobsite with 200 people and ladders and we say we look at how you guys use ladders, so was it setup properly? Yes, was it secured? Yes, was that at the right angle? No, so we don't have one ladder on the jobsite we have 200 ladders, so if one worker is doing it wrong, it is not clear that how it should be measured and the accuracy of inspection is decreased.

Another weakness of current ICT devices and applications is that they are not specially designed for safety professionals. In other words, the accuracy of some types of data collected (e.g. level of noise, lights, and heat stress that are measured with different software) is based on the sensors of a phone and it is not scientifically considered valid as a normal measuring device. As a result, this method of audit does not comply with the OSHA requirements for a standard safety inspection.

### Distribution of technologies in different safety phases

In the survey, the respondents were asked what types of technology they use in different phases of safety. Table 4 displays distribution of safety technologies.

*Table 4: Distribution of Technologies in Different Safety Phases*

| | Safety Inspection | Safety comunication | Safety planning | Safety monitoring | Physical improvement |
|---|---|---|---|---|---|
| BIM | 6.5% | 12.9% | 16.1% | 3.2% | 16.1% |
| ICT devices | 29.0% | 35.5% | 25.8% | 25.8% | 9.7% |
| software and apps | 58.1% | 38.7% | 41.9% | 25.8% | 6.5% |
| Drone | 6.5% | 0.0% | 0.0% | 6.5% | 6.5% |
| Wearable techs | 3.2% | 0.0% | 0.0% | 0.0% | 0.0% |
| RFID tags | 12.9% | 0.0% | 0.0% | 3.2% | 0.0% |
| GPS | 3.2% | 9.7% | 12.9% | 3.2% | 3.2% |

58% of the participants mentioned that they apply safety specific software and applications for inspection. This results are consistent with our data analysis in previous section. It suggests that wide variety of software and applications that are developed for safety auditing and inspection are largely known and applied by users in construction. ICT devices are mostly used for safety communication. This result is also acceptable given that communication is a general and common use of ICT like iPhone and iPad. The most use of RFID tags is for safety inspection and safety monitoring. It is explained by the fact that RFID tags can be used for controlling and locating material and workers on the jobsite to identify and address safety hazards. In addition, as it expected, the highest usage of BIM is for safety planning, that enables project team to look at model before the construction and provide a solution for safety concerns.

Another survey question determines the safety phases that can potentially benefit most from applying technologies. The results are provided in the table 5:

*Table 5: Safety Phases that Benefit Most from Using Technologies*

| Safety Phases | Benefit (%) |
|---|---|
| Safety inspection | 70.4% |
| Safety communication | 44.4% |
| Safety planning | 48.1% |
| Safety training | 55.6% |


*Figure 11: The Safety Phases that May Benefit More from Technology Adoption*

Accordingly, the top three phases are safety inspection, safety training, and safety planning, respectively. The interviewees' responses to this question generally confirm the results of the survey. Interviewees also mentioned safety communication as an area that may influenced positively by applying new technologies. Figure 11 provides the safety phases that can benefit more from technologies adoption.

According to the safety experts, applying new technologies allows for getting people a plan which can reduce the rate of injuries. Pushing more planning up front and looking at safety issues in advance may reduce the number of changes raising during construction. Safety planning ahead of time is especially important since changes in scope of work put people at a high risk and increase the probability of unexpected hazardous situation.

Safety training is another area that was emphasized by the interview respondents. online safety program and ergonomics training, computer driven online safety orientation and web-based classes are some examples of applying technology in this field. Safety training in virtual world also helps to identify potential hazards and reduce risks in execution. Technology application for safety training such as web-based classes including training videos and quizzes enable workers to review training materials in advance and before they come to site. In addition, providing technology-based training methods or digital training platforms may be an effective way to teach the next generation of construction professionals who relate better with technology and are more open to smarter methods of doing tasks instead of sticking with traditional ways. It needs to be mentioned that, although applying innovation may benefit safety training, nothing can compare to on field training. The training component is much more face-to-face in the field work where people can do hands on demonstration type of things.

## 4.3. Individual and Organizational/Managerial Factors

This section discusses different factors that influence applying new technologies for safety. The factors include barriers and drivers that have been identified through the survey and interview data analysis.

During the survey, participants were asked to determine the most significant barriers for technology adoption in their company or in their own work. From a different perspective, they were asked to identify the barriers that were a reason for give up using a safety technology in their field. The results are summarized in the table 6.

*Table 6: Most Significant Barriers for Applying Technologies*

| Factors | Most Significant Barriers | Reasons for Give up a Technology |
|---|---|---|
| Cost | 51.6% | 40.0% |
| Complexity to use | 45.2% | 40.0% |
| Time needed to learn and adopt the tool | 35.5% | 40.0% |
| Need for additional training | 29.0% | 0.0% |
| Need for changes in routine methods/process of doing tasks | 25.8% | 13.3% |
| Uncertainty in obtaining benefits | 41.9% | 26.7% |
| Additional initial setup of the tech | 9.7% | 26.7% |
| Lack of organizational and top management support | 19.4% | 20.0% |
| Lack of technical infrastructure support | 12.9% | 46.7% |

According to the results, cost is the most significant barrier with about 52% following with “complexity to use” and “uncertainty in obtaining benefit” both with 45% and the “time needed to learn and adopt the tool” with 38%. A comparison between the results of second and third column of the table indicates that the initial barriers the companies face when they’re making decision for applying a new technology may be different from those they face when applying a new technology. In other words, when a construction company use and stick to a new technology some previous factors would not be challenging for them but they may face some new barriers. For instance, “need for additional training” is a factor that companies face when they start to apply a new technology, but after the users get trained, it would not be considered a challenge anymore. On the other hand, as it is indicated in the table the “lack of technical infrastructure support” was reported as the main cause of give up a technology, even though it was not among the most significant barriers for technology adoption. It is possible that the lack of infrastructure support is a problem that only raises up in practice while a safety technology is being adopted, but it may be not be an evident issue prior.

In order to gain a better understanding of the survey results, the similar questions with more details were asked during the interviews and a comparison study were conducted.

The interview analysis is generally consistent with the survey results in terms of identifying the most significant barriers for applying new technologies. The interview specifically mentions complexity of use, uncertainty in obtaining benefits, and time (needed to learn and adopt the tool) as the top barriers. It seems that cost is not a big challenge in the opinion of experts were interviewed because they all are from large construction companies with sufficient fund resources and technical infrastructure supports. However, safety managers consider the cost as an important factor during decision making for technology adoption to ensure cost efficiency and return on investment.

**Complexity to use**

Complexity to use is one of the main barriers that hurts technology adoption. “The case has to been made that something is simple and low-cost and has positive outcomes for what they do in a regular day. If something is too complex or expensive it just will not be adopted”, a safety director said. The time needed to learn and adopt the tool would also feed into complexity. If something is too complex and takes too long not only for the safety professionals but for labors to understand, it has a lower chance to be deployed. In this regard, some companies modify the way they use a specific safety tech because of its complexity, for instance, one interviewee reported that they use paper form instead of software apps for auditing to make it very simple for their people who are randomly selected to do inspection on site.

**Uncertainty about practicality and benefits**

According to the survey, 90% of safety experts believe that they can directly benefit from applying new technologies in their own work. In spite of this, many construction companies are not usually willing to adopt a new tech if they are not assured about its effectiveness. In other words, uncertainty about practicality and benefits of new technologies is a serious barrier for applying them. The uncertainty about using safety technologies can be studied in two aspects: 1. When a new tech does not show clear benefits or is not useable the way it is expected to be used. For example, some interviewee reported that there are some safety applications that are just a marketing tool and their performance for improving productivity and safety is not proven. Also, Sometimes, the data gathered by a tech is not useful for its users because they do not know how those data should be used or they do not see a direct relationship between applying that tech and safety enhancement. 2. Sometimes, the safety professionals are passionate about

testing/adopting a certain technology. However, they are not the only end users of safety technologies in their company. In general, the construction industry is risk averse. So, safety people face a challenge to get upper management supports if there are not many clear benefits for using a new tech. Also, there are many individuals (field workers, superintendents, foremen etc.) with different backgrounds involved in the safety and they need to see how exactly a new tech is going to help them with their jobs.

**Time**

Time is another factor identified as a challenge by both survey and interview respondents. Even large companies are struggling with this factor when they want to deploy a new tech in their projects. The point is, time as limited resource may intensify the impact of some other factors such as complexity of and uncertainty about benefit of technologies. In a case that a safety tech is complex to use and its value is not easy to see by users, people are more sensitive and hesitant to spend their time to learn and adopt it.

**Technical features/limitations**

Based on the data analysis technical features of current safety technologies can become a barrier for use in safety practices. For instance, one safety expert reported that RFID tags installed in their jobsite were frequently broken or destroyed if they were exposed to chemicals. Also, there are several complaints about safety apps that become down while used on jobsite. Lack of editability is another technical issue. Actually, some of the existing technologies are not well developed or they are not specifically designed for construction/safety. So, they cannot be tailored based on the unique project conditions or safety purposes. For example, an interviewee mentioned that the safety application he uses for inspection can be confusing for users because it is very general and has many questions that are not applicable to their needs in the project. Finally, the effectiveness of some new technologies strongly depends on the user. In other words, the quality of data gathered by the user determines if that tech is beneficial. Such dependency is a particularly barrier when users are not very fluent with that technology.

**Need for additional training**

Need for additional training could also be a barrier for adopting new technologies. Essentially, this barrier should be discussed from the perspective of different people that are involved in the process namely mangers and users/workers. Sometimes, the quality of training is an obstacle for adopting a good new technology. About 62% of the survey participants believes that training people for applying a new tech should not be limited to technical aspects of the technology but

rather on its application in daily function. However, in practice, some users do not receive sufficient training for using a tech or they are not really trained for applying tech in their daily operation. In other situation, training is an issue when not enough support is provided by the top management team or diversity of users (in terms of their knowledge, experience with technology, and need for additional training) makes it difficult to offer appropriate training to everyone. Also, it should be mentioned that some respondents believe that training could be a barrier just temporarily while people are learning new technologies but as long as they have proper training and time to learn it (there are some workers that need extra training) it would not be a problem.

**Technology as a distraction**

Another challenge for a proper adoption of a new tech arises when it functions as a distraction for users or other workers in the field. According to the experts, applying a new tech could be a learning curve. It could be distracting especially at the beginning when people have to find a new way for doing tasks. In a case that a new tool needs users to put so much info into it, then it is taking more of their time than they getting the benefits from. As an example, a safety manager mentioned that “when you’re doing audit on the jobsite you’re doing with your eyes and if you have to stop and enter something then it’s taking your eyes and concentration of what else is going on”. Nevertheless, it seems that the distracting effect of a new tech may be just initially and it would not be a barrier when people in the field become familiar with it. So, when a new tech become adopted it’s just another tool.

Another type of distraction may happen when using a technology like electronic devices interferes with worker’s regular jobs. For example, using cellphone on jobsites is now a major cause of distraction for construction workers because they may use it to play music or access social media during their daily working hours.

**Top management and leadership support**

Leadership and management’s approach is another factor that can influence on applying technologies as either a driver and a barrier. Top management as a barrier can be discussed from two different aspects. Top management support is needed for assigning resources to a new technology. For successful adoption of a new tech, top management should be convinced for providing enough money, time, and proper training for users. This aspect of top management support is not a barrier in many larger construction companies, because they have resources and constantly look for smarter, faster and more accurate new technologies to keep their people safer. In these companies, as long as there is a new tech that can benefit safety, cost, additional training,

infrastructure support etc. would not be a challenge. What can be a barrier in these companies is lack of top management support related to their act on the information who received from safety professionals. As it mentioned before, ICT devices and safety specific applications are used for gathering information, reporting and identifying a trend of safety issues. In some cases, people put all the time and effort to gather information from the jobsite and then they don't see any specific reaction toward their findings. In practice no changes or new decisions are made. So it can be frustrating and push people think that there is no benefit of applying the new tech. Top management also can promote applying technologies within their company, by providing required support for applying the new tech and pushing people to learn and adopt it

**Traditional and old-school attitude**

Old-school attitude towards technology and safety is another factor that considered to be a challenge for technology adoption. There are some people in construction who are used to perform their job in more old school and traditional ways. When it comes to safety, many people, especially the older generation trained in a certain way to do their job safely. So, many of them trust more on old methods and resist to apply new methods and technologies. This traditional attitude leads them to show unproductive behaviors towards safety issues, keeps them away from taking a more proactive safety approach, being patient for trying new things and think about long-term benefits safety technologies may bring to them. In addition, older generation has usually limited abilities to learn and adopt technologies compared to younger generation. Although, senior staff are valuable assets for any company this weakness in this case is a barrier for using technologies. For example, video trainings are not much useful for older generation and they need more hands on training in which a supervisor really show them how to do things. Also, some managers reported that older members have more difficulty to use safety apps and electronic devices.

**Social and cultural impacts**

A deep data analysis revealed that "social & cultural impacts" is a factor that may prevents users from adopting new tech in the current construction industry. The social and cultural impacts is a complex term and its different aspects should be discussed separately for a better interpretation.

- One aspect refers to the general expression "safety culture" that is defined as individual's or organization's approach regarding safety issues/concerns in their field. During a construction project many groups of people (workers, managers, engineers, etc.) work on a jobsite and some individuals do not care much about the safety. They think that safety regulations and

stuffs are disturbing with their regular jobs on project site. Safety managers' complaint that despite of every hard works for adopting technologies and actual improvements they made the injury rates do not reduce much because ultimately everyone on a jobsite should use safety technologies properly while some people do not even follow the basic rules of fall protection. In fact, managers can develop safety best practices and provide new technologies with enough training to workers but the attitude of safety technologies end-users cannot be fixed just by technologies. Therefore, safety managers may think that applying technologies is not beneficial as long as the general safety culture does not change.

- It is understood from the survey and interview that in some cases, the construction industry does not have practical expectation from safety technologies and this may create an unrealistic guard against trying new technologies. For example, one interviewee mentioned some construction people especially the older generation expect to see very clear benefits or huge changes when applying a new technology. He added "We have seen technology in construction that is really improving but have not seen much in safety other than some new materials like different kind of knee pads, cut level protection, and gloves. But generally new technologies (and electronic devices in particular) have not proven anything". On the contrary, some safety experts believe that expecting huge improvements in new technologies that make big changes in safety is not possible and such high expectation should be moderated.
- The construction market and peers have influence (either positive or negative) on the way safety experts may think about adopting a new technology. The survey results show that 74% of safety professionals feel encouraged to use new technologies for safety by their peers. Also, many interviewees mentioned that they look at their peers to see what safety technologies are in use in the market. In addition, 75% of survey respondents are disagree or extremely disagree with the expression that "you don't feel you need to switch over to new safety technologies when your partners in the industry are not using them. In other words, this factor does not pull experts away from using new technologies even if it is not used by others. But it can push people to try a new tech by spreading the word through the market. This result in comparison with the interview results indicate that encouragement from peers or construction industry is working more as a driver than a barrier in the current (Seattle) community.
- Based on the data analysis, the current industry has a reactive approach in dealing with safety issues and performing safety practices. This is shown to be a barrier when compared to a potential proactive behavior. For example, a safety manger explained his experience about using a new lighting technology on a jobsite. They used LED besides of traditional head lights

on the site and it showed a considerable improvement in site housekeeping and the way people were taking care of their environment. Also, it had a positive phonological influence on the workers that led to a higher level of safety. Such proactive practices have benefits that are long term or hard to quantify. Although, 80% of the survey participants believe that applying technologies bring long-term benefits to their company mangers usually follow a reactive behavior which is not only a barrier for using new technologies but also is ineffective for preventing many safety injuries.

- The last aspect of social and cultural impacts is the tendency for adopting a new tech based on user's previous experiences. In general, this aspect can also be a barrier or driver. According to the survey, 61% of respondents agree or extremely agree that they are more inclined to use technology for safety if they have previous experience of using it. On the other hand, the interview results indicate that if a manger spend all the time and effort to adopt a safety tech but does not see much positive changes in return he/she will gain a negative intuitive attitude about trying new technologies (even if the new tech has none of the weaknesses of the previous used technologies). Furthermore, ignoring the influence of previous experience as a barrier may cause father problems for construction companies. If a company try too many new ideas, learning curve of new technologies cannot be stabilized, so people put time and effort to apply new innovations without getting an actual result from them. As an example in this regard a safety manager explained they see many new ideas for safety and their company get all on the board. So people try and when they do not get much from them, they will back to the way they have done before. What happens is that the people guard it more when the next one comes out. In other words, it would be dangerous to have immature technology in the company because it harms people' opinion and their trust in new technologies.

A summary of the identified factors is provided in the table 7. The below indicates the factors influencing technology adoption for construction safety, as well as classifies them into individual or organizational/managerial factors.

*Table 7: Factors Influencing Technology Adoption for Construction Safety*

| Factors | Individual | Organizational managerial |
|---|---|---|
| Cost | | X |
| Complexity to use | X | |
| Uncertainty about practicality and benefits | X | X |
| Time | X | X |
| Technical features/limitations | X | |
| Need for additional training | | X |
| Technology as a distraction | X | |
| Top management and leadership support | X | X |
| Traditional and old-school attitude | X | X |
| Social and cultural impacts | X | X |

## 4.4. Recommendations and Solutions

This section provides potential recommendations and solutions to overcome current barriers and challenges towards technology adoption for construction safety. The solutions are suggested to construction companies (users) as well as technology developers based on their unique abilities and responsibilities. The following points are interpreted from the results of this study and what safety experts recommend to facilitate technology transition to the construction industry.

- Recommendations for construction companies
    1. Have practical expectation.

       As it mentioned in the previous section, uncertainty about benefits of a new tech discourages users to adopt it. The point is this factor depends on the level of users' expectation of seeing a value of applying a tech. In this regard, looking at the end goal and not having unrealistic high expectation may increase the user tendency to try new methods. In other words, applying tech project by project and do not inundate people with too many new ideas may increase the chance of success. At the same time, companies should be selective regards bring a new tech to their projects and set clear objectives to make sure that they purchase a tech that provides practical benefits.

    2. Gradual integration of new technologies

In addition, applying new technologies needs to integrate slowly with the current practices in construction. It is critical especially for the users who used to perform their tasks in a certain way or those (like blue collar labor) who are less exposed to new technologies and need more training.

3. Active leadership support

Getting the management in a position to push technologies increase user's tendency to adopt new technologies. The important point is that the role of top management for pushing new technologies is not to dictate applying a tech to the users but he/she should promote technology adoption by providing resources/training and facilitating the adoption process.

4. Enhance the overall safety culture

Enhancing the overall safety culture within a company is essential for successful technology application. The actual usage of a new tech occurs when users really believe and want to use it. So, the general people behavior toward safety issues has an impact on the way they apply a new tech for safety purposes. This point become more important when it comes to that type of technologies like safety specific applications that their effectiveness highly depend on how people use them.

5. Start with the more open-minded employees

Start innovations within a company by selecting team based on their abilities to innovate and desire to learn technologies. However, this method may have a disadvantage because older generation and people with limited proficiency in technologies will not be chosen and it keeps them even much more far away from technology adoption.

- Recommendations for technologies developers

1. Understand the problems first

To develop a technology that can really benefit safety, designers need making sure they understand what the problems are and then try to solve them with the technology.

Otherwise, there would be a gap between what people receive from the technology and what they really need to improve safety.

2. Develop technologies from users' perspective

As it mentioned before, one weakness of current safety technologies is some of them are not designed and developed properly. Working directly with the people who are the end-

users of technology is essential to understand their needs and limitations. For example, a safety manger explained a safety application (called Zonar) that was not designed for construction safety. The lack of consulting with construction experts who know what needs to be added caused to developing a program which was a great concept but did not have needed details and so was not successful. According to a safety manager “struggle is that when you design a technology you need to feel part of it.  you need to understand how it affects the field”. Sometimes the technologies are designed for people in construction can really change the way they can work. So it is critical that designer understand the work environment from the first-person perspective.

3. Incorporate flexibility in technology features

Design application that can be used across different platforms and be editable and customizable based on users’ needs in a unique project. For instance, customization for vertical construction vs horizontal. It helps users relate better with the technology and increases the chance of its adoption.

# 5. Conclusion

This section provides a summary of the research questions and their corresponding results that are studied in this research. The limitation of this study is explained, and the research contribution is discussed in the following parts.

## 5.1. Summary

This research study was conducted to investigate cultural, individual and organizational factors influencing technology adoption for construction safety. The three main aspects/questions studied in this research include the current practice of technology adoption for construction safety, the most significant barriers/factors that influence construction companies' tendency to apply a new technology, and the potential solutions and recommendations to overcome the current barriers. The methodology of this research includes a web-based survey which gives a more general picture of different types of technologies that are currently applied in construction projects. It also extracts industry perspectives regarding new technologies and the possible reasons leading to the application or refusal of a new technology. To obtain more insights on the topic, the survey results were expanded by in-person interviews with construction experts.

The results demonstrate that in the studied population (all from the Puget Sound area), companies started applying new technologies for safety almost 7 years ago and the trend has been accelerated in the past 2-3 years. Currently, about 83% of participants apply at least one type of technologies for construction safety. The top three technologies that are used mostly by construction companies are safety-specific software applications, ICT devices, and BIM, respectively. On the contrary, wearable technologies are completely new to the construction industry and are least used among the studied technologies. In general, this study reports that according to the construction experts, safety inspection, safety training, and safety planning are the top three phases that can benefit more from applying new technologies. Also, safety communication is mentioned as an area that may be influenced positively by the applications of new technologies.

The distribution of new technologies for construction safety indicates that the highest usage of BIM is for safety planning: enabling project teams to plan ahead, addressing safety concerns and providing solutions before projects begin. BIM is considered a great tool for identifying hazards and conflicts. Nevertheless, the results suggest that BIM hasn't fully come together with safety yet and there is still a disconnection between safety personnel and BIM coordinators in terms of

applying BIM to benefit safety. Right now, ICT devices and software applications are widely applied by construction companies. The most common use of safety applications is for safety auditing and inspection, and ICT devices are mostly used for safety communication. However, inspection and auditing applications haven't been received favorably because they are complex to use (compared to the traditional approaches), cannot be customized based on the unique needs of a project, and are costly in some instances.

During this research, the most significant barriers for technology adoption were identified, including: complexity to use; uncertainty about practicality and benefits of applying a new tech; time needed for additional training; and cost. Although cost is not included in the most-reported challenges by larger construction companies, they still consider it during decision making when evaluating the potential of a technology to ensure its cost efficiency and return on investment. Regarding the reasons for giving up a technology, the "lack of technical infrastructure support" was reported as the main cause, even though it was not among the most significant barriers for technology adoption. It is possible that the lack of infrastructure support is a problem that only raises up in practice while a safety technology is being adopted, but it may be not be an evident issue prior. Besides these factors, leadership support was also emphasized by construction experts as both a driver and a barrier that affect the process of technology adoption significantly.

The last part is related to the potential recommendations and solutions to overcome current barriers and challenges towards technology adoption for construction safety. The solutions are provided to construction companies (users) as well as technology developers. The following points are some examples: "Enhance the overall safety culture", "Have practical expectation", "Look at from users' perspective" and "Flexibility in technology features".

## 5.2. Research Limitations

The participants in this research are mostly occupied in the field of construction safety and almost half of them are older than 50 years old with more than 15 years of experience in construction. In addition, most of the survey respondents work for medium to large-size companies. All interviewees are currently working (or they were working) for the construction industry in Puget sound area (which is relatively considered to be open to innovations in construction) and half of them are from the top General Contractors companies in terms of size. In general, most of the participants in this research are in contact with academic environment and they belong to the population who are aware and open to new innovations. So the results of this study in terms of popularity of technology adoption might be slightly different from other parts of the construction

industry. In addition, more than one third of the survey respondents and all of the interviewees are from the companies with more than 200 number of employees. The small-size construction companies have less resources to assign for technology adoption and they probably have more issues, for instance, for providing training, leadership support and their overall safety culture. So, tendency of applying new technologies, distribution of technologies applied for construction safety, and the barriers for technology adoption could be different in small-size construction companies. It also needs to be mentioned that more than 80% of contributors in this study are safety managers or project managers and so their responses to the questions are mostly from the managerial perspective. The answers from field-workers, foremen and superintendents could create different insights.

## 5.3. Research Contribution

This research study aims to evaluate the use of technologies in construction safety. The results of this study provide a big picture on the current practices of technology adoption for construction safety. It investigates different types of technologies existing in the market, determines the most uses of safety technologies, and reports the actual benefits they may bring to the industry. In addition, this research provides a unique and comprehensive list of the significant barriers for applying safety technologies, which helps safety managers to accurately address the existing or potential issues in their own companies and make needed decisions on time. Also, the results of this study benefit technologies developers and enable them to better understand the areas that need improvement and the approach that need to be taken to meet the demands in the construction industry.

## 5.4. Next Steps

The target audience of this research are construction companies and safety tech developers. Therefore, the findings of this research should be provided to these groups to solicit feedback for revising and improving the research.

In addition, there is an opportunity for researchers and R&D departments to leverage the results of this research. As this research was designed to study the general approach of the current construction industry regarding safety technology adoption, it provides a comprehensive classification of the current practices and the most significant barriers. However, this research does not conduct a deep investigation on each identified technology or barrier, separately. In addition, as mentioned before, the list of the current barriers comes from surveying and

interviewing with safety professionals. Therefore, as a next step, an in-depth analysis should be performed on these concepts. One idea could be to focus on a certain technology that is currently applied by construction companies and develop a case study to test it in practice. It helps to evaluate a specific technology directly in field to accurately assess its benefits/weaknesses and identify specific barriers surfaced during application. It is also an opportunity for getting direct feedback from different types of users such as field workers, superintendents, and foremen.

The other idea is to focus on a certain barrier to understand its causes, intensity, and side effects, and to suggest lean solutions which best fit that problem. For example, uncertainty about practicality and benefit of a new technology is a significant barrier that construction companies face. So for instance, in the case of applying safety specific applications, it needs to be investigated that what types of information should be gathered to provide accurate and reliable outcomes. In addition, it is still unclear how this information (assuming it is accurate) can be used to benefit and improve safety. So a solution for best uses of gathered safety data should be provided.

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# 7. Appendices

The following items are included in this section:

- Appendix I: Survey Questionnaire
- Appendix II: Survey Summary Sheet
- Appendix III: Interview Questionnaire

## Appendix I:

## Survey Questionnaire

# How Do Cultural and Behavioral Factors Influence Technology Adoption for Construction Safety



**Introduction**

This survey has been developed to investigate the technology adoption for construction safety. The data will be collected to evaluate the current applications of new technologies, as well as to identify individual and organizational factors influencing technology adoption for supporting safety in construction projects. All collected data and personal information will be confidential and only aggregated data will be published. Your participation will provide valuable inputs, guide industry-academic partnerships, and is very much appreciated.

**General Information**

**Age**

- ◯ 20-30
- ◯ 31-40
- ◯ 41-50
- ◯ > 50

**Job title**

- ◯ Project manager
- ◯ Safety manager
- ◯ Other:

**Years in construction**

- ◯ 1-5
- ◯ 6-10
- ◯ 11-15
- ◯ >15

**Size of company (by number of employees)**

- ◯ < 20
- ◯ 20-50
- ◯ 51-200
- ◯ > 200

**Next >>**

# How Do Cultural and Behavioral Factors Influence Technology Adoption for Construction Safety



**Question 1**

**Which of the following technologies have you applied in your projects? (Choose all that apply)**

- ☐ BIM (Building Information Modeling)
- ☐ ICT devices (Information and communication technology e.g. tablet)
- ☐ RFID tags
- ☐ Wearable technologies (e.g. smart watches)
- ☐ Software and apps
- ☐ GPS/GIS
- ☐ Drone
- ☐ None
- ☐ Other:

**Question 2**

**Which of the following technologies have you applied for construction safety?**

(Please click on to see the definitions of the following terms: safety inspection, safety communication, safety planning, safety monitoring, physical improvement)

| | Safety Inspection | Safety communication | Safety planning | Safety monitoring | Physical improvement |
|---|---|---|---|---|---|
| BIM | ☐ | ☐ | ☐ | ☐ | ☐ |
| ICT devices | ☐ | ☐ | ☐ | ☐ | ☐ |
| Safety specific software and apps | ☐ | ☐ | ☐ | ☐ | ☐ |
| Drone | ☐ | ☐ | ☐ | ☐ | ☐ |
| Wearable technologies | ☐ | ☐ | ☐ | ☐ | ☐ |
| RFID tags | ☐ | ☐ | ☐ | ☐ | ☐ |
| GPS/GIS | ☐ | ☐ | ☐ | ☐ | ☐ |

**Question 3**

**Your company believes that using new techs for safety brings long-term benefits to the company.**

- ◯ 5 strongly agree
- ◯ 4
- ◯ 3
- ◯ 2
- ◯ 1 strongly disagree

**Question 4**

**Your company doesn't tend to invest in new techs until their effectiveness is proven otherwise.**

- ◯ 5 strongly agree
- ◯ 4
- ◯ 3
- ◯ 2
- ◯ 1 strongly disagree

**Question 5**

**Which of the followings do you think are the most significant barriers in safety tech adoption in your company? (Choose all that apply)**

- ☐ Cost
- ☐ Complexity to use
- ☐ Time needed to learn and adopt the tool
- ☐ Need for additional training
- ☐ Need for changes in routine methods/process of doing tasks
- ☐ Uncertainty in obtaining benefits
- ☐ Additional initial setup of the tech
- ☐ Lack of organizational and top management support (e.g. provide training, incentives)
- ☐ Lack of technical infrastructure support
- ☐ Other:

**Question 6**

**How enthusiastic are you to adopt new techs for safety use?**

- ◯ 5 Extremely enthusiastic
- ◯ 4
- ◯ 3
- ◯ 2
- ◯ 1 Not enthusiastic

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# How Do Cultural and Behavioral Factors Influence Technology Adoption for Construction Safety



**Question 7**

**I am more inclined to use technology for safety if I have previous experience using it.**

- ◯ 5 strongly agree
- ◯ 4
- ◯ 3
- ◯ 2
- ◯ 1 strongly disagree

**Question 8**

**I believe I can directly benefit from applying new techs in my own work.**

- ◯ 5 strongly agree
- ◯ 4
- ◯ 3
- ◯ 2
- ◯ 1 strongly disagree

**Question 9**

**I feel encouraged to use new techs for safety by my peers.**

- ◯ 5 strongly agree
- ◯ 4
- ◯ 3
- ◯ 2
- ◯ 1 strongly disagree

**Question 10**

**I would use new safety techs if they would be supported by top management in our organization.**

- ◯ 5 strongly agree
- ◯ 4
- ◯ 3
- ◯ 2
- ◯ 1 strongly disagree

**Question 11**

**I believe that current software applications are NOT designed based on our needs in construction safety.**

- ◯ 5 strongly agree
- ◯ 4
- ◯ 3
- ◯ 2
- ◯ 1 strongly disagree

**Question 12**

**Adopting new safety technologies distracts workers from focusing on their tasks.**

- ◯ 5 strongly agree
- ◯ 4
- ◯ 3
- ◯ 2
- ◯ 1 strongly disagree

**Question 13**

**The most significant barrier to employees training when applying new safety techs is that our people are in broad phases of knowledge and experience.**

- ◯ 5 strongly agree
- ◯ 4
- ◯ 3
- ◯ 2
- ◯ 1 strongly disagree

**Question 14**

**Having a reward and punishment management system motivates employees to apply a new safety techs.**

- ◯ 5 strongly agree
- ◯ 4
- ◯ 3
- ◯ 2
- ◯ 1 strongly disagree

**Question 15**

**In your opinion, which of the following phases can benefit more from applying safety techs? (Please choose the top 3 options)**

- ☐ Safety inspection
- ☐ Safety monitoring
- ☐ Safety training
- ☐ Safety planning
- ☐ Safety communication

# How Do Cultural and Behavioral Factors Influence Technology Adoption for Construction Safety



**For the rest of the questions please answer:**

- **Part A if you do NOT have experience using techs for safety.**
- **Part B if you HAVE experience using techs for safety.**

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# How Do Cultural and Behavioral Factors Influence Technology Adoption for Construction Safety



**Part A: Please answer the following questions if you do NOT have experience using techs for safety.**

**Question 16**

**You don't need to use new techs in your company because you have a good safety performance without using new techs.**

- ◯ 5 strongly agree
- ◯ 4
- ◯ 3
- ◯ 2
- ◯ 1 strongly disagree

**Question 17**

**You don't use new safety techs because your budget doesn't allow you to invest in them.**

- ◯ 5 strongly agree
- ◯ 4
- ◯ 3
- ◯ 2
- ◯ 1 strongly disagree

**Question 18**

**You don't use new techs for safety because of the technical complexity.**

- ◯ 5 strongly agree
- ◯ 4
- ◯ 3
- ◯ 2
- ◯ 1 strongly disagree

**Question 19**

**You don't use safety technologies because you are not aware of the current options in the market.**

- ◯ 5 strongly agree
- ◯ 4
- ◯ 3
- ◯ 2
- ◯ 1 strongly disagree

**Question 20**

**You don't tend to use new techs because they require extensive training to upgrade user skills.**

- ◯ 5 strongly agree
- ◯ 4
- ◯ 3
- ◯ 2
- ◯ 1 strongly disagree

**Question 21**

**You don't feel you need to switch over to new safety techs when your partners in the industry are not using them.**

- ◯ 5 strongly agree
- ◯ 4
- ◯ 3
- ◯ 2
- ◯ 1 strongly disagree

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# How Do Cultural and Behavioral Factors Influence Technology Adoption for Construction Safety



**Part B: Please answer the following questions if you HAVE experience using techs for safety.**

**Question 16**

**For training employees to use new techs you don't only focus on technical knowledge but rather on the application of new techs in daily function.**

- ◯ 5 strongly agree
- ◯ 4
- ◯ 3
- ◯ 2
- ◯ 1 strongly disagree

**Question 17**

**How significant have technical nuisances (e.g. false alarms from a proximity detection device) been in using safety techs?**

- ◯ 5 Extremely significant
- ◯ 4
- ◯ 3
- ◯ 2
- ◯ 1 Not significant

**Question 18**

**Have you given up using a particular technology in your company? If yes, which of the followings were the main reasons? (Choose all that apply)**

- ☐ Cost
- ☐ Complexity to use
- ☐ Time needed to learn and adopt the tool
- ☐ Need for additional training
- ☐ Need for changes in routine methods/process of doing tasks
- ☐ Uncertainty in obtaining benefits
- ☐ Additional initial setup of the tech
- ☐ Lack of organizational and top management support (e.g. provide training, incentives)
- ☐ Lack of technical infrastructure support
- ☐ Technical problem
- ☐ Other: _____

**Question 19**

**If you answered "yes" in the previous question, what type(s) of technology have you stopped using?**

**Question 20**

**If you answered "yes" in question 18, how long did you use the technology before you gave it up?**

- ◯ less than 4 months
- ◯ 4-6 months
- ◯ 7-12 month
- ◯ 1-5 years
- ◯ more than 5 years
- ◯ Not sure

**Question 21**

**When did you start using a new technology for safety in your projects?**

- ◯ More recently
- ◯ 2-3 years ago
- ◯ 4-6 years ago
- ◯ More than 6 years ago

**Question 22**

**Based on your experience, does applying new techs conflict with your current organizational policies and approaches?**

- ◯ No
- ◯ Yes: (please explain briefly)

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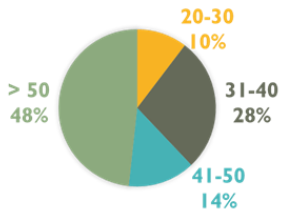
## Appendix II:

## Survey Summary Sheet

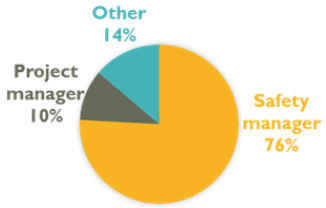
## SURVEY RESULTS
## TECHNOLOGY ADOPTION FOR CONSTRUCTION SAFETY
## SUMMARY SHEET

### GENERAL INFORMATION

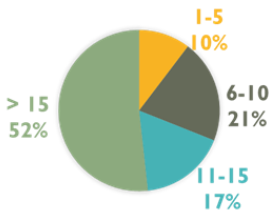
#### AGE



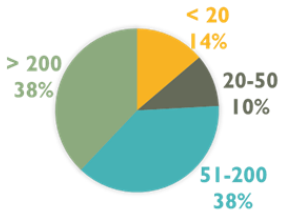

#### JOB TITLE




#### YEARS IN CONSTRUCTION

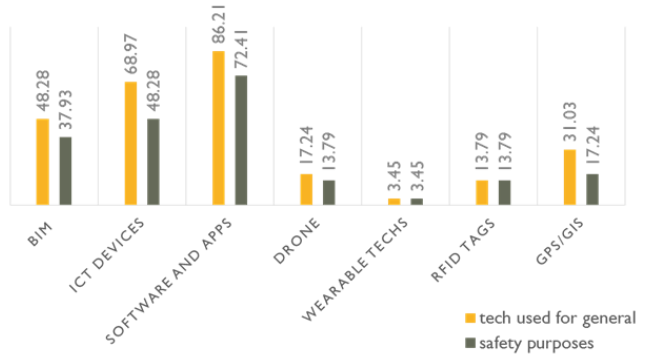



#### SIZE OF COMPANY




8 OUT OF 10 PARTICIPANTS BELIEVE THAT APPLYING TECHS FOR SAFETY BRINGS LONG-TERM BENEFITS TO THEIR COMPANY.

### TECH USED FOR GENERAL VS. SAFETY PURPOSES



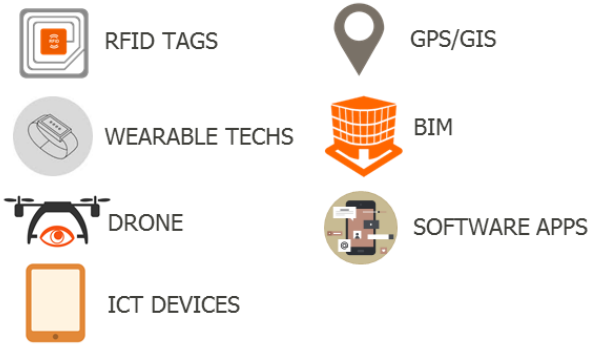

### THE MOST SIGNIFICANT BARRIERS IN TECHNOLOGY ADOPTION FOR CONSTRUCTION SAFETY

- COST 52%
- COMPLEXITY TO USE 45%
- UNCERTAINTY IN OBTAINING BENEFITS 45%
- TIME NEED TO LEARN AND ADOPT THE TOOL 38%

## HOW CONSTRUCTION INDUSTRY APPLIES TECHNOLOGY FOR SAFETY

| | Safety Inspection | Safety communication | Safety planning | Safety monitoring | Physical improvement |
|---|---|---|---|---|---|
| BIM | 7% | 14% | 17% | 3% | 17% |
| ICT devices | 31% | 38% | 28% | 28% | 10% |
| software and apps | 55% | 38% | 38% | 28% | 7% |
| Drone | 7% | 0% | 0% | 3% | 3% |
| Wearable techs | 3% | 0% | 0% | 0% | 0% |
| RFID tags | 14% | 0% | 0% | 3% | 0% |
| GPS/GIS | 3% | 10% | 14% | 3% | 3% |

## 83% APPLY AT LEAST ONE TYPE OF TECHNOLOGY FOR CONSTRUCTION SAFETY

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## Appendix III:

## Interview Questionnaire

## Introduction

Thank you for agreeing to do this interview. My name is Atieh Borhani, and I am a master student at the UW, department of construction management. Under supervision of Prof Ken-Yu Lin, I am conducting a research study for my master thesis regarding safety in construction projects. The purpose of this interview today is to learn more about your experiences with and recommendations related to technology adoption for construction safety.
The interview will last about 30 min. Do you have any questions before we begin?

---

1. General information
   a) Age
      ☐ 20-30 ☐ 31-40 ☐ 41-50 ☐ >50
   b) Job title
      ☐ Project manager ☐ Safety manager ☐ other: ☐
   c) Years in construction
      ☐ 1-5 ☐ 6-10 ☐ 11-15 ☐ >15
   d) Size of the company (by number of employees)
      ☐ < 50 ☐ 50-200 ☐ > 200
   e) Types of projects
      ☐ Residential ☐ Mixed-use ☐ Industrial ☐ Institutional ☐ Infrastructure & heavy civil

2. What is your general opinion about the safety performance in your company?

3. a) Which of the following technologies have you applied for general purposes in your projects? (Choose all that apply)
      ☐ BIM
      ☐ ICT devices
      ☐ Safety specific software applications
      ☐ Drone
      ☐ Wearable technologies
      ☐ RFID tags
      ☐ GPS
   b) Please provide an example for each of the technologies you selected.

4. a) Which of the following technologies have you applied for construction safety specifically?
   - ☐ BIM
   - ☐ ICT devices
   - ☐ Safety specific software applications
   - ☐ Drone
   - ☐ Wearable technologies
   - ☐ RFID tags
   - ☐ GPS

   b) Please provide an example for each of the technologies you selected. Which one was more advantageous?

5. When did you first start using a new technology for safety in your projects?
   - ☐ Less than 3 months
   - ☐ 4-6 months
   - ☐ 7-12 months
   - ☐ 1-5 years
   - ☐ More than 5 years
   - ☐ Not sure

6. Are you ready to try a new safety tech in your company when its effectiveness is still uncertain? Why?

7. have you used safety specific software applications? If yes, do you think that current software applications are designed based on your needs in construction? What weakness(es) have you noticed in these software applications?

8. Do you feel encouraged to use new technologies for safety by your peers? (please give an example). Is the current industry culture encouraging in this regard? Why?

9. a) Which of the following barriers are most significant when it comes to adopt safety technologies? (Choose all that apply)
   - ☐ Cost
   - ☐ Complexity to use
   - ☐ Time needed to learn and adopt the tool
   - ☐ Need for additional training
   - ☐ Need for changes in routine methods/process of doing tasks
   - ☐ Uncertainty in obtaining benefits
   - ☐ Additional initial setup of the tech
   - ☐ Lack of organizational and top management support
   - ☐ Lack of technical infrastructure support
   - ☐ other

   b) Please give an example why it causes barrier?

10. a) Have you given up using a particular technology for safety in your company? If yes, which of the followings were the main reasons and why? (Choose all that apply)
    - ☐ Cost
    - ☐ Complexity to use
    - ☐ Time needed to learn and adopt the tool
    - ☐ Need for additional training
    - ☐ Need for changes in routine methods/process of doing tasks
    - ☐ Uncertainty in obtaining benefits
    - ☐ Additional initial setup of the tech
    - ☐ Lack of organizational and top management support
    - ☐ Lack of technical infrastructure support
    - ☐ other:

    b) what type(s) of technology have you stopped using?

    c) how long did you use the technology before you gave it up?

11. Do you think that applying new safety technologies distracts workers from focusing on their tasks? How?

12. Does your previous experience with a technology have an impact on your tendency to adopt/abandon it for safety? why?

13. Based on our survey results, among the following list, safety inspection, safety training, and safety planning are the top three phases that can potentially benefit more from applying safety technologies. Do you agree with this? Why?
    - Safety Inspection
    - Safety communication
    - Safety planning
    - Safety monitoring
    - Safety planning
    - Physical improvement

14. How does applying innovative technologies benefit safety in your company?

15. What would you suggest to overcome the current barriers against safety tech application?

16. What challenges have you experienced when training people to apply a new safety tech? what do you do when your people are in broad phases of knowledge and experience?

17. Do you have an incentive program to promote the application of a new tech? Do you believe that such a system is effective?

18. Does applying new safety technologies conflict with your current organizational policies and approaches? If so, how?

19. What would you recommend to researchers and technology developers if you were asked to advice on improving safety technologies to meet demands in construction?