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International Journal of Occupational and Environmental Safety

IoT-based safety monitoring from the perspective of construction site workers

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Abstract

Occupational safety and health is traditionally a challenging area in the labor-intensive construction industry as accidents at work and non-ergonomic work conditions lead to absences and premature retirement of construction workers. Recently, the rise of the Internet of Things (IoT) and its accompanying technologies (e.g. wearable technologies) has enhanced interest in the occupational safety and health of construction work. The level of technology acceptance among construction workers is a crucial element in the adoption of these technologies. The main objectives of this study are to enhance understanding about construction workers' attitudes towards IoT-based data-intensive work safety and wellbeing solutions and to identify factors that can promote technology adoption. Data for the study was collected through an online survey of 4385 construction workers. Based on the survey data it seems that construction workers would accept the sharing and utilizing data collected from them in the worksite environment if it could help identify employee personal health risks or promote personal and colleagues' occupational safety. Respondents were most concerned about privacy and security regarding wearables in the workplace. It can be concluded that user acceptance and trust building are key components in the adoption of IoT-based occupational safety and health solutions. Future studies should investigate methods for actively involving construction workers in the design and development process of IoT-based work safety solutions and examine technological solutions that promote trust building among construction workers.

1. INTRODUCTION

The construction industry is a challenging domain from the perspective of occupational health and safety. In addition to non-fatal and fatal accidents at the construction work site (Winge & Albrechtsen, 2018) musculoskeletal disorders are decreasing workers' ability to work effectively (Wang et al., 2017). The adoption of complex ergonomic solutions at construction sites is not simple and requires time and the involvement of a wide range of different stakeholders (Dale et al., 2017). Safety and wellbeing at work is a global priority. In addition to construction industry companies, public and governmental organizations are also working to promote better safety and health in the construction industry. For example, the International Labour Organization (ILO) and numerous country-specific occupational safety and health-related organizations are contributing to developing construction work safety and health as well as investing in related research.

Digitalization presents great opportunities for the development of the construction industry.

Building information modelling (BIM), wireless sensing, and data analytics have the potential to transform construction processes (Renz et al., 2016). Moreover, adopting new technologies has many economic benefits for the construction industry including the enhancement of safety (Oesterreich & Teuteberg, 2015). Even though several studies have shown the potential benefits of new technologies for safety and productivity in the construction industry (Zhou et al., 2015; Cheng & Teizer, 2013; Goodrum et al., 2009; Li & Becerik-Gerber, 2011; Zhai et al., 2009), the industry is known for being conservative and slow to adopt new technologies (Sepasgozar & Davis, 2019; Sardroud, 2012).

The rise of the Internet of Things (IoT) and its accompanying technologies has increased interest in the construction industry, where benefits can be gained by either adding intelligence to buildings to boost, for example, energy efficiency (Bashir & Gill, 2017), or providing new services with smart building technologies (Zhang et al., 2016). The IoT can provide support for real-time decision making for managerial activities and improve the productivity of the construction industry (Maskuriy et al., 2019). As wearable IoT sensors can be carried by humans (and animals), they or their behavior will also become a part of the information flow (Perera et al., 2015). Improving safety with IoT technologies will benefit from using sensors with workers at the construction site and there are some prototypes and many future visions about how IoT sensors could be integrated with protective clothing or helmets (Altho Beyon et al., 2018; Blecha et al., 2018; Edirisinghe, 2019). Although such sensor-integrated safety equipment and clothing could be provided by the employer, continuous monitoring of employee's activities raises many questions and trust between different stakeholders is needed. Resistance to change in the construction industry highlights the need to investigate the underlying factors behind technology adoption also from the perspective of construction site workers.

Although studies investigating human aspects as part of technology acceptance in the construction industry are rare (Edirisinghe, 2019), some studies have been conducted investigating technology adoption and factors affecting user acceptance of new technologies in the context of construction site safety and health. Some of these earlier studies have presented empirical models affecting user acceptance of new technologies, focusing, for example, on mobile computing devices (Son et al., 2012), scanner technologies (Sepasgozar et al., 2017) and building information modeling (Acquah et al., 2018; Son et al., 2015). In addition, some previous studies have examined customers' intentions to adopt wearable technologies (Yang et al., 2016) and employee acceptance of wearables in workplaces (Jacobs et al. 2019). Although there are many technology adoption and user acceptance related studies, research on employees' perceptions of emerging IoT technologies in the construction industry has remained limited. Particularly, studies focusing on construction workers' perceptions concerning the use of measured personal data for promoting safety and wellbeing in the construction site environment are lacking.

The main objectives of this study were to enhance understanding about construction worker's attitudes towards IoT-based data-intensive work safety and wellbeing solutions and to identify factors that can promote technology adoption. This work contributes to the design of IoT-based work safety and wellbeing services that will meet the needs of employees and improve acceptance of these services among employees. The main research questions of this study are:

- How do construction workers perceive the application of IoT-based safety and wellbeing solutions at the construction site?

More detailed sub research questions (SRQs) that aim to answer underlying elements of the main research question are:

- SRQ1: How willing are construction workers to use wearable devices in a construction work context?
- SRQ2: Does work experience affect willingness to use wearable devices at work?
- SRQ3: Does previous usage experience of wearable devices affect willingness to use wearable devices in a work context?
- SRQ4: How willing are construction workers to share their personal data in a work context for promoting safety and wellbeing?
- SRQ5: How concerned are construction workers about the use of data and related devices in a work context?

2. LITERATURE REVIEW

The IoT allows things and sensors to be connected to the internet in real time providing information flow that enables vast amounts of applications and services. In the construction industry a lot of attention has been paid to monitoring the construction site itself, while safety has remained relatively less addressed (Mehata et al., 2019). Wearables and other sensor networks have, however, been introduced to monitor potential safety and health hazards (Mehata et al., 2019; Park et al., 2019). Despite a degree of resistance to adopting new IoT technologies at construction sites due to perceived uselessness and privacy risks among workers (Choi et al., 2017), the development is strong with many solutions and pilots focusing on monitoring fatigue (Aryal et al., 2017), monitoring work ergonomics and postures (Nath et al., 2017), tracking workers' physical demands (Hwang & Lee, 2017), implementing activity recognition (Joshua & Varghese, 2014), and monitoring workers' heart rate and temperature (Mehata et al., 2019). Numerous types of sensors have been used for detecting various construction site hazards from workers, the main types being accelerometer, gyroscope, ECG/EKG, infrared and RFID sensors (Awolusi et al., 2018). In addition to measuring hazards based on the qualities of the individual worker, also the surrounding conditions are being tracked by, for example, collision detection with proximity sensors (utilizing Bluetooth Low Energy) (Cho et al., 2017), detecting unsafe construction site locations with GPS (He & Peansupap, 2018), and collision prevention with RF transceivers and ultrasounds sensors (Kanan et al., 2018). Taken together, recent advances in the IoT and data analysis are enabling the procurement and integration of various personal and workplace data not previously available, and the provision of (personalized) services to improve the work productivity, safety and wellbeing of construction site workers.

Trust has been shown to significantly affect technology adoption. Technological trust can be defined as the belief that a given technology can support the individual in achieving their goals in situations where they may be exposed to uncertainty and vulnerability (Lee & See 2004, Mayer et al., 1995). In general, the formation of trust is based on an assessment of ability, integrity and benevolence (Mayer et al., 1995). However, trust formation is complex and influenced by a multitude of factors. In the context of IoT adoption, AlHogail (2018) has defined a trust model wherein trust can be assessed through three dimensions of variables: product, social influence, and security. Product (e.g. safety monitoring system) related factors include product functionality and reliability, helpfulness, ease of use, and user's perceptions of usefulness. Social influence related factors include social influence and community interest. Security-related factors include product security and user's perceptions of risks.

A user's decision to adopt a certain technology can critically depend on the level of trust the user has in the technology (Tams et al., 2018). In general, IoT-based solutions comprise different types of interconnected devices collecting and processing (personal) data. Adoption of IoT-based solutions can be hindered by security and privacy concerns especially regarding anonymity, confidentiality and the integrity of the user's personal data (Roman et al., 2013). Therefore, IoT-based solutions are always associated with uncertainty and vulnerability.

In addition to the abovementioned factors affecting trust, personal characteristics, such as gender, age and personality, and culture (i.e. social influence) can affect technology adoption (Rupp et al., 2018). For example, older adults may avoid new technologies because of a lack of experience and competence and women tend to have more negative attitudes towards technological innovations (Röcker et al., 2014). Moreover, personality traits can also influence technology acceptance and adoption (e.g., Svendsen et al., 2013; Rupp et al., 2018); for instance, people with a more tolerant and cooperative nature tend to more readily accept new technologies.

Self-tracking of daily activities, sleep, stress and different types of health-related measures has become more popular among the general public despite the challenges of data interpretation and privacy concerns (Choe et al., 2014). According to Choe et al. (2014), people are more committed to self-tracking when the self-tracking tool provides meaningful and easy-to-understand information and real-time feedback. One study that investigated the sharing of behavioral and personal health data showed that people are still unwilling to share their data; however, they are more willing to share their personal data if the goal of sharing is either to improve their own wellbeing or to benefit society in general (Vilaza & Bardram, 2019). Moreover, sharing physiological data was seen as less concerning than sharing psychological data because of concerns about social discrimination (i.e., stigma related to mental health problems). Thus, willingness to share personal data is always linked with trust.

Very few studies have focused on investigating IoT technologies and, more specifically, wearable technologies from the perspective of the construction worker. A previous study of Choi et al. (2017) suggested that construction professionals' intention to adopt wearable technologies is especially linked with perceived usefulness, social influence and perceived privacy risk. According to the study of Callejas-Sandoval and Kwon (2019), perceived risk, cost, trust, and lack of knowledge are the most important factors affecting the acceptance of wearable technologies by the aging construction workforce. Based on an online survey of 1,273 employed adults, Jacobs et al. (2019) suggest that the use of wearable devices at work should be primarily aimed at improving safety in construction, and trust must be engendered with employees by clearly informing them about the use of their data.

3. MATERIALS AND METHODS

An anonymous online questionnaire was used to collect data on construction workers' views regarding IoT-based work safety and wellbeing solutions at the construction site. The online questionnaire made it possible to reach a large amount of potential respondents from the construction domain. The online questionnaire "Use of data for work safety in construction", mainly consisting of 5-point Likert scale questions, focused on construction workers' perceptions relating to wearables and personal data in the work safety and wellbeing context. In addition, the open-ended question at the end of the questionnaire complemented the quantitative Likert scale data.

The researchers designed the online questionnaire to focus on wearables and personal data in construction. In addition to discussions with construction domain experts, earlier research was used as background information in the questionnaire design. The questionnaire covered wearables and data related topics. Table 1 presents the questionnaire questions that were used in the data analysis of this study. An invitation to the questionnaire was sent to 37,066 members of the Finnish construction trade union. These members were actively involved in working life and practical construction site work. To ensure anonymity no personal data were collected. In total, 4,385 members representing different areas of construction responded to the questionnaire during June 2019 and the response rate of the questionnaire was 11.8%. Most of the respondents were involved in building construction work.

The collected data provided a starting point for quantitative and qualitative data analysis for identifying the attitudes of construction workers towards the use of wearables and related safety and wellbeing data. Different methods were utilized in the data analysis. The SPSS Statistics tool was used for analyzing the collected quantitative data. The following Table 1 presents data that was utilized in the quantitative data analysis. SPSS was used to calculate descriptive statistics and identify relationships between variables.

Table 1. Data for the analysis of the study.

#	Data item	Question type
1	Work experience	Single selection
2	Earlier usage	Polar (Yes/No)
3	Willingness to use personal measurement devices in a work context	5-point Likert Scale
4.1	Willingness to share data for identification of personal health risks and wellbeing at work	5-point Likert Scale
4.2	Willingness to share data for personal and colleagues' work safety	5-point Likert Scale
4.3	Willingness to share data for workflow support	5-point Likert Scale
5.1	Employer, boss, or colleagues could use collected data against me	5-point Likert Scale
5.2	Employer could get private or sensitive information about me	5-point Likert Scale
5.3	Someone external could get access to my data	5-point Likert Scale
5.4	Data-related solutions could disturb my working	5-point Likert Scale
6	Textual feedback	Open-ended

Cross tabulation and Spearman's correlation analysis were used to examine relationships within the survey data. The cross tabulation was used to identify relationships between willingness to use data-related solutions (row 3), work experience (row 1), and earlier usage experience (row 2). Spearman's correlation analysis focused on analysis of relationship between willingness to share data (rows 4.1-4.3) and concerns (rows 5.1-5.4).

In addition to analysis of the quantitative survey response data, the NVivo qualitative data analysis tool was used to analyze responses to the open-ended question (row 6). The analysis was a three-step process. First, data was imported to the tool and open-ended responses potentially relevant to this study were identified from all of the collected qualitative data. Second, common themes were identified based on the collected and relevant data. Third, data was coded to identify theme-specific categories and the number of references in each category was calculated.

4. RESULTS

In order to answer to the first sub-research question (SRQ1) regarding workers' willingness to use wearable devices in a work context, respondents were asked how interested they would be in using activity wristbands, a mobile phone or another device for monitoring their movement or physical activities during the workday. In total, 4,385 respondents selected a single option from the 5-point Likert scale question, in which options ranged from very little interested (1) to very interested (5). About half of the respondents (49.7%) were very (18.2%) or rather interested (31.5%) in using the above-mentioned devices during their workday. In contrast, 27.4% of respondents were less interested in using the devices during their workday: interest was rather low in 12.6% and very low in 14.8% of respondents, respectively. In total, 18.7% of responses were neutral and 4.2% of respondents selected the "Don't know" option. The mean (M) of responses in a scale ranging from 1 to 5 was 3.27 with a standard deviation (SD) of 1.33 and the median of all responses was 4. The following Figure 1 illustrates the respondents' willingness to use personal measurement devices in a construction work context.

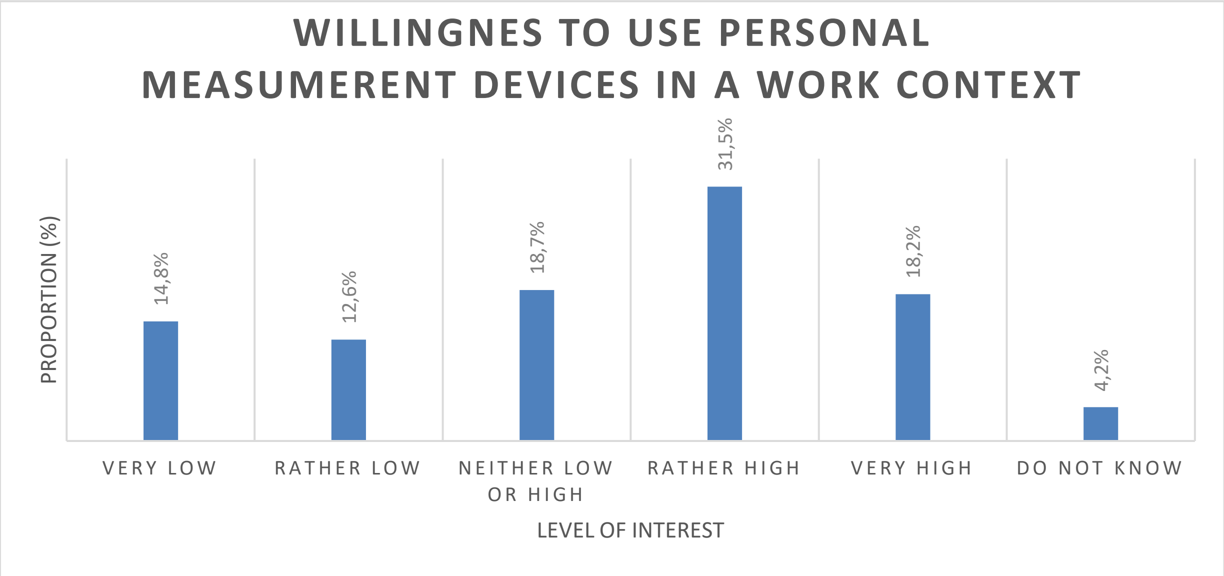

Figure 1. Interest levels regarding the use of self-monitoring devices in a work context.

The second sub-research question of the study (SRQ2) focuses on the possible effects of work experience on willingness to use wearable devices in a work context. To compare interest in using wearable devices in a work context between different work experience groups, respondents were asked in the survey about their work experience. Based on the responses regarding length of work career, two work experience groups were created; workers with under 20 years' work experience and workers with 20 years or longer work experience. In total, 184 (4.2%) "Don't know" responses were excluded from the analysis, resulting in a sample size of 4,201.

According to the survey data, workers with less than 20 years of work experience (*N* = 2275, *M* = 3.46, *SD* = 1.30, *Median* = 4) were more interested in using wearable devices at work than workers with 20 years or longer work experience (*N* = 1926, *M* = 3.04, *SD* = 1.33, *Median* = 3). Figure 2 illustrates the survey response distribution across 5-point Likert scale based interest levels between these two work experience groups. When comparing the distribution of responses between these two groups, the graphs show that the responses of less experienced workers are more represented on the "positive" side with "Very high" and "Rather high" interest levels and more experienced workers are more represented on the "negative" side with "Rather low" and "Very low" interest levels. In total, 58.6% of less experienced workers' responses were in the "Very high" (23.8%) and "Rather high" (34.8%) interest level categories. More experienced workers' interest in using wearable devices at work was lower, with 43.9% of their responses falling into the "Very high" (13.3%) and "Rather high" (30.6%) interest level categories.

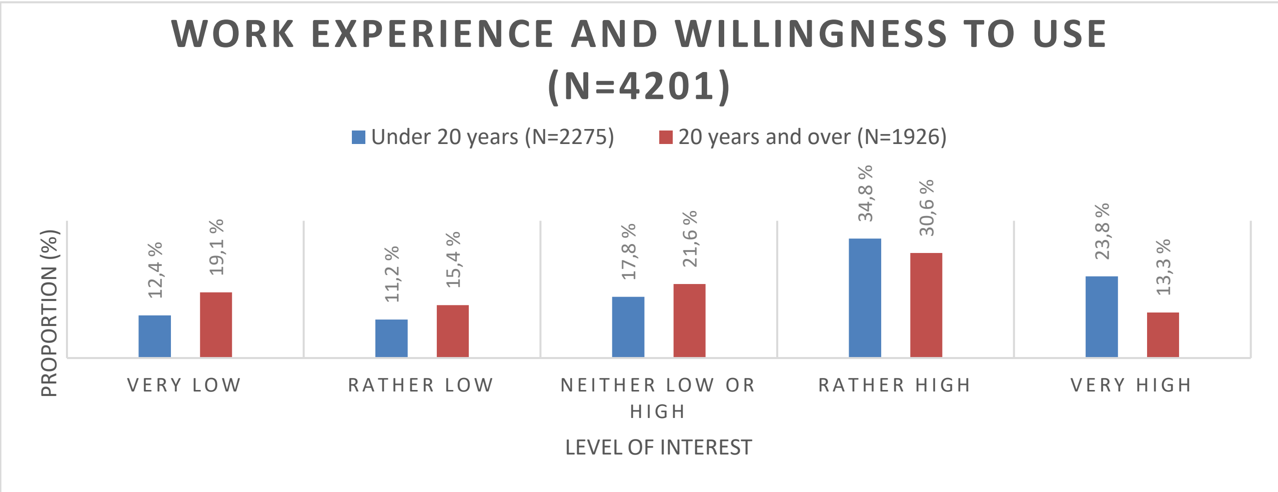

Figure 2. Interest levels regarding the use of self-monitoring devices during the workday in two work experience groups.

In order to answer the third sub-research question (SRQ3) focusing on the effect of usage experience on willingness to use the wearable devices in a work context, the respondents were divided into two groups — experienced and non-experienced users — based on their previous experience of self-monitoring using a smart phone or other devices. Users in the experienced group were currently using some type of self-monitoring device, and users in the non-experienced group were not using any devices for monitoring their physical activities. "Don't know" responses were also excluded from the analysis related to this research question, resulting in a sample size of 4,201.

According to the collected data it seems that experienced users (*N* = 1642, *M* = 4.0, *SD* = 0.96, *Median* = 4) are more interested in using the wearable devices for monitoring movement or physical activities during the workday than non-experienced users (*N* = 2559, *M* = 2.8, *SD* = 1.32, *Median* = 3). Figure 3 illustrates the response distribution across different interest levels. In total, 77.1% of experienced users' responses were in the "Very high" (33.1%) and "Rather high" (44.0%) interest level category, respectively. Non-experienced users' interest in using wearable devices at work was lower, with 35.8% of non-experienced users' responses falling into the "Very high" (10.0%) and "Rather high" (25.8%) interest level categories, respectively. In addition, non-experienced users were clearly more associated with "Rather low" and "Very low" interest levels than experienced users. In total, only 8% of experienced users reported either "Very low" or "Rather low" interest, compared to 41.7% of non-experienced users.

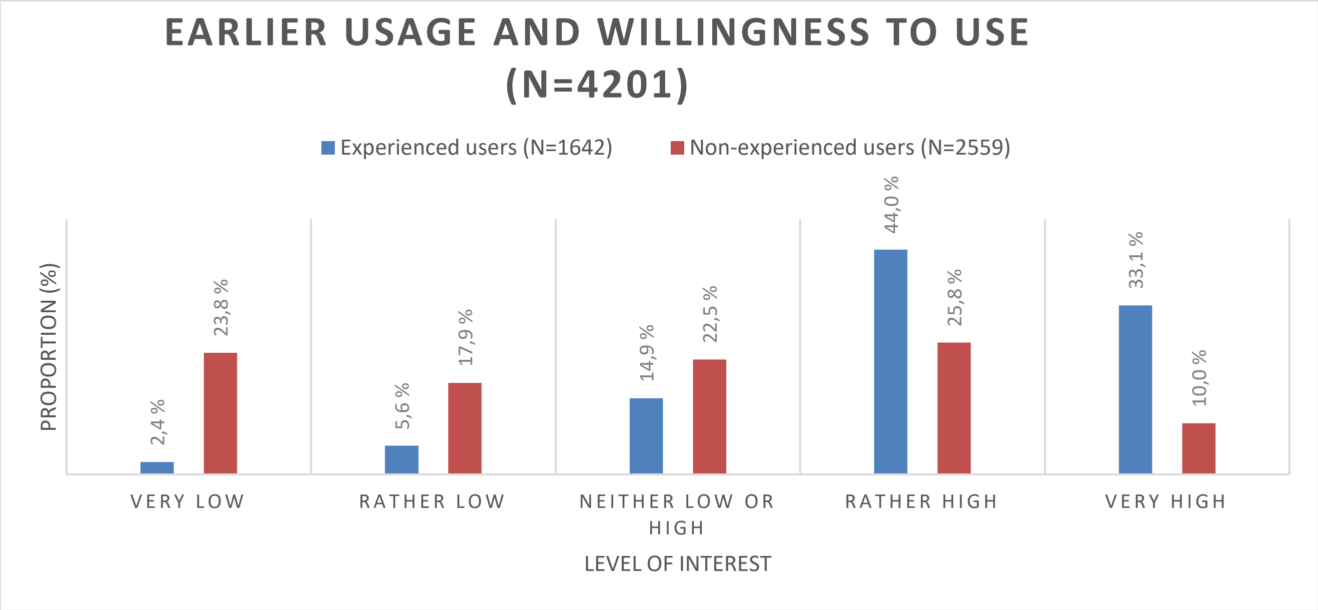

Figure 3. Interest levels regarding the use of self-monitoring devices during the workday in two usage experience groups.

The fourth research question of the study (SRQ4) was designed to identify workers' willingness to share their personal data for promoting safety and wellbeing in a work context. Respondents were asked to indicate on a 5-point Likert scale how willing they were to share physical activity data for three different purposes of use: 1) Sharing data for promoting identification of personal wellbeing and identification of health risks, 2) sharing data for promoting their personal and colleagues' work safety, and 3) sharing data to support workflow. Options on the Likert scale ranged from "totally disagree (1)" to "totally agree (5)".

Table 2 presents how the respondents' willingness to share data varied between three different purposes of use. The collected data shows that the respondents were more willing to share data for promoting identification of personal wellbeing and identification of health risks (M = 4.19, SD = 1.03), and for promoting their personal and colleagues' work safety (M = 4.06, SD = 1.10) than to share data to support workflow (M = 3.55, SD = 1.28). In addition to a lower mean for the workflow question, the standard deviation was also higher for the workflow-related responses. The higher standard deviation indicates that there was less consensus among the respondents regarding sharing their activity data in a work context for supporting workflow than for work safety or personal wellbeing purposes. The median of the responses across all purposes of use was 4.

Table 2. Willingness to share data for three different purposes.

Purpose of use of collected data	N	Mean	Std. Deviation	Median
Identification of personal health risks and wellbeing at work	4264	4.19	1.03	4
Personal and colleagues' work safety	4220	4.06	1.1	4
Workflow support	4205	3.55	1.28	4

The fifth sub-research question of the study (SRQ5) focused on the concerns of employees regarding the use of data and related devices in a work context. Respondents were asked how concerned they would be about four specific potential threats if their physical activities were measured in a work context. Respondents responded on a 5-point Likert scale with options ranging from "Not at all concerned (1)" to "Very concerned (5)". The four pre-defined potential concerns/threats presented in the survey and related statistics based on the survey responses are shown in Table 3.

The first three concerns were privacy and security related and the fourth was a more practical concern related to performing work. According to the collected data, the respondents were most concerned that their personal data could end up in the wrong hands (*M* = 3.39, *SD* = 1.36, *Median* = 3).

Table 3. Respondents' perceptions about data-related concerns in construction work.

Potential data-related concern	N	Mean	Std. Deviation	Median
Employer, boss, or colleagues could use collected data against me.	4154	2.95	1.40	3
Employer could get private or sensitive information about me.	4206	3.09	1.39	3
Someone external could get access to my data.	4202	3.39	1.36	3
Data-related solutions could disturb my working.	4067	2.70	1.28	2

The next most worrying threats according to the respondents were that employers could obtain private or sensitive data about them (M = 3.09, SD = 1.39, *Median* = 3) and that an employer, boss or colleagues could use their data against them (M = 2.95, SD = 1.40, *Median* = 3). The least cause for concern among the respondents was related to the potential interruption of work by the use of data collection related solutions (M = 2.70, SD = 1.28, *Median* = 2).

Respondents also had a possibility to share their thoughts regarding the use of data-based solutions in a work context or give general feedback about the questionnaire. In total, 573 respondents gave widely varying comments to the open-ended question, and 122 feedback comments related to work safety and wellbeing were identified as being relevant to the scope of this research. Privacy-related comments were clearly most highlighted among the responses. In total, 81 comments of the respondents were related in one way or another to data-related privacy and security issues. Respondents especially highlighted that the use of such data-driven solutions can weaken the privacy of the employee and could be used for ulterior purposes. No other issues were given a similar level of attention by the respondents. The second most highlighted topic was related to air quality and dust at the construction site with 13 mentions in the survey responses. The third most mentioned topics were "smart device as a disturbing element in work" and "hurry as a cause of risks", both of which were highlighted in 12 comments. In addition, noise as a risk in the construction site environment was highlighted in five comments.

The relationship between concerns and willingness to share data was also examined. Firstly, a reliability test was conducted based on Cronbach's method. Cronbach's analysis was conducted on the "willingness to share personal data" subscale of the "utilizing data for work safety in construction" survey. This subscale consists of three items, as presented in Table 2. The subscale's alpha level was found to be .83, which indicates that the subscale has an adequate level of inter-item reliability. A Cronbach's analysis was also conducted on the "concerns regarding personal data collection" subscale of the survey. The analyzed four items of this subscale are presented in Table 3. The alpha level of the subscale was found to be .90, indicating that also this subscale has an adequate level of inter-item reliability. It was found that deleting any of the items would not have significantly increased the above-mentioned alpha levels. Secondly, "willingness to share personal data" and "concerns" were determined based on Spearman's correlation analysis. Spearman's correlation coefficient indicated that these two variables were negatively related (r_s = -.339, p < .001). This means that one variable increases as the other decreases, and vice versa. Table 4 presents the results of the Spearman's correlation analysis.

Table 4. Correlation between "willingness to share" and "concerns".

Correlations[b]

			Willingness to share	Concerns
Spearman's rho	Willingness to share	Correlation Coefficient	1.000	-.339**
		Sig. (2-tailed)	.	.000
	Concerns	Correlation Coefficient	-.339**	1.000
		Sig. (2-tailed)	.000	.

**. Correlation is significant at the 0.01 level (2-tailed).

b. Listwise N = 3796

5. DISCUSSION

The results of the online survey showed that a relatively large proportion of construction workers would be willing to use wearables for monitoring their movement or physical activities during the workday. According to the survey data, more experienced construction professionals seem slightly less interested in using wearables in a work context than younger workers. This may partly result from the fact that younger generations are used to using different types of smart devices as part of their daily routines from an early age. On the other hand, older people may not want to be dependent on technology and lose their autonomy (Röcker et al., 2014). Earlier experience of using wearables also seems to positively affect willingness to use wearables in a work context. This is consistent with what has been found in the previous study of Callejas-Sandoval and Kwon (2019), which highlights lack of knowledge as one of the key elements to acceptance among older construction workers.

Based on the survey data, the respondents were most positive about sharing and utilizing the data collected from them in a worksite environment when it could help to identify an employee's personal health risks or to promote personal and colleagues' occupational safety. This finding is also congruent with the results of Vilaza and Bardram (2019), which indicated that people are more willing to share their personal health data when it supports their own or their society's health. Employees were more reluctant to share their data for supporting workflow. Jacobs et al. (2019) suggested that the use of wearable data collection technologies in the work context should be aimed at improving workplace safety in order to achieve user acceptance and realize the potential benefits of wearable technologies. Our findings show that employees' willingness to share their personal data is linked with safety improvements.

Respondents were most concerned about privacy and security regarding wearables in the workplace. Privacy concerns were highlighted in both the Likert scale and open-ended survey responses. Over a quarter of the respondents were very concerned that the measured data could be accessed by external parties who are not entitled to see the data. Some respondents also expressed concern about the disclosure of private or sensitive information to employers. The responses to the open-ended question strengthened these findings. Some respondents felt that measuring employees in the workplace can lead to more effective monitoring of workers, which is not primarily aimed at improving occupational safety and health. Privacy and trust are essential elements when promoting the use of wearables at the construction site, as indicated by previous studies (Jacobs et al., 2019; Callejas-Sandoval & Kwon, 2019; Choi et al., 2017). The results of the survey also showed a negative association between concerns and willingness to share work-related personal data. Overall, based on the results of the survey, employees are interested in deploying solutions that measure physical activity to improve occupational safety and health. The results of the survey highlight the importance of data security and privacy when designing and developing employee safety solutions based on wearable technologies, which is also supported by findings from previous research.

When designing new solutions and services for the construction industry domain based on wearable technologies, the relation between end-user acceptance, legislation and regulations, as well as economic benefits should be always considered. The construction industry is looking for ways to improve its productivity (Renz et al. 2016). If IoT infrastructures are utilized for work safety, it would be economically reasonable to use them for other purposes as well. Once construction site workers become accustomed to using wearable technologies for safety reasons, this opens an opportunity to exploit the same data for improving productivity as well, for example in terms of workflow.

It is evident that when an employer begins to measure or monitor its employees with wearable devices, trust in the employer's intentions and acceptance of the used technology are needed from the employee's perspective. When using wearables to improve safety, their acceptance is quite easy to gain, as our findings show, but the formation of trust can be more difficult. Privacy issues are strongly guided by the General Data Protection Regulation (GDPR) that came into force in 2018 across the European Union. Overall, the GDPR governs the rights of EU citizens to data protection and the confidentiality of their personal data processing. However, it does not automatically generate trust. The GDPR also aims at harmonizing fragmented data protection practices across EU countries. As the use of IoT technologies is growing, GDPR standards require further investigation and specifications regarding the design and implementation of IoT technologies in order to minimize conflicts between GDPR and deployment of IoT-enabled solutions (Wachter, 2018).

Technology providers can increase trust by designing data pipelines and distributed system architectures where privacy-sensitive data is anonymized and analyzed as close to the wearable (user) as possible thus reducing the traffic to the cloud (Shi & Dustdar, 2016). The data identifying the worker can be even removed because the raw data can be processed in wearable and edge computing platforms before sending the aggregated and anonymized data to company processes. Naturally, there is a trade-off between anonymity and personal identification. However, personal identification is needed, for example, in alarm systems that warn individuals about hazardous situations.

Transparency of the data can also increase trust. The parties contributing data should be able to see the data aggregated from them and how it is being used. This is an obligation of the GDPR, but, furthermore, user interfaces should be easy to use and everybody should be able to understand the interpretations and usage of the data (Vilaza & Bardram, 2019; Choe et al., 2014). Nowadays, data is often interpreted by artificial intelligence (AI), which can cause confusion among people as decision making based on AI is not open, and the logic behind it does not comply with human decision making. Explainable AI (Hagras, 2018) can provide tools to address this problem and increase the transparency and understanding of the process, from the concrete physical action of the worker to aggregated interpretation of AI. For the formation of trust, we should also consider solutions to situations where data analytics and the conclusions derived from it are not correct or fair.

In general, user acceptance among workers could be promoted by involving them actively in the design and development of construction IoT applications. Approaches highlighting end-user involvement have been successfully applied to tackle user acceptance related challenges in many different areas. According to Harris and Weistroffer (2009), involving the end user in the information system development process is crucial for achieving user satisfaction and overall system acceptance. Similarly, active involvement of end users in the design and development of IoT applications provides potential benefits for IoT solutions (Russo & Gkouskos, 2019). User-centric approaches traditionally used in software engineering can also be applied in the design and development of IoT solutions. For example, user-centered design (UCD) (Abras et al., 2004), user experience (UX) design (Law et al., 2008) and participatory design (Muller, 2007) methods provide a set of tools that can be applied in different types of design and development projects. What these methods have in common is that they all approach the design and development of the system primarily from the end-user perspective. Involving users by applying these methods in construction IoT development initiatives could essentially promote trust and user acceptance among construction workers and generally improve technology adoption and implementation in the construction industry. Application of user-centric methods calls for the specific characteristics of the construction industry to be taken into account to achieve a successful outcome. For example, long subcontracting chains, construction site employee turnover, and workers' cultural background must be taken into account when it comes to involving workers in the design and development of IoT-based solutions in the construction environment.

A key limitation of this study is related to the sample of the study. The survey was conducted in Finland, where much attention is paid to occupational safety and health. In addition, there are differences, for example, in the information security behavior of employees (Connolly et al., 2019) and people's privacy-related behavior (Li et al., 2017) between different countries. This limits the generalization of the results and implies that confirmation of the results is needed. Further research covering a wide range of construction workers from different countries could reveal country- and culture-specific differences in workers' attitudes towards IoT-based safety systems.

6. CONCLUSIONS

This work investigated the perceptions of construction site workers towards deploying IoT technology in a work safety context. The findings show that construction workers are interested in using wearables and willing to share their data if the data is used for work safety and wellbeing purposes. Identified security and privacy related concerns among the workers highlighted the importance of trust in IoT-based data-intensive work safety and wellbeing solutions. Anonymization of data perceived as sensitive by workers is a crucial element in trust building regarding the use of wearable technologies in the work context. The results of the study also revealed the importance of data transparency for promoting user acceptance among workers. In this context, data transparency especially means providing an easy way for individual workers to get an understandable view of the data aggregated from them and how it is being used.

Extensive user acceptance and building trust are prerequisites for the successful implementation and deployment of occupational safety and health applications based on sensors and personal data. Although there is willingness to adopt novel wearable technologies among construction workers, especially for improving safety and wellbeing at work, there are also some barriers, such as privacy issues, that must be tackled in order to achieve the acceptance of construction workers. IoT-based technology solutions must be designed so that they support trust building among workers. In addition to technically ensuring security and privacy issues, it must be carefully specified how data on improving occupational safety can be used within the organization. These issues should also be communicated clearly and openly to all groups involved in the data collection and analysis within the occupational safety solution in order to build trust in the use of the solution. Involving construction workers actively in the design and development process of IoT applications can be seen as one of the key factors to promote technology adoption in the construction industry. In addition, data transparency must be guaranteed so that workers have access to the data derived from them and the possibility to easily utilize the data.

In future work, investigating the use of user-centered methods in the construction IoT might prove important. In addition, a deeper investigation of technological solutions that promote trust building among construction workers is needed in order to guarantee wider user acceptance. Research focusing on utilizing anonymized and aggregated data is needed to open the discussion of the benefits of wearables in industrial contexts. Another avenue of future research is to investigate the wider potential benefits of IoT-based safety solutions to society. Societal and economic benefits require wider knowledge sharing and dissemination of research results between stakeholders to establish common understanding and approval of wearable technologies in the construction industry.

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