Women in the Construction Industry: Can Assistive Robotic Technologies Help to Close Employment and Pay Gaps?

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Abstract: This study explores the potential of wearable sensing and assistive robot technologies to reduce gender gaps in employment and wages in the construction industry. Our regression estimates from U.S. microdata indicate that being a woman and having strength and mobility impairments are both associated with a substantial employment and pay gap in the construction industry compared to non-construction jobs. Further analysis of the critical skills required in detailed occupations within construction shows a high negative correlation between the representation of women and the ability levels required in those occupations. The paper discusses several robotic assistive technologies under development for people with upper-body and lower-body impairments, focusing on how these innovations could be integrated into construction jobs. We conclude that wearable assistive robots can enhance physical activities by reducing strain and increasing strength and help to close these employment and pay gaps in construction.

Keywords: Robotics, Artificial Intelligence, Gender, Construction, Workplace Safety, Future of Work

JEL Codes: J1, J2, L7, O3

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Introduction

In recent decades, women have increased their representation in many non-traditional, previously male-dominated occupations, such as automobile mechanics, police, firefighting, and airplane pilots (Zula 2014). Nevertheless, women's share of construction trade jobs has remained stubbornly low, rising only from 2.5% to 4.2% in the U.S. over the past two decades (BLS 2024a). Major barriers to women's entry and retention in construction jobs include harassment, discrimination, feelings of isolation on the job, inadequate jobsite sanitation, low participation in apprenticeship programs, and insufficient access to leadership positions in the industry (Berik and Bilginsoy 2006; Eisenberg 2018; Paap 2006; Tapia et al. 2020). The entrenched reputation of construction as a "macho" industry further discourages women from entering and remaining in the construction trades (Hanna et al. 2020). Gendered words such as "craftsman," "foreman," and "chain boy" perpetuate the poor image of construction as a man's world, and recruitment practices that emphasize above-average upper-body strength requirements further discourage women from applying for construction jobs (Fielden et al. 2000). Women's representation is low in construction compared to other industries, and construction exhibits one of the highest levels of occupational segregation among all industries (Graham and Hotchkiss 2003).

The U.S. construction industry can ill afford to have these barriers to entry and retention facing women workers. The industry has faced chronic shortages of skilled workers since the 1980s, and these shortages are projected to continue in the coming decade (Chini et al. 1999; Kim et al. 2020). The main reasons for this labour shortage include high workplace injuries, high turnover, and early retirement. Construction workers exert intense physical effort, and they experience serious safety and health risks in hazardous, dynamic working environments. As a result, construction ranks among the highest-risk industries in the US, accounting for 20% of all workplace fatalities reported in 2019 (BLS 2020; Mridha and Khan 2023). A substantial proportion of retirements from construction are not due to old age but rather work-related injuries and disabilities. Between 2007 and 2011, the construction industry lost nearly 2 million workers, and in 2018, 80% of construction firms had trouble hiring skilled craft workers (Hearns 2019). Low motivation among young adults to enter and problems attracting and retaining women workers are key factors contributing to the persistent labour shortage (BLS 2020; Chini et al. 1999; Kim et al. 2020).

A potential solution to address both the labour shortage and the underrepresentation of women in construction is to leverage emerging robotic technology using wearable assistive robots – often referred to as wearable exoskeletons or exosuits – which are designed to support physical activities by reducing strain and increasing strength through mechanical interaction with the body (De Looze et al. 2016). To the extent that the obstacles that women face are physical in nature, their participation in construction may be improved through the use of such technologies. To date, most studies on workplace automation and robotics have centred on the displacement of human workers by machines, particularly in manufacturing jobs. In the construction industry, the adoption of new technology has been similarly associated with a decline in employment, largely because robots tend to be more productive than humans in tasks such as welding and bricklaying (Acemoglu and Restrepo 2020). However, less is known about the economic benefits of human-robot collaboration. While robotic technology can replace humans in conducting certain job functions, it can also assist or enhance worker productivity (Acemoglu and Restrepo 2018, 2019; Autor 2015; Ernst et al. 2019). Besides augmenting worker efforts, wearable robots such as exoskeletons can also protect workers from injuries and musculoskeletal disorders.

Most studies in this area of research treat new technologies as exogenous and assume that workers are passive users or adopters of these innovations. However, this assumption has been increasingly challenged by researchers who suggest that new technologies can create new job tasks and functions that give labour a comparative advantage over capital (Acemoglu and Restrepo 2018b). These complementarities have the potential to increase productivity, boost earnings, and stimulate greater demand for labour (Autor 2015). More research is needed on the augmentation effect of new technology and the collaboration between humans and robotics, given the strong complementarities between automation and labour.

To date, the jury is out regarding the impact of new technologies on women workers in occupations dominated by men. Some studies have found that new technologies help to lower the gender gap in labour force participation and earnings in a wide range of industries (Anelli et al. 2019; Juhn et al. 2014). However, others have shown that women are at a substantially higher risk of job displacement by new technologies than men (Brussevich et al. 2019). Women's jobs are more vulnerable to automation as women tend to be engaged in more routine work across all occupations than men (Brussevich et al. 2019). There is also mixed evidence on the gender pay gap. While Ge and Zhou (2020) find that an increase in robotics reduces the overall wage gap (because men's wages fall more than women's wages), Aksoy et al. (2021) find that the adoption of robotic technologies exacerbates the gender pay gap in skilled occupations in which women are underrepresented. However, less is known about wearable devices and their gendered effects.

We aim to fill this knowledge gap by exploring the potential of wearable robot technologies to reduce gender disparities in employment and wages in the construction industry. To achieve this goal, we first use worker-level data from the U.S. Survey of Income and Program Participation (SIPP) to estimate employment and wage differences by gender and by mobility and strength impairments. We also compare these gender and mobility/strength gaps between construction and non-construction jobs. Next, we compile occupational-level data in the construction industry by merging the O*NET data from the Bureau of Labor Statistics (BLS) with public-use microdata from the American Community Survey (ACS). This enables us to examine variations in employment composition, physical skill requirements, and earnings across detailed construction occupations. By identifying women's participation in construction and the specific physical demands required, we can provide insights into how wearable technology may help alleviate some of the key barriers that individuals with different abilities face in entering and remaining in construction jobs. Finally, we discuss several robotic assistive technologies under development for people with upper-body and lower-body impairments, focusing on how these innovations could be integrated into construction jobs. This research contributes to the growing literature on technology and work by focusing on how human-robot collaboration may impact gender gaps in employment and pay – a crucial but neglected policy issue that has implications for labour market equity and inclusion. The study also contributes new knowledge on the extent to which occupational ability requirements related to strength and mobility serve as an obstacle to women's entry into the construction industry.

Literature review

Background: women in construction

Because of the large number of construction jobs in the U.S. economy, more women are employed in the construction trades compared to other occupations, such as educational counsellors, social workers, librarians, pharmacists, veterinarians, and dental hygienists (BLS 2024a). Between 2021 and 2022, the number of women working in construction trades increased by 12.6%, rising to almost half a million (353,934) (BLS 2024a). Yet the percentage of all construction occupations held by women has remained stubbornly low, staying below 5% for the past twenty years (Figure 1). Compared to many female-dominated jobs (such as home health aides, maids, housekeepers, and childcare workers), construction trades provide well-paid jobs that do not require a college degree. Construction jobs thus provide an important pathway for low-income women workers to improve their economic security and independence.

[FIGURE 1 HERE]

Within construction, women's representation in production-oriented occupations is especially low (less than 20% of all jobs), while their representation is much higher in clerical and support positions (45.8%) (CPWR 2018). Women face numerous barriers to entering and remaining in construction, including harassment, biased recruitment practices, incompatibility with caregiving responsibilities, male-dominated training courses, the industry's poor image as being male-centric, limited knowledge about career opportunities, and a lack of supportive networks (Amaratunga et al. 2006; Worrall 2012; Navarro-Astor et al. 2017). In addition, the obstacles that women face in many of the production occupations in construction include safety and health hazards as well as strength requirements (Eisenberg 2018; Paap 2006; Blanchflower and Wainwright 2005; Morello et al. 2018). The construction industry is notoriously dangerous, as it accounts for nearly one in five workplace fatalities; more than one-third of these deaths are caused by falls, slips, and trips (BLS 2021). Moreover, musculoskeletal disorders are prevalent among construction workers who frequently suffer from overexertion and repetitive motions. Musculoskeletal disorders encompass a range of injuries to the muscles, tendons, joints, and nerves, including sprains, strains, nerve compression, and herniated discs (CPWR 2024). Moreover, a large literature has documented gender differences in physical strength between men and women, including Miller et al.'s (1993) seminal study showing that women have approximately 52% the upper body strength of men and 66% the lower body strength of men. Given that some of the obstacles that women face in construction are physical in nature, the use of robotic assistive technologies may offer a viable solution to increase their participation.

Wearable robot technologies in construction

The construction industry is widely recognized as a high-risk sector due to the high incidence of work-related injuries and fatalities. It accounts for nearly one in five workplace fatalities, with more than one-third of these deaths caused by falls, slips, and trips (BLS 2021). Moreover, musculoskeletal disorders (MSDs) are particularly prevalent, resulting primarily from repetitive motions, overexertion, and the physical demands associated with construction tasks. MSDs encompass a range of injuries affecting muscles, tendons, joints, and nerves, including sprains, strains, nerve compression, and herniated discs (CPWR 2024).

Traditionally, safety management in the construction sector has been reactive, focusing on addressing incidents only after they occur. Nevertheless, advancements in wearable technology offer new opportunities to transition towards proactive safety strategies (Wang et al. 2017). These technologies enhance safety by actively monitoring workers' physiological and environmental data in real time, enabling the continuous measurement of key indicators such as heart rate, breathing patterns, and posture. Specifically, wearable robot technologies in construction encompass a variety of systems, including radio-frequency identification, Bluetooth, ultra-wideband, magnetic field sensors, sonar, GPS, and video-based tracking (Awolusi et al. 2018; Okpala et al. 2022). Body sensor networks further integrate sensors such as accelerometers, gyroscopes, magnetometers, and galvanic skin response sensors to monitor workers' movements and physiological states. Devices like electrocardiograms and electromyography sensors provide valuable data on cardiac and muscular health, facilitating the detection of potential risks. Together, these technologies create a comprehensive network capable of improving workplace safety through several key functionalities, including physiological monitoring, environmental sensing, location tracking, and proximity detection.

Although wearable technologies hold significant potential to enhance worker safety and productivity, empirical evidence has primarily emerged from pilot studies. For example, Zhu and Yi (2023) presented an integrated wearable sensing system combined with exoskeleton-enabled fall prevention, and they reported promising results of decreasing unexpected foot slips. Wearable devices also improve situational awareness by tracking environmental conditions and monitoring workers' proximity to hazardous zones (Awolusi et al. 2018). In addition, data-driven insights allow workers and their supervisors to identify early signs of fatigue, stress, or unsafe postures, helping to prevent injuries before they occur.

Despite their potential, the adoption of wearable technologies in construction remains in its early stages. The limited number of documented use cases highlights the importance of further research to evaluate the economic benefits of these technologies and facilitate their adoption in the construction industry.

Adapting Wearable Exoskeletons to Accommodate Women Workers in Construction

Despite the potential benefits of wearable robot technologies for construction tasks, the design of most exoskeletons is primarily based on male physiological and biomechanical data, leaving their applicability and effectiveness for women workers in the construction industry inadequately examined. However, recent research efforts are beginning to address this gap, demonstrating that tailored exoskeleton designs for women are both feasible and beneficial (Lamers et al. 2020; Gutierrez et al. 2024).

Women and men differ in body proportions, including shoulder width, arm length, and torso dimensions (Janssen et al., 2000). Additionally, women adopt different postural adjustments due to their wider pelvis and different centre of gravity. These differences significantly impact the anthropometric fit and functionality of exoskeletons, influencing how body weight and the additional weight of the device are distributed and how the exoskeleton stabilizes the body during use (Barnes et al. 2001). To accommodate these anthropometric differences, researchers suggest incorporating custom and adaptive ergonomic designs to enhance the viability and comfort of wearable robot technologies for female workers.

In construction-related tasks, there are three priorities for having inclusive exoskeleton design include lightweight materials, module-based configurations with flexible joints, and user-friendly interfaces, thereby supporting increased participation and retention of women in the construction industry. First, exoskeleton designs should prioritize lightweight materials and ergonomic engineering to reduce physical strain on users, making the devices more comfortable and effective during prolonged use, particularly for women who may have lower muscle mass and different endurance levels compared to men (Lamers et al. 2020; Gutierrez et al. 2024).

Second, women may adopt distinct postural adjustments and kinematic strategies when using an exoskeleton for construction-related tasks, resulting in unique movement patterns compared to men, which could influence the device's effectiveness (Hudson et al. 2024). Design adaptations should include modular components that can be reconfigured based on individual movement patterns, allowing for personalized support that aligns with each worker's specific needs. Additionally, as women tend to have a greater range of motion in their joints compared to men, wearable exoskeletons should incorporate adaptive joint mechanisms that allow for a wider range of motion without compromising stability (Sood et al. 2007). Third, incorporating user-friendly interfaces and intuitive controls can further improve the accessibility and functionality of exoskeletons for female workers, ensuring that they can easily adjust settings to suit their individual needs and preferences (Gutierrez et al. 2024).

Empirical evidence supports these design adaptations. Lamers et al. (2020) conducted a study with six subjects, including two women and four men. They found that five of the six subjects showed consistent reductions in fatigue rates (ranging from 26% to 87%), while the only subject who did not exhibit significant improvement was a man. These findings suggest that gender-inclusive exoskeleton designs are necessary to ensure a secure and comfortable fit for individuals, especially women, with varying shoulder widths and torso lengths. More importantly, the study demonstrates that wearable exosuits can effectively reduce back muscle fatigue for women, potentially improving endurance in various occupations, including construction.

Data and methodology

The first part of this study uses microdata from SIPP to estimate how gender and physical mobility and strength impediments are associated with employment and wage rates in construction versus non-construction jobs. Following the methods outlined by Kruse et al. (2024), we use the 2014 SIPP, the only wave that contains the Social Security Association Supplement's detailed information about mobility and strength impairments. In particular, the data include nine indicators of difficulty with physical activities (climbing stairs, walking, standing, sitting, kneeling, reaching overhead, lifting, grasping, and pushing/pulling large objects), along with information on employment and earnings as well as demographic indicators such as education, race/ethnicity, and age. After restricting our sample to working-age individuals (18-64), we have a sample of 20,146 individuals, 6,554 of whom are not employed and 13,592 who are employed. The employed individuals are further divided into two categories according to their industry: construction (1,001 observations) and non-construction (12,591).[1]

We applied the SIPP data to a multivariable regression analysis of the determinants of employment and pay in the construction industry. These estimations are performed separately for construction and non-construction jobs. We use linear probability models to predict employment, and we use a Heckman selection model to predict the natural log of hourly earnings. Consistent with Kruse et al. (2024), we adjusted hourly earnings at the top and bottom 1% of the earnings distribution by replacing extreme values with the values at those percentiles. The excluded variables that identify the Heckman equation are family size, number of children under age 18, other household income, and other household income squared. These models yield coefficients that indicate the percentage difference in employment and earnings associated with the key variables of interest, namely gender and mobility/strength impairments. These key indicators are included as binary variables in the separate regressions for construction and non-construction jobs.[2] These regression results provide an upper-bound estimate of the extent to which wearable assistive robots, designed to improve strength, dexterity, and range of motion, could draw more women into construction and increase their pay.

In the second part of the analysis, we merged the BLS O*NET data with public-use microdata from the ACS (2018 to 2022) to examine variations in employment composition, physical abilities, and earnings across jobs within construction. This approach expands upon the first part of our analysis in three ways. First, the ACS data is more recent than the SIPP, providing updated insights into employment and earnings. Second, the larger sample size in the ACS enables a more detailed examination of occupations within construction at the six-digit Standard Occupation Code (SOC) level, compared to the broader comparison of construction versus non-construction jobs in the SIPP data. Third, the O*NET data provides a comprehensive assessment of 52 specific abilities across occupations, categorized into four main groups: cognitive, physical, psychomotor, and sensory abilities (Peterson et al. 2001). Notably, the data on physical abilities encompass nine specific dimensions: stamina, dynamic flexibility, extent flexibility, gross body coordination, gross body equilibrium, dynamic strength, explosive strength, static strength, and trunk strength. Each of these dimensions of ability is measured between 0 and 7, with higher values representing higher levels of physical ability. Take "trunk strength" as an example: "sit up in an office chair" is rated as 2; "shovel snow for half an hour" is rated as 4; and "do 100 sit-ups" is rated as 6. Note that while the numbers reflect a ranked order, they do not imply equal intervals (Handel 2016). Finally, to calculate average annual earnings and percent female in each of the occupations, we adjusted earnings to reflect 2022 dollar values using the ACS earnings adjustment factor and the U.S. Consumer Price Index.

Gender and mobility/strength gaps in construction versus non-construction jobs

Sample statistics from the SIPP data in Table 1 show that while women make up half of all non-construction jobs, they constitute just 8.3% of individuals employed in construction. By contrast, women are over-represented among individuals who are not employed, largely due to their caregiving responsibilities. Also of note, of the nine types of mobility and strength impairments that are tracked in the SIPP data, seven impairments are associated with lower employment shares in construction compared to non-construction jobs. For example, 3.1% of individuals employed in non-construction jobs have difficulty climbing up ten flights of stairs, compared to just 1.6% of people in construction jobs. Only for standing and sitting impairments are the employment shares in construction higher, but the differences are close to zero. Consistent with other data reported by the Census, individuals with any of the impairments listed in Table 1 are more likely to be out of the labour force than employed (BLS 2024b). Also, individuals working in construction have less education, are more likely to be Hispanic, are less likely to be young (ages 18-24) or mature (ages 55-64) and earn less compared to those in non-construction jobs.

[TABLE 1 HERE]

Regression results in Table 2 in the first two columns show the probability change in construction employment (or non-construction employment) relative to the base of no employment, associated with a one-unit change in each indicator variable. Model 1 clearly indicates that being a woman is associated with a substantial employment gap in construction (0.249 lower probability of employment in construction, or 24.9 percentage points, compared to men). None of the other explanatory variables in the employment estimation for construction yield as large a coefficient estimate. Model 2 suggests that the employment gap associated with being a woman is considerably smaller in non-construction jobs, at 7.9 percentage gaps.

[TABLE 2 HERE]

Table 2 further shows that individuals with four different types of mobility/strength impairments experience statistically significant employment gaps in construction compared to individuals without such impairments: difficulty walking, standing, stooping/crouching/kneeling, and pushing/pulling large objects. Three additional impairments are associated with employment gaps only in non-construction jobs: climbing stairs, reaching overhead, and lifting/carrying 10 pounds. Given that these physical activities are quite common in many construction jobs, it is possible that the relatively small sample size for construction jobs could explain the imprecise estimates in the construction employment regression. Other results in the employment regressions are as expected. Individuals with higher education are less likely to be employed in construction compared to people with a high school degree or less, individuals who are Black non-Hispanic, Asian, or multiracial/other are relatively less likely to be employed in construction, and people above the age of 25 are more likely to be in construction compared to young adults ages 18 to 24.

Models 3 and 4 of Table 2 show earnings penalties or premiums associated with each indicator. Being a woman is associated with a 0.356 log point earnings penalty compared to being a man in construction, which is substantially larger than the earnings penalty of 0.231 log points for non-construction jobs. Among the mobility/strength impairments, only difficulty with stooping/crouching/kneeling is associated with a statistically significant earnings penalty in construction jobs. Interestingly, individuals working in construction jobs who have trouble walking earn a premium (0.442 log points), which could potentially be explained as an occupational effect within construction: people who have trouble walking may be more likely to have administrative jobs in construction that pay more. In terms of race and ethnicity, Hispanic and other race individuals experience sizeable pay penalties compared to white non-Hispanic people, and these penalties are similar in magnitude to the penalty experienced by women. The remaining results are intuitive: in construction and non-construction jobs, individuals with higher education enjoy earnings premiums compared to people with high school or less, and those premiums rise with greater educational attainment. In addition, there is a positive earnings gradient that comes with age.

Table 3 reports results for ability requirements, pay, and women's representation across detailed occupations within the construction industry. Women are most likely to be hazardous materials removal workers, inspectors, painters, and paper hangers. Their representation among hazardous materials removal workers is particularly high (double that of the next category) and may be explained by the fact that some jobs within this category, such as asbestos and lead-based paint abatement, do not require the same level of physical strength as other construction-related jobs. Overall, the jobs where women are most highly represented pay less than jobs where men are highly represented, such as elevator installers, derrick and rotary drill operators, mining machine operators, and steel workers. A simple correlation analysis reveals that occupations with higher percentages of women workers have a lower level of income (r=-0.413) and lower ability levels (r=-0.331). The implication is that technologies that enhance women's manual dexterity, balance, and physical strength have the potential to improve their representation in some of the higher-paying occupations with more strenuous physical ability requirements.

[TABLE 3 HERE]

Examples of wearable assistive robots

As demonstrated by the empirical results, physical activity limitations can prevent people from getting or keeping jobs in the construction industry, and they can also contribute to substantial earnings penalties. Researchers across sectors, including academia and private industry, are working on technology that can reduce these limitations. Although robotics technologies have seen increasing use in construction in recent years, most of these technologies focus on robots to help conduct construction tasks. More recent developments with wearable sensors and exoskeletons, machine learning, and virtual-, augmented- and mixed-reality technologies offer promise for improving workers' safety and health (Bär et al. 2021; Okpala et al. 2022). These devices differ from other robotic technologies by providing external support through a rigid or flexible framework targeting specific body parts, such as the lower back or upper extremities. There are two primary types of exoskeletons (Yang et al. 2008): active and passive. Active exoskeletons are powered by actuators such as electric motors, enhancing the strength and endurance of human limbs to ease physically demanding tasks. In contrast, passive exoskeletons do not require external power or actuators and instead use mechanical elements like springs and shock absorbers to support the user. Though passive exoskeletons offer less power, they are lighter, more affordable, and commonly used across industries in recent years.

Research has demonstrated the significant potential of occupational exoskeletons to reduce musculoskeletal injuries and improve worker performance (Zhu et al. 2021). For example, Frost et al. (2009) found that back-assist exoskeletons reduced back muscle activity by 10 to 44% during handling tasks in lab settings. Similarly, Bosché et al. (2016) reported a 24% reduction in hip extensor muscle activity and a 50% reduction in neck muscle strain when using back-assist exoskeletons. Additionally, Chen et al. (2021) found that wearable knee assistive devices decreased knee muscle activation by up to 39% and reduced knee-ground contact pressure by 15% during tasks like kneeling, a common activity in construction work. Zhu and Yi (2023) and Sreenivasan et al. (2024) further reported that knee exoskeletons have shown great potential to mitigate injuries and musculoskeletal disorders for construction workers under awkward gaits and locomotion such as unexpected foot slip and prolonged stance or kneeling, respectively. However, the widespread adoption of exoskeletons remains limited due to the dynamic and varied nature of construction sites, where tasks often require different movements and postures (Kim, Nussbaum, Esfahani, Alemi, Alabdulkarim et al. 2018; Kim, Nussbaum, Esfahani, Alemi, Jia et al. 2018). Moreover, the effectiveness of exoskeletons depends on factors such as the specific task, the user's posture, and the fit of the device (Golabchi et al. 2023).

Ensuring a proper fit for exoskeletons is critical for both safety and usability. Historically, work-related equipment, including personal protective gear, has been designed based on data from male military recruits or industrial workers from the mid-20th century. This design approach often fails to accommodate the diverse body shapes and sizes found in today's workforce, including women and minority groups (Søraa and Fosch-Villaronga 2020). Even "unisex" exoskeletons tend to be designed with male bodies in mind, leading to discomfort for many women. Common issues include bulky breastplates, poorly positioned chest pads, and incorrect proportions that fail to account for the average woman's torso length or hip width. These design flaws can result in awkward postures, increasing the risk of musculoskeletal strain, particularly in the shoulders and back.

In response to these challenges, recent research and commercial developments have focused on making exoskeletons more inclusive and adaptable for diverse users, particularly women. Below, we highlight several promising exoskeleton applications in the construction industry, highlighting both commercially available models and prototypes that have shown solid results in pilot testing and early field studies.

Case 1: HeroWear Apex Back Exosuit

The HeroWear Apex Back Exosuit is a lightweight, passive exosuit designed to reduce strain on the lower back by transferring weight to the hips during lifting and bending tasks. Weighing only 3.4 pounds, it is comfortable for extended use and does not require batteries or electric motors. The exosuit is adjustable with custom fit options to accommodate different body types. Its modular design allows it to be worn with various work attire, ensuring flexibility and adaptability in multiple work environments. Lamers et al. (2018) found that the prototype reduced erector spinae (ES) muscle activity by 23-43% during leaning tasks and 14-16% during lifting tasks. A follow-up study indicated significant reductions in muscle fatigue during leaning tasks (Lamers et al. 2020). Further research by Goršič et al. (2021) observed a 15% decrease in erector spinae electromyogram activity during object lifting and lowering, with participants reporting the exosuit as mildly to moderately helpful. These studies suggest that the HeroWear Apex provides notable ergonomic benefits in reducing muscle strain and preventing fatigue during physically demanding tasks.

Case 2: Hilti EXO Shoulder Exoskeleton

The Hilti EXO Shoulder Exoskeleton is a passive, lightweight exoskeleton designed to reduce fatigue during repetitive or overhead tasks, such as drywall installation, painting, or pipefitting. Weighing only 2.4 kg, the EXO allows workers to move freely while shifting the load from the shoulders to the hips, thus reducing strain on the upper body. This exoskeleton is particularly beneficial in the construction industry, where physical strain from upper-body tasks often limits worker endurance and increases injury risk. Bennett et al. (2023) examined the effect of the Hilti EXO-S on shoulder flexion (raising the arm to the front) and extension (pushing the elbow to the back of the body) and found a reduced 9-95% range of motion (ROM) in the shoulder. They also noted that the device reduced the time required for tasks like pushing/emptying gondolas and installing/removing wooden blocks, though the reduction was small.

Case 3: Ekso EVO

Building on their expertise with rehabilitative exoskeletons, Ekso Bionics developed the Ekso EVO, a lightweight exoskeleton designed to provide upper-body support, particularly for overhead and repetitive tasks. The Ekso EVO reduces strain on the neck, chest, shoulders, and back by offering multiple levels of spring-assisted support without the need for batteries, making it practical for extended use. The predecessor to the EVO, the EksoVest, did not significantly reduce perceived discomfort, but it did decrease shoulder muscle activity by up to 45%, particularly during overhead tasks (Kim, Nussbaum, Esfahani, Alemi, Alabdulkarim et al. 2018; Kim, Nussbaum, Esfahani, Alemi, Jia et al. 2018). This set of studies also showed that drilling task completion time decreased by 20% when using the vest, though there was a slight increase in errors. The Ekso EVO improves upon the EksoVest by being lighter and offering a more customizable fit. For instance, its arm cuffs, which range from 9 to 20 inches, make it adaptable for different body types, including women workers.

Discussion

Most previous studies on the future of work, workplace automation, and robotics have centred their analyses on the replacement of human labour with machines. Less is known about the economic costs and benefits of wearable assistive robots. For workers and employers, costs include the cost to workers and employers of purchasing and maintaining the technologies, while benefits include increased productivity and enhanced workplace safety. There is also potential for macro-level gains through employment creation, reduced health insurance costs, and spillover effects to other sectors.

Our estimates suggest that the adoption of wearable assistive robots, particularly in a physically demanding industry such as construction, could lead to employment growth and higher wages in a range of occupations. Such a change has the potential to empower a future-ready workforce, and to create construction workplaces that are safer, more diverse and equitable, and more innovative. Increased participation of women in construction jobs, facilitated by such technologies, may also help to mitigate the labour shortage (shrinking supply of male labour) that construction companies are expected to face in the next decade. Developing and implementing new technology tools for construction worksites are among the most promising ways to address the shortage of skilled workers and attract women workers to traditionally male-dominated fields (Menches and Abraham 2007). Wearable assistive robots are critical to expand employment opportunities for women and to help improve health outcomes in the construction industry. In addition, these technologies can motivate incumbent skilled workers to remain in construction due to the positive effects of the technology on safety and health outcomes as well as productivity and earning levels.

Despite the significant potential benefits of wearable assistive robots, especially exoskeletons, they are often tested primarily on male workers. Even with multiple size options, proper fit alone does not guarantee comfort or usability, especially for women. For instance, the HeroWear Apex requires selecting the correct shoulder harness, thigh strap size, and elastic band length with appropriate band strength. The Hilti EXO requires adjusting the elastic band system to engage one band at the maximum moment arm setting. The Ekso Evo involves choosing the right waistband size, vertical dorsal pillar height, and armband size. Women's bodies differ from men's not only in size but also in movement patterns, friction points, and areas of sensitivity. For exoskeletons to be safe, comfortable, and effective in increasing women's participation in physically demanding industries, they must be redesigned with gender-specific considerations in mind. In addition, bringing these technologies to scale is not without its challenges. The prototypes are rather bulky and intimidating, so development efforts are focusing on making them more commercial and consumer friendly.

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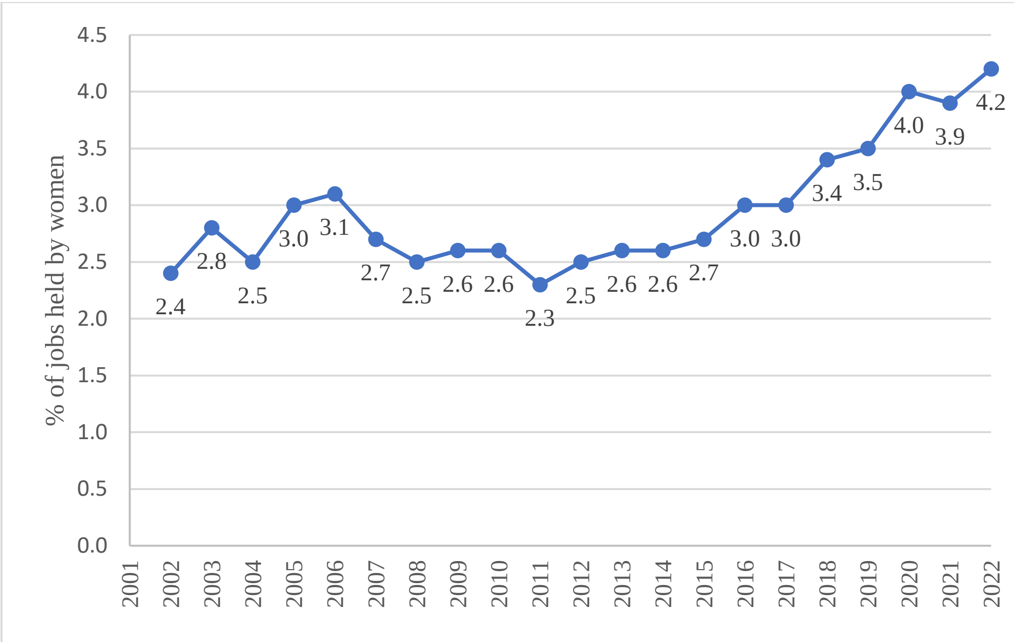
ENDNOTES

[1] Construction jobs are coded as having industry code 0770. Because this yields a sample cell size of only 888 people in construction, we added people in other industries with occupations related to construction (occupation codes 0220, and 6200-6765), for an additional 113 observations and a total sample of 1,001 in construction.

[2] Ideally we would want to perform the regressions separately for women and men, or interact gender with all the indicator variables for mobility/strength impairments. However, only 78 out of the 1001 individuals in our sample of construction workers are women, leaving us with a cell size that is too small to generate reliable results for the construction industry regressions.

Figure 1. Percentage of Construction Jobs Held by Women



Source: Constructed by authors using U.S. Bureau of Labor Statistics, Current Population Survey, Table 11, for each year (BLS 2024a).

Table 1. Sample Means by Industry, SIPP Data

	Not Employed	*Construction*	*Non-Construction*
Woman	0.601	0.083	0.499
	(0.490)	(0.276)	(0.500)
Mobility/strength impairments			
Climb 10 stairs	0.207	0.016	0.031
	(0.405)	(0.127)	(0.174)
Walk 3 blocks	0.227	0.026	0.031
	(0.419)	(0.158)	(0.174)
Stand 1 hour	0.264	0.050	0.047
	(0.441)	(0.218)	(0.211)
Sit 1 hour	0.167	0.030	0.029
	(0.373)	(0.170)	(0.168)
Stoop/crouch/kneel	0.287	0.074	0.077
	(0.453)	(0.261)	(0.267)
Reach overhead	0.152	0.020	0.024
	(0.359)	(0.141)	(0.154)
Lift/carry 10 pounds	0.195	0.018	0.023
	(0.396)	(0.135)	(0.149)
Grasp small objects	0.109	0.017	0.019
	(0.311)	(0.128)	(0.135)
Push/pull large objects	0.246	0.036	0.045
	(0.430)	(0.186)	(0.206)
Other impairments			
Vision	0.073	0.030	0.025
	(0.261)	(0.170)	(0.156)
Hearing	0.059	0.025	0.029
	(0.236)	(0.156)	(0.167)
Speech	0.043	0.010	0.005
	(0.204)	(0.098)	(0.074)
Mental/cognitive	0.181	0.066	0.052
	(0.385)	(0.249)	(0.222)
Education			
High school or less	0.518	0.605	0.301
	(0.500)	(0.489)	(0.459)
Some college/associate's degree	0.292	0.259	0.291
	(0.455)	(0.438)	(0.454)
College degree	0.131	0.091	0.252
	(0.337)	(0.288)	(0.434)
Post-college degree	0.060	0.045	0.156
	(0.238)	(0.207)	(0.362)
Race/ethnicity			
White non-Hispanic	0.546	0.621	0.654
	(0.498)	(0.485)	(0.476)

Black non-Hispanic	0.164	0.054	0.114
	(0.370)	(0.225)	(0.318)
Hispanic	0.191	0.279	0.151
	(0.393)	(0.449)	(0.358)
Asian	0.066	0.031	0.061
	(0.247)	(0.174)	(0.239)
Other/Multiracial	0.034	0.015	0.020
	(0.181)	(0.121)	(0.141)
Age group			
18-24	0.219	0.073	0.132
	(0.414)	(0.260)	(0.339)
25-34	0.174	0.235	0.235
	(0.379)	(0.424)	(0.424)
35-44	0.157	0.248	0.221
	(0.364)	(0.432)	(0.415)
45-54	0.180	0.292	0.232
	(0.384)	(0.455)	(0.422)
55-64	0.270	0.153	0.179
	(0.444)	(0.360)	(0.383)
Ln(monthly earnings)	--	2.893	2.920
	--	(0.672)	(0.740)
Sample size	6,554	1,001	12,591

Notes: Sample means for employed individuals using 2014 SIPP data. Standard deviations in parentheses. Means are weighted to population averages using SIPP sample weights.

Table 2. Gender and Mobility/Strength Gaps in Construction and Non-Construction Jobs, SIPP Data

	Employment		*Earnings*	
	Model 1: Construction	*Model 2: Non-Construction*	*Model 3: Construction*	*Model 4: Non-Construction*
Woman	-0.249***	-0.079***	-0.356***	-0.231***
	(0.009)	(0.007)	(0.118)	(0.014)
Mobility/strength impairments				
Climb 10 stairs	-0.022	-0.035*	0.110	(0.069)
	(0.014)	(0.020)	-0.178	-0.049
Walk 3 blocks	-0.055***	-0.128***	0.442***	-0.095*
	(0.014)	(0.021)	-0.153	-0.058
Stand 1 hour	-0.048***	-0.145***	(0.163)	0.052
	(0.017)	(0.020)	-0.157	-0.041
Sit 1 hour	0.002	0.009	0.095	0.025
	(0.012)	(0.018)	-0.264	-0.048
Stoop/crouch/kneel	-0.040**	-0.032**	-0.277**	(0.029)
	(0.016)	(0.015)	-0.121	-0.031
Reach overhead	-0.003	-0.032*	0.095	(0.002)
	(0.011)	(0.018)	-0.139	-0.051
Lift/carry 10 pounds	0.011	-0.104***	0.031	0.013
	(0.015)	(0.021)	-0.224	-0.057
Grasp small objects	-0.005	-0.014	(0.063)	-0.101*
	(0.012)	(0.019)	-0.239	-0.054
Push/pull large objects	-0.036***	-0.092***	0.077	(0.016)
	(0.013)	(0.018)	-0.142	-0.043
Other impairments				
Vision	-0.012	-0.057***	0.109	-0.113*
	(0.014)	(0.019)	(0.151)	(0.067)
Hearing	-0.043***	-0.009	-0.194*	0.010
	(0.014)	(0.017)	(0.111)	-0.048
Speech	-0.027	-0.127***	-0.88	-0.178*
	(0.023)	(0.025)	(0.769)	-0.1
Mental/cognitive	-0.045***	-0.107***	-0.149	-0.105***
	(0.012)	(0.014)	(0.159)	-0.038
Education (reference: high school or less)				
Some college/associate deg.	-0.019*	0.093***	0.193***	0.199***
	(0.010)	(0.009)	(0.059)	-0.018
College degree	-0.078***	0.150***	0.315***	0.551***
	(0.013)	(0.010)	-0.111	(0.019)
Postgraduate degree	-0.069***	0.180***	0.535***	0.822***
	(0.021)	(0.011)	-0.116	-0.022
Race/ethnicity (reference: white non-Hispanic)				
Black non-Hispanic	-0.101***	-0.058***	(0.222)	-0.121***
	(0.012)	(0.012)	-0.144	-0.023

Hispanic	0.004	-0.059***	-0.368***	-0.164***
	(0.013)	(0.011)	(0.061)	(0.022)
Asian	-0.063***	-0.126***	0.134	-0.018
	(0.017)	(0.017)	(0.163)	(0.034)
Other/Multiracial	-0.065***	-0.086***	-0.347**	(0.043)
	(0.019)	(0.022)	(0.166)	-0.041
Age group (reference: 18-24)				
25-34	0.173***	0.151***	0.494***	0.385***
	(0.015)	(0.014)	(0.126)	-0.03
35-44	0.225***	0.184***	0.737***	0.644***
	(0.015)	(0.014)	(0.124)	-0.029
45-54	0.242***	0.210***	0.774***	0.685***
	(0.015)	(0.014)	-0.125	(0.028)
55-64	0.140***	0.105***	0.827***	0.684***
	(0.012)	(0.014)	-0.126	(0.029)
Constant	0.216***	0.604***	2.243***	2.188***
	(0.012)	(0.013)	-0.124	-0.028
Observations	7,548	19,119	1,001	12,591

Notes: Estimates derived from 2014 SIPP data. Employment results are from linear probability regressions, and earnings results are from Heckman selection regressions of log hourly earnings. Standard errors in parentheses. *** statistically significant at 1%, ** at 5%, and * at 10% in 2-tail t tests.

Table 3. Physical ability levels, percent female, and annual earnings by occupation in construction

Six-digit Occupations	Percent Female	Physical Level	Annual Income
Hazardous materials removal workers	22.52	2.21	47,255
Construction and building inspectors	11.03	1.47	66,697
Painters and paperhangers	9.09	2.35	37,701
Explosives workers, ordnance handling experts, and blasters	7.07	2.20	55,750
Helpers, construction trades	6.35	2.65	29,509
Sheet metal workers	4.84	2.40	53,131
First-line supervisors of construction and extraction workers	4.18	1.84	76,052
Other construction and related workers	4.16	2.25	44,635
Construction labourers	4.10	2.78	39,797
Solar photovoltaic installers	3.94	2.25	43,244
Insulation workers	3.71	2.44	51,741
Drywall installers, ceiling tile installers, and tapers	3.48	2.46	40,986
Carpet, floor, and tile installers and finishers	3.28	2.41	42,980
Highway maintenance workers	3.27	2.36	46,454
Underground mining machine operators	2.77	2.51	74,573
Other extraction workers	2.71	2.40	62,043
Roofers	2.70	2.90	40,368
Rail-track laying and maintenance equipment operators	2.67	2.63	65,682
Construction equipment operators	2.65	2.04	59,131
Carpenters	2.49	2.69	46,153
Electricians	2.48	2.67	64,052
Boilermakers	2.33	2.32	69,704
Fence erectors	2.21	2.75	37,402
Plumbers, pipefitters, and steamfitters	2.02	2.60	59,937
Glaziers	1.82	2.18	51,626
Structural iron and steel workers	1.72	3.13	60,882
Surface mining machine operators and earth drillers	1.70	1.93	62,836
Pipelayers	1.63	2.35	52,292
Plasterers and stucco masons	1.44	2.69	42,009
Derrick, rotary drill, and service unit operators	1.41	2.40	73,838
Elevator installers and repairers	1.37	2.03	99,999
Brick masons and reinforcing iron and rebar workers	1.33	2.51	45,662
Cement masons, concrete finishers, and terrazzo workers	0.98	2.81	47,508

Note: Calculated by authors using data from the Occupational Information Network (O*NET) merged with 2018-2022 American Community Survey data.