Digitalization & Automation in the Construction Trades

CONSTRUCTION SECTOR IN THE NETWORK ECOMONY

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Seattle Jobs Initiative

Seattle Office of Economic Development

Construction Sector in the Network Economy

We are in the midst of a Fourth Industrial Revolution, changing the nature of work as **digital and automation technology** takes over tasks, freeing humans to do other things.[1] Automation and the growing networks of Internet-connected people and devices are driving this revolution.[2,3] The emerging economic system, the Network Economy, will increasingly leverage information technology.

The current economic contraction has already had profound impacts on employment and undoubtedly will on wages. The recession plus the nature of the COVID-19 pandemic is likely to accelerate the emergence of the Network Economy and the longtime structural changes in the demand for labor. Digital and automation technology allows work to continue while minimizing face-to-face contact and the spread of the virus. Before this crisis, substantial and growing economic disparities existed across our workforce, characterized by inequitable access by and representation of racial and ethnic groups in living-wage jobs. COVID-19 and the evolving labor market needs of the Network Economy threaten to compound existing economic inequalities as we have explored in this series.[4,5]

The growth of technology increases the baseline skills needed for employment. This paper explores the implications of the **digital skill gap, introduction of automation, and Network Economy for the construction workforce**. This analysis looks at construction employment as a whole in metropolitan Seattle, including residential, commercial, industrial, and heavy civil construction. The key findings are:

- **Workers will need more digital skills to use digital and automation technology during training and on job sites**. The use of digital technology is increasing in all aspects of the construction sector, from using basic computer and internet programs for training to accessing project management platforms on a job site to managing automated equipment. Digital skills are rapidly becoming essential employability skills.
- **Workers of color, women, and young workers are the most likely to be impacted by the digital skill gap and the introduction of automation technology. This technology may affect access to construction training opportunities, entry-level jobs, and career growth**. Also, those with low education attainment and other barriers to employment will find it more difficult to access the labor market. This will restrict the pipeline of workers into skilled trades and hamper efforts to increase racial, ethnic, and gender diversity in the construction sector.
- **Job-readiness programs, pre-apprenticeships, and apprenticeships must integrate digital literacy into their curricula to protect construction career pathways**. Apprenticeships may also need to incorporate specialized digital skills for emerging technologies into their training.
- **The introduction of automation is part of a broader evolution in the construction sector: end-to-end digital integration. This integration will demand that all workers have more digital skills, regardless of the risk of automation directly impacting their jobs.**

Digital Skills

Digital skills were emerging as essential employability skills well before the COVID-19 pandemic. However, the shutdown and ongoing physical distancing requirements have accelerated and expanded the need for all workers to have digital literacy and digital access.

The construction industry has been slow to adopt digital technology. However, the need to limit face-to-face contact increases the demand that construction workers have basic computer and internet skills. These skills include knowing how to use email and collaborative project management platforms and maintain data security.

More skilled positions may require intermediate digital skills, like using productivity software (e.g., Excel) or occupation-specific software. For example, bricklayers, welders, and other skilled workers may operate robotic technology in addition to doing tasks manually when robots are not practical.

While employers are often willing to invest in training for more advanced and specialized digital skills, they typically assume employees have these basic skills.[6] Workers who lack them fail to advance or lose their job when they do not complete tasks that involve digital skills (e.g., communicating with a supervisor via email). It is essential as training, support services, and communication have necessarily moved online that training programs ensure that all participants have these basic skills. There are many curricula available to integrate into job-readiness programs, pre-apprenticeships, and apprenticeships. They are also available through libraries, community colleges, and online for self-directed learning. However, there are two main barriers to this the widespread adoption of this training.

First, **there is no widely accepted credentialing for these skills**. Specific software platforms offer certifications recognized by employers. Still, there isn't anything comparable with any marketable value for basic digital literacy.

Second, **individuals in low-income households often lack reliable access to the Internet and a computer**. They use limited mobile data plans and access the Internet via a mobile device or depend on libraries and community based organizations' public computer labs. This limited access was not adequate pre-pandemic and has been further restricted now.

It is critical to adapt training to include these skills and focus on emerging technologies. It is necessary to fill skilled labor shortages, maintain pathways to careers with livable wages, and diversify the workforce. These skills are also highly transferable and required to work in most other sectors. In the COVID-19 world, they also allow individuals to access services, training, and education and stay in touch with friends and family.

End-to-End Digital Integration

The growing demand for digital skills is linked to the introduction of automation technology to the construction site is part of **end-to-end digital integration of the construction industry**.** Digital integration means that all steps along the construction process use digital technology. The digital technology at one stage of the process produces digital information to be used by technology at another stage.

The implementation of digital integration technologies will only accelerate the growth in the digital skills necessary to work in construction. Workers will need digital skills to interact with and manage automation technology. The changing skills will change the structure of the workforce.

For example, engineers and architects create 3D models and uploaded them to a project management platform. Contractors access the models and use it to sequence tasks, schedule workers, and order equipment and materials.†† Equipment operators access the platform and download the models to the computerized equipment. This equipment is programmed to read the model to direct its operation. The sensors in the equipment feed information back to the model on the project management platform. The models incorporate the new information, adjust, and resolve conflicts in the design virtually to prevent delays onsite.

This integration requires personnel, equipment, and materials to have a digital identity that can be used at multiple stages in the process. For example, fabricators tag materials and components with radio frequency identification (RFID) labels. Contractors log these labels to track inventory more efficiently, reducing overstock and waste. RFID labels on components direct automated equipment as it positions and installs them.

The same RFID tags are used to more efficiently manage the ongoing maintenance and operation and, finally, in decommissioning of the building.

** Digitalization: converting tasks from analog to digital.

†† They are 4D models when contractors add the time dimension.

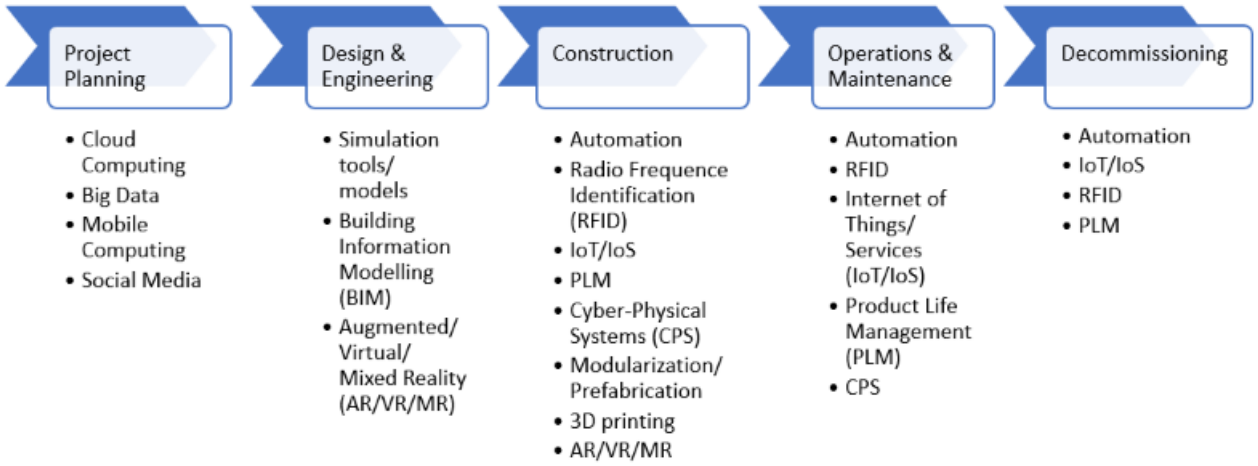

Figure 9. Digital Technology in the Construction Process (adapted from Oesterreich & Teuteberg, 2016[7] and Saidi, Bock, & Georgoulas, 2016[8])

The Impact of the Digitalization of the Workforce

Nearly all occupations require more digital skills now than they did in 2002.[9] Though most construction sector occupations are still in the low digital skill category, the overall increase is significant (Figure 10). Construction is an industry in which people with a high school diploma or less can enter the sector and work their way up. Through seniority and apprenticeships, workers gain access to jobs with livable wages. Increasing digitalization increases the baseline skills required for employment. While entry-level positions may still require limited to no digital skills,‡‡ having those skills will increasingly be necessary to move from entry-level positions. At the same time, entry-level positions tend to be the most routine and easily automatable.

‡‡ Increasingly, even accessing the workforce requires digital skills as job postings and applications have moved to online platforms. Finding, applying for, and communicating with potential employers requires access to and skill in using online job search tools, navigating webforms, and using email. Once hired, submitting timecards, accessing work schedules, navigating benefits, and communicating with supervisors are increasingly done via electronic communication. Though the construction sector has lagged others, COVID-19 has encourage more dependence on these systems to minimize face-to-face contact

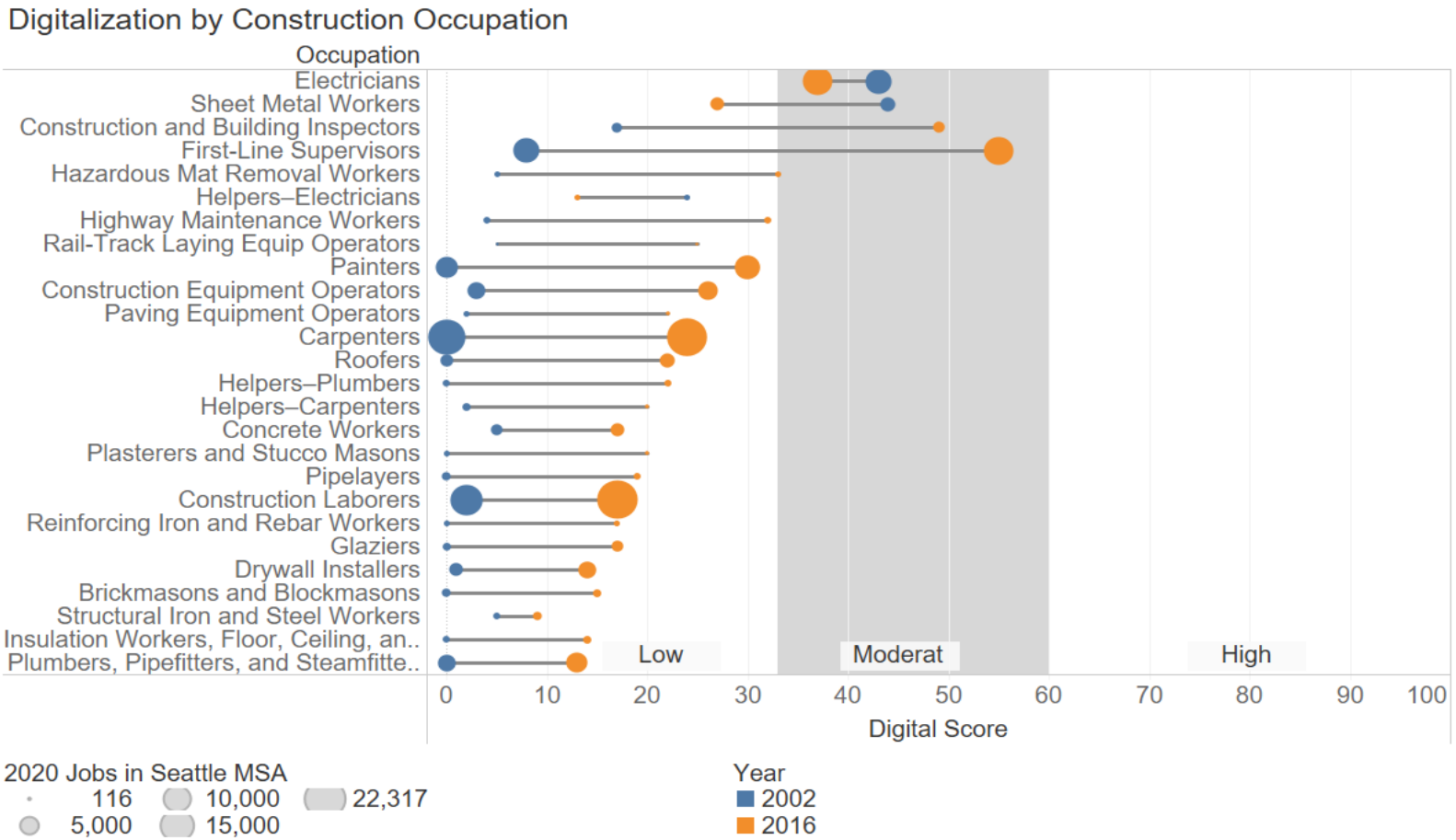

Figure 10. Digitalization of Construction Sector Occupations (adapted from Muro et al., 2017)[14]

Occupations Impacted by Automation and Digital Skill Needs

The COVID-19 has brought into relief how much individuals need basic digital skills to access the job market, keep a job, and advance in their career. This trend has been driven by the growth in automation technology across the workforce.** Automation technology still requires people to interact with it, whether it is to direct it, monitor it, or be directed or monitored by it. And individuals need digital skills to do any of those things.

There are two primary methods for estimating how likely an occupation is to be impacted by automation. The first is estimating the probability of being able to automate an occupation's tasks.[10,11] The second is assessing if the technology exists to do those tasks (exposure).[12] Surprisingly, these two methods are not highly correlated. However, combining them can help us identify the occupations with the highest risk of being impacted by automation.

Similar to "green jobs," automation does not primarily create (or eliminate) whole occupations. It changes how workers in existing occupations work, shifting the skills and competencies those workers require. In the medium- and long-term, this may also change the number employed in occupations and the wages those workers command but is unlikely to eliminate any single occupation.

** There are three main types of automation technology: robotics, software, and artificial intelligence. Robotics automates physical labor, software automates the retrieval and storage of information, and artificial intelligence automates tasks that involve cognition.

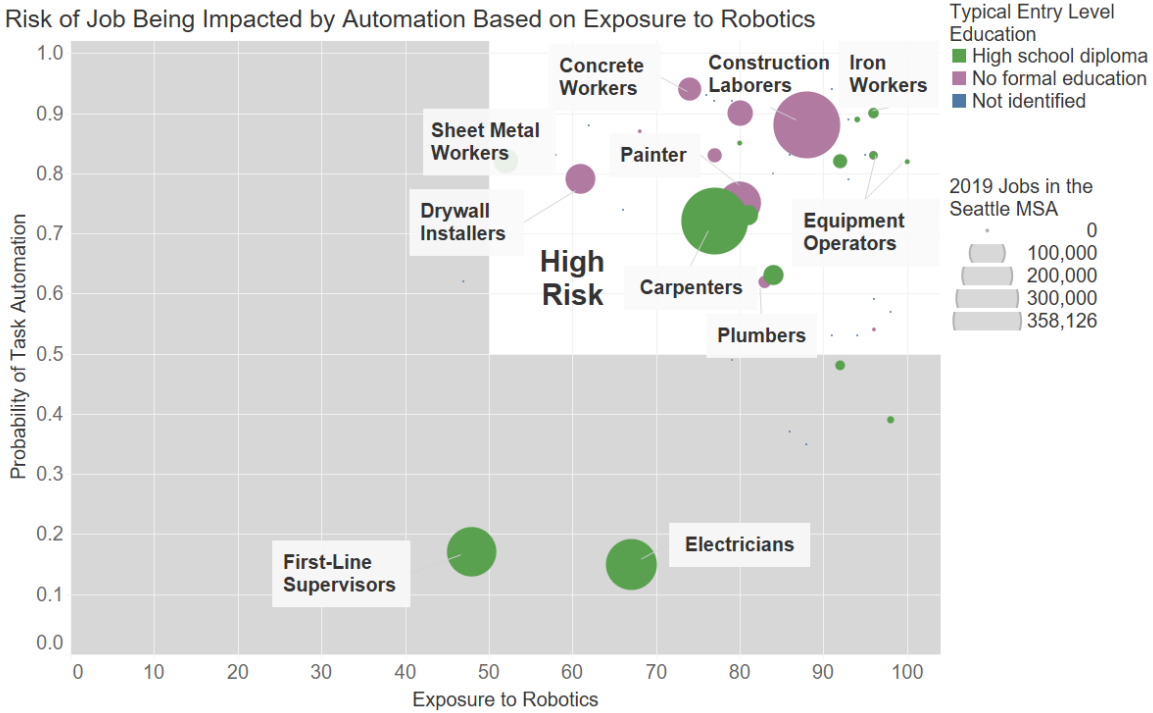

Figure 1. Construction Sector Occupation Risk of Automation – Average Exposure to Robotics, Software, and AI Technology[11–13]

Most of the occupations in the construction sector have both a high probability of tasks being automated and a high exposure to automation technology (Figure 1, upper right corner, Appendix). This means they have a high risk of being impacted by automation. Only first-line supervisors and electricians have a low estimated probability of tasks being automated and moderate exposure to automation technology.

As we can see in Figure 2, the construction sector is fifth for the share of jobs at high risk for being impacted by automation, closely following manufacturing occupations.

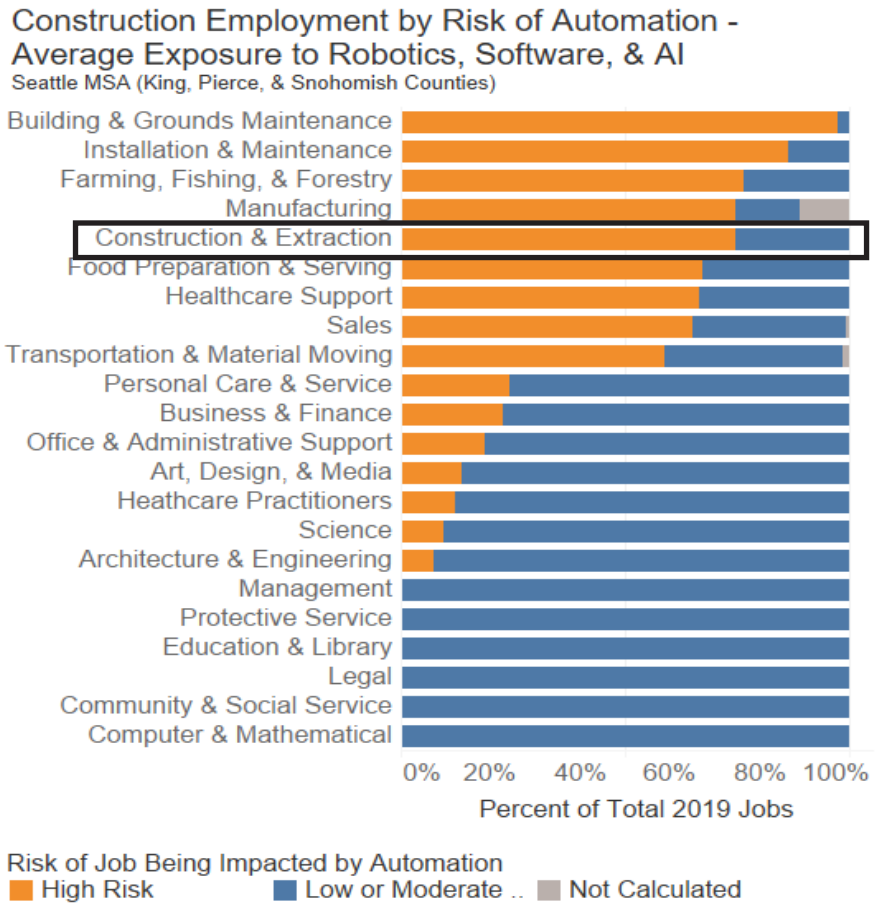

Figure 2. Occupational Categories Risk of Automation–Average Exposure[11–13]

The other sectors that have a larger proportion of workers at risk are exposed to many of the same types of automation. Manufacturing automation does many of the same sorts of tasks as construction automation under different conditions. Farming, fishing, forestry, and buildings and grounds maintenance face many of the same challenges to implementation that construction does because the occupations typically operate in highly variable conditions. Thus, advances in technology in one sector may bleed into others.

At the same time, the workforce in these sectors is very similar. They are disproportionately male, and the majority of entry-level positions require a high school diploma or less. And, this is consistent with the pattern across the workforce, that men are more exposed to automation.[4,5,11,12]

Robotics

Like manufacturing occupations, construction occupations are mostly highly exposed to robotics (Figure 3). However, automation depends on a predictable environment, which is not typical of construction sites. The irregularity of the construction site has been a barrier to the introduction of automation, but it is not insurmountable. The “smarter” the technology, the more variability in can accommodate.

It is important to note two caveats. The first is that everything that can be automated will not necessarily be automated.[14] The second is that automation has historically changed occupations, not eliminated them.[15] Over time, automation, particularly automation via robotics, is correlated with declines in both wages and overall employment, but the occupations themselves are not eliminated.[12]

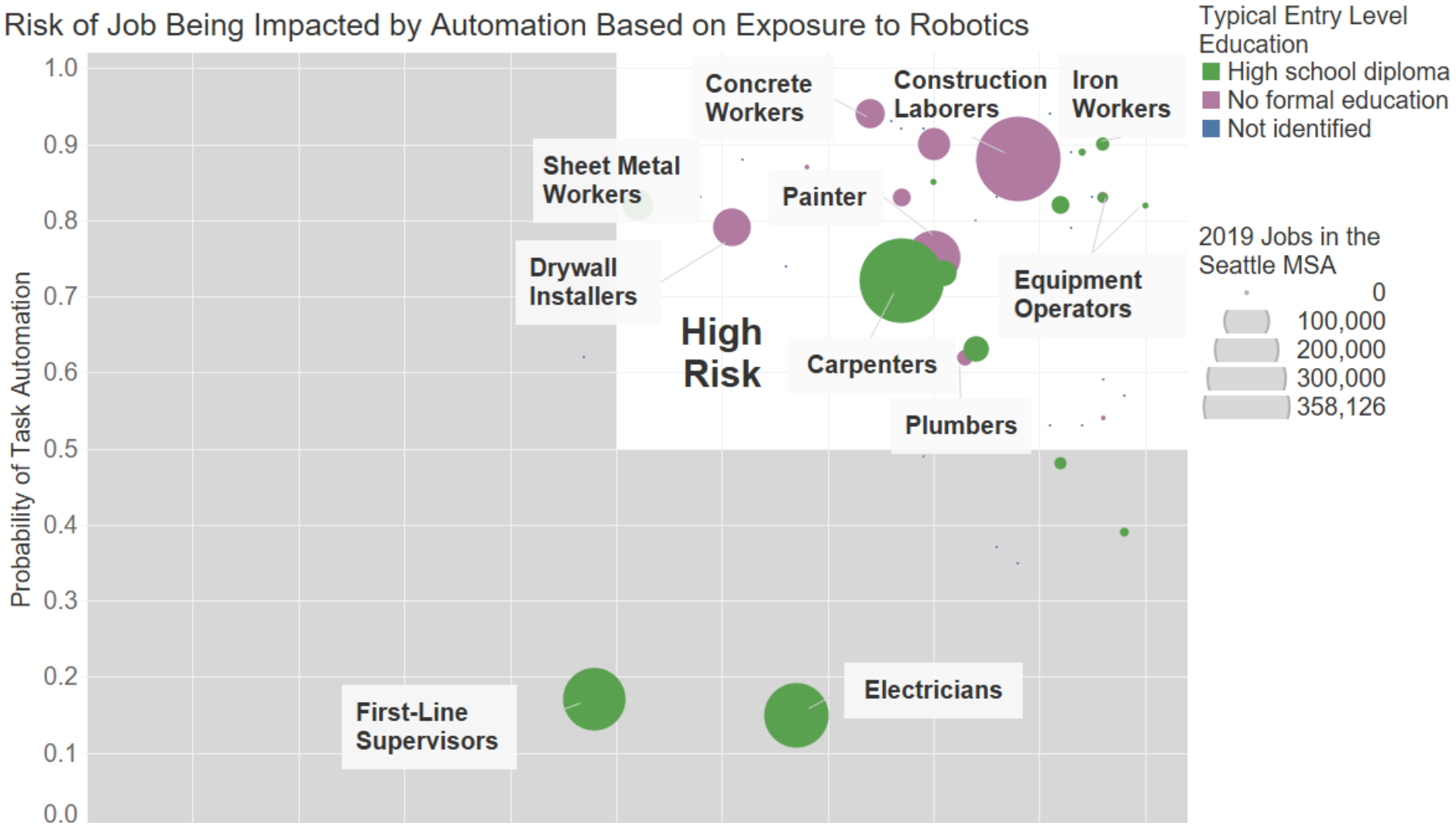

Figure 3. Risk of Jobs Being Impacted by Automation - Exposure to Robotics[11–13]

As we can see in Figure 4, most occupations, and the top two occupations by employment in the construction sectors, are at high risk of being impacted by automation.

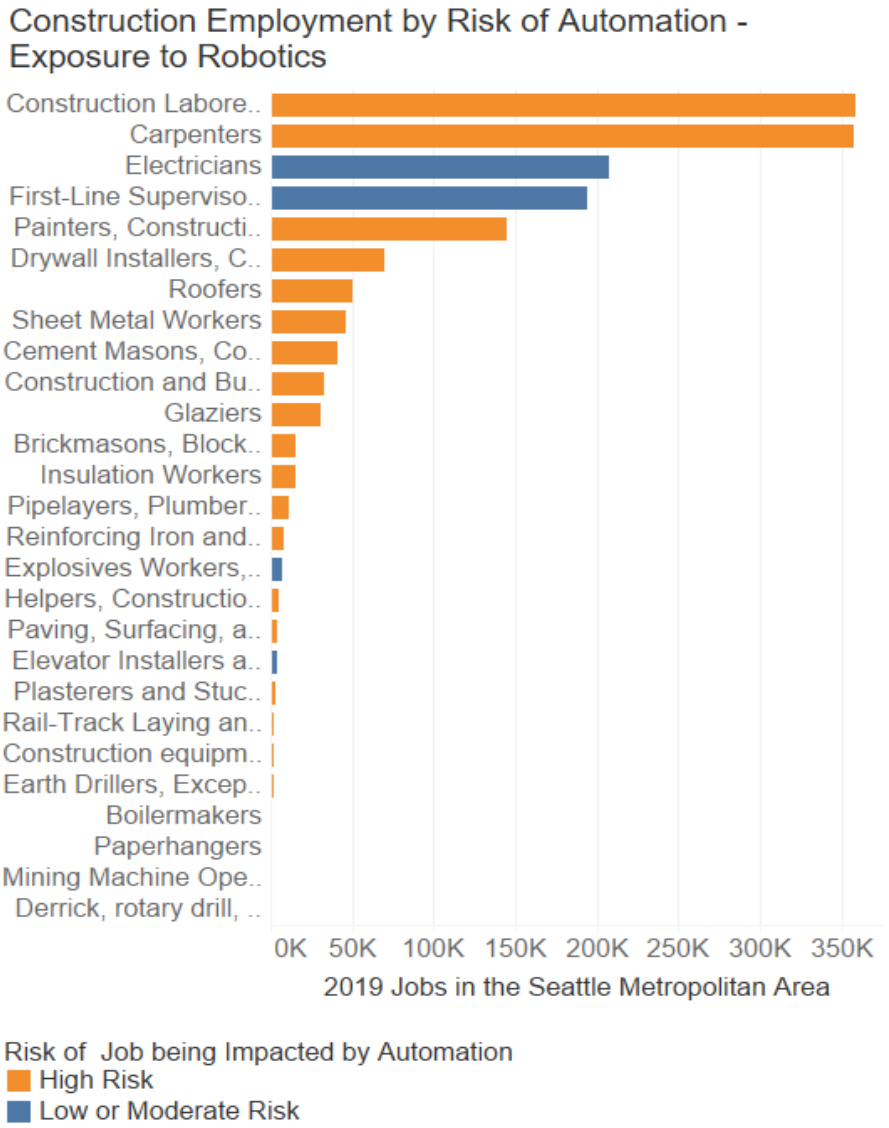

Figure 4. Occupations by Employment and Risk of Being Impacted by Automation[11–13]

Workers Most Impacted

The construction industry is disproportionately white. Despite this, workers of color are at the highest risk of automation impacting their jobs (Figure 5). While, again, this does not mean automation will eliminate their jobs, the long-term pattern is that exposure to automation technology, particularly robotics, depresses wages and employment.[12]

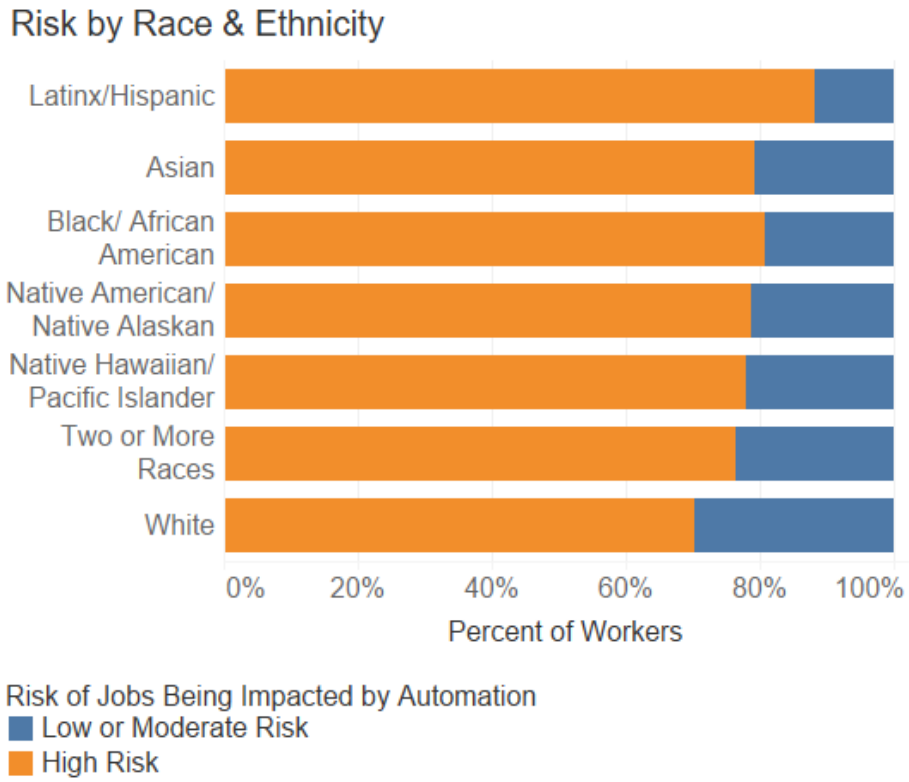

Figure 5. Risk of Job Being Impacted by Automation by Race & Ethnicity[11–13]

As expected, younger workers are more at risk than mid- and late-career workers (Figure 6). They are more likely to work in entry-level jobs that are more easily automatable. They are also the least likely to have developed specialized skills that will continue to be in demand as automation is implemented. These workers may also lack critical digital skills because they are required to have a high school diploma or less.

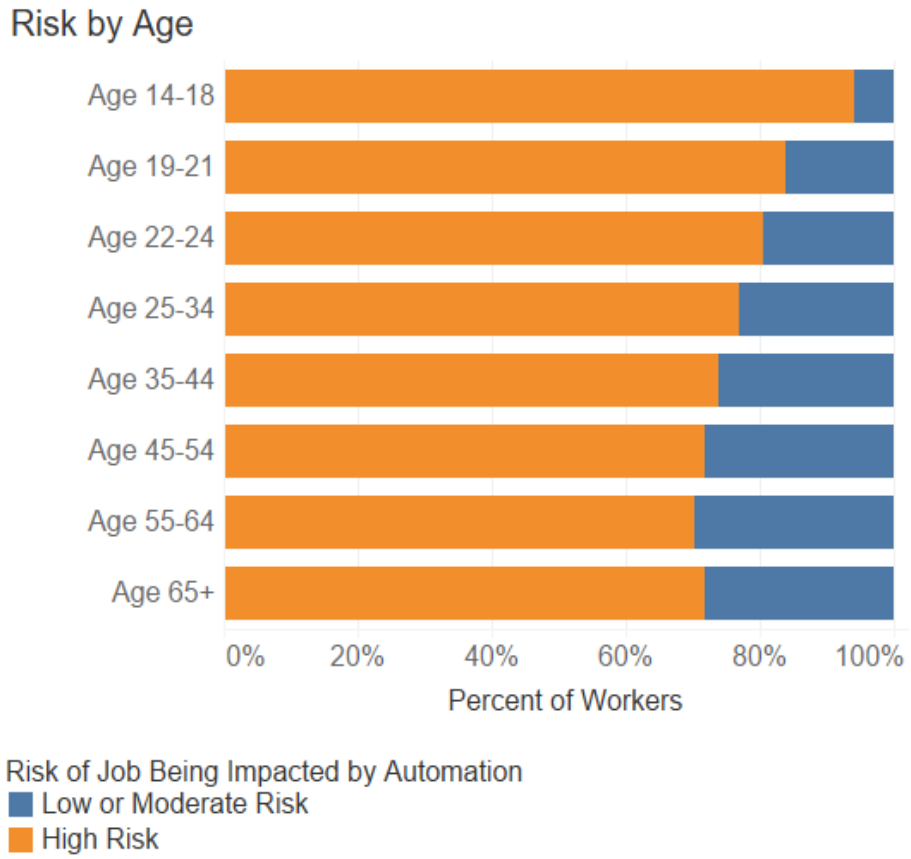

Figure 6. Risk of Job Being Impacted by Automation by Age[11–13]

Women are at higher risk of their jobs being impacted by automation than men (Figure 7). This pattern is the reverse of the workforce at large, where women tend to work in occupations that require more complex impersonal interactions that are less like to be impacted by automation. This reversal may reflect that there are fewer women in the construction sector and they are, on average, younger and underrepresented in highly skilled positions and positions with seniority.

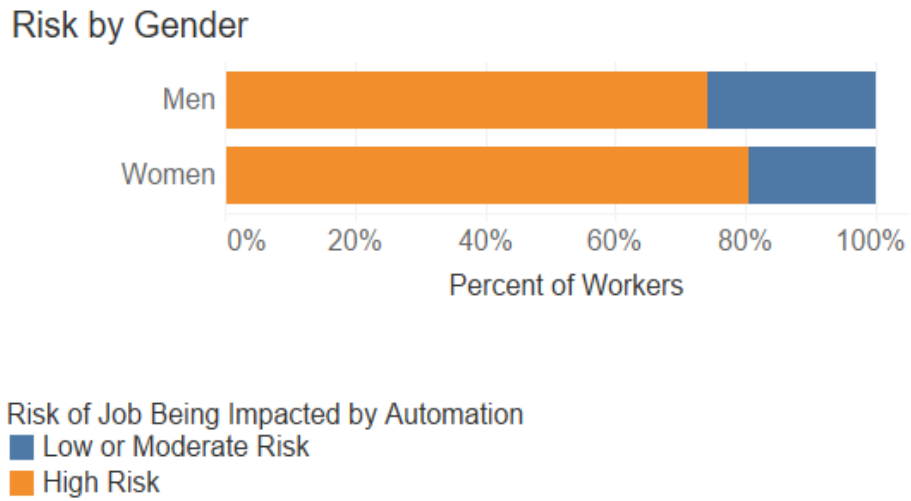

Figure 7. Risk of Job Being Impacted by Automation by Gender[11–13]

What Is Being Automated

The efforts to develop automation technology in the construction industry are parallel to those in the manufacturing industry. Various national sectors have sought to address the **challenges of an aging workforce (e.g., Japan) and skilled labor shortages[16] and to make work safer and less physically demanding for workers.**** The irregular and unpredictable environment of the construction site has been a significant hurdle. There are two mechanisms for addressing this challenge. The first is **prefabrication and modularity**, which moves much of production into a predictable factory environment where manufacturing robots can be used. The second is **developing smarter technology** that can sense and adapt to a variety of conditions.[7]

Modularity and prefabrication, used for decades, can facilitate onsite automation. Prefabricated and modular elements are more regular than conventional materials, and they can be produced with features that allow robots to position and install them.††

Onsite automation is only more recently becoming feasible as the necessary computing power has developed. Some of these technologies are mature and being adopted. Others are still in developmental stages.

** Robots reduce activities that cause long-term damage to workers' joints and hearing, reduce exposure to hazardous materials, and allow human workers to work outside areas with physical hazards.

†† For example, they can be designed to be picked up by specific machine with markings to guide their precise placement and fasteners designed for robot to attach.[17]

Levels of Automation

There are five levels of automation (Figure 8). Nearly all automation requires a **human-in-the-loop**; they vary in the degree to which a human is directing or monitoring operations.

The first level is **operator assistance**. At this level, a human operator runs smart machinery with a computer that runs a single element. This level of automation is relatively common.[17] For example, a human drives a stakeless grading machine, but it runs a program that uses CAD plans and GPS to automatically adjust the pitch and depth of the grading blade to move earth without the guidance of stakes.

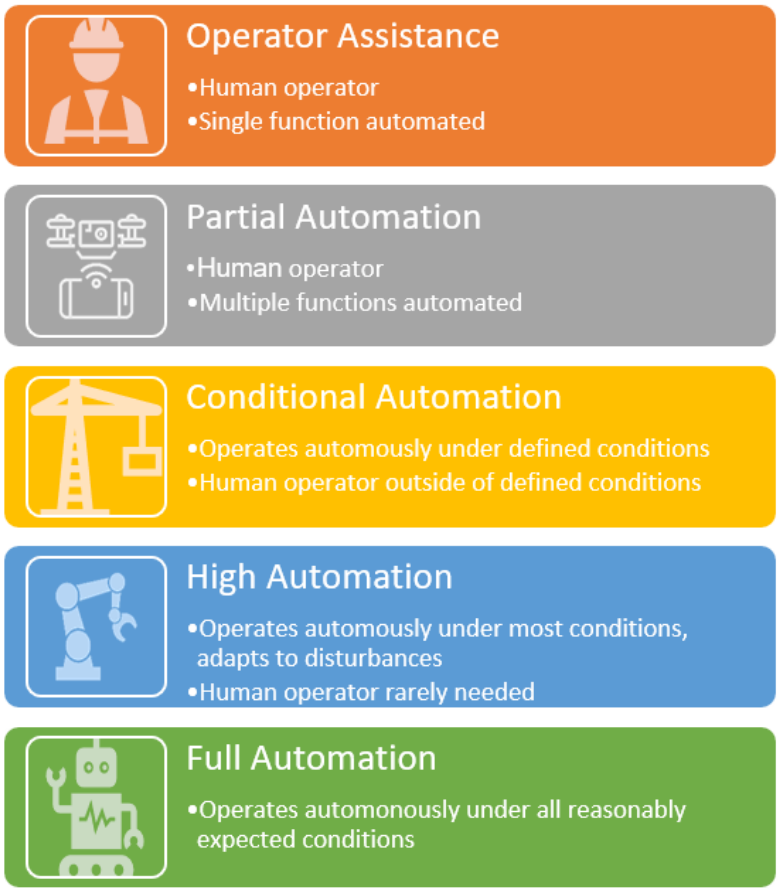

Figure 8. Level of Automation (adapted from Melenbrink, Werfel, Menges, 2020[17])

Partial automation also requires a human operator but automates multiple functions. **Conditional automation** can operate without a human operator under defined conditions but needs a human operator to run it outside of those conditions. **High automation** can operate without a human operator under most circumstances. **Full automation** can work autonomously under any reasonably expected site conditions. We were unable to locate any commercial applications of full automation.

Lower levels of automation will demand additional technical skills. Workers will still need conventional skills but will also need **digital skills that will allow them to interact with and operate the automation equipment.**

Often the number of workers needed for any given task or project is the same as conventional construction. However, they complete the job with more precision and speed. This may ultimately depress the overall demand for workers. They can complete projects faster, requiring fewer crews over time. However, it could also increase demand for labor if the demand for construction increases as construction costs decline because more projects are completed on-time and on-budget.

Higher levels of automation, particularly those that are fundamentally new methods of construction, are going to demand new skills sets. These skills will be mostly digital but not exclusively so. It is much more difficult to predict the impact on labor demand. These are, in effect, new trades and will depend on how quickly the technology advances and how widely the novel product (e.g., 3D printed building) is adopted.

Contractors are already adopting technology at the lower levels of automation. Some have been using operator assistance and partial automation technologies for many years. Higher levels of automation have limited adoption for two primary reasons. First, the cost and availability of operators limit their adoption. Second is that higher levels of automation require additional integration with the other phases of the construction process, namely the design and planning process.

Figure 9. 3D Printing Construction

Table 1 is an overview of the tasks that are currently automatable and the level at which they can be automated.

	Site Preparation	Substructure	Superstructure
Operator Assistance	Grading	Pile driving	Materials handling
	Bricklaying	Concrete pouring	Concrete pouring
	Materials handling		Concrete finishing
	Erosion control		
	Concrete finishing		
Partial Automation	Earthmoving	Pile driving	Bricklaying
	Excavation	Pipe installation	Fabricate architectural components (in place)
	Pavement placement		Install façade components
	Concrete finishing		Position structural components
	Pavement repair		Tying rebar
			Concrete finishing
			Materials handling
Conditional Automation	Material hauling	Assemble forms	Assemble architectural components
	Stormwater management	Boring	Assemble structural components
		Spray concrete	Bricklaying
			Fabricate structural elements (in place)
			Welding
High Automation	Earthmoving		Assemble architectural components
	Excavation		Assemble structural components
	Material handling/hauling		Install structural foam
Full Automation			

Table 1. Automatable Tasks by Level of Automation and Task Group (adapted from Melenbrick, Werfel, & Menges)[17]

The introduction of automation will reduce the entry points onto the career ladder and make it harder to move up from entry-level positions. This reduces opportunities for employment for those with low education attainment and other barriers to employment (e.g., justice-involved, English language learners). **It also restricts the pipeline of workers up into skilled positions, exacerbating the shortages of skilled labor as experienced workers retire, and hampers efforts to diversify the construction trades.**

There is limited data about this occurring in the construction sector because the implementation of these technologies has lagged behind other industries. However, this is the typical pattern as automation technology is adopted.

Factors Influencing Automation and Digitalization

There are both **barriers and driving factors** that will influence the timeline of adoption and implementation of the various automation technologies.

Barriers

In general, the nature of the construction sector has inhibited the adoption of new technology. Contractors, consulting firms, and tradespeople work together temporarily on discrete projects and are often working on several unrelated projects with different players at the same time. This makes it challenging to collaborate to develop standards and processes needed for the pieces of digital and automation technology to be able to "talk to each other."[7]

The construction sector is also highly cyclical, which discourages long-term investments. Finally, engineers and architects often do not fully develop the models because they typically bear the extra cost of doing so. They are also reluctant to share their complete digital models because it is not clear who assumes legal liability when contractors use them.

Driving Factors

At the same time, many benefits will encourage adoption. There is the need to reduce the environmental impact of construction, fill shortages in skilled labor, and keep pace with the advances in architecture and engineering.

Architecture and engineering have widely adopted BIM and other 3D modeling software in both the design process and product. The industry is not making full use of these technological advancements in part because of gaps in both technical capacity and skill on the worksite. Architects and engineers frequently produce complex models and, per the contract, still deliver plans printed on paper.

Impact of COVID-19

COVID-19 has made predicting the influence of each of these factors very challenging. On the one hand, the shutdown and subsequent economic contraction will undoubtedly depress construction for some time, reducing the demand for labor and the capital available for projects. On the other hand, the move to remote working for design professionals and the need to **increase physical distance on worksites** make the investments in smart equipment and processes more cost-effective. This is particularly the case if it allows work to continue despite restrictions on the number of people on a worksite.

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Appendix

Construction Occupations Risk of Job Being Impacted by Automation

Risk of Automation	Occupations	2019 Jobs Seattle MSA	Median Hourly Earnings	Exposure to Robotics (0-100)	Probability of Task Automation (0-1.0)
High Risk	Construction Laborers	358,126	$22.45	88	0.88
	Carpenters	357,037	$28.83	77	0.72
	Painters, Construction and Maintenance	144,646	$19.29	80	0.75
	Drywall Installers, Ceiling Tile Installers, and Tapers	69,829	$28.88	61	0.79
	Roofers	50,503	$26.54	80	0.90
	Sheet Metal Workers	45,757	$29.92	52	0.82
	Cement Masons, Concrete Finishers, and Terrazzo Workers	41,439	$30.48	*	*
	Construction and Building Inspectors	32,774	$38.63	84	0.63
	Glaziers	31,112	$28.85	81	0.73
	Brickmasons, Blockmasons, and Stonemasons	15,240	$33.44	*	*
	Insulation Workers	14,943	$25.78	*	*
	Pipelayers, Plumbers, Pipefitters, and Steamfitters	11,454	$33.01	83	0.62
	Reinforcing Iron and Rebar Workers	8,186	$35.49	96	0.90
	Helpers, Construction Trades	5,397	$20.97	*	*
	Paving, Surfacing, and Tamping Equipment Operators	4,520	$36.93	96	0.83
	Plasterers and Stucco Masons	3,421	$29.99	66	0.84
	Rail-Track Laying and Maintenance Equipment Operators	2,196	$26.98	94	0.89
	Construction equipment operators except paving, surfacing..	1,734	$42.05	*	*
	Earth Drillers, Except Oil and Gar	1,547	$23.09	80	0.85
	Boilermakers	1,535	$38.38	91	0.68
	Paperhangers	799	$18.73	68	0.87
	Mining Machine Operators	449	$24.04	96	*
	Derrick, rotary drill, and service unit operators, and roustab..	0	$0.00	*	*
	Structural Iron and Steel Workers			95	0.83
	Miscellaneous construction workers including solar Photov..			*	0.83
	Highway Maintenance Workers			89	0.87
	Hazardous Materials Removal Workers			94	0.53
	Fence Erectors			77	0.92
	Carpet, Floor, and Tile Installers and Finishers			*	*

Construction Occupations Risk of Job Being Impacted by Automation (continued)

Risk of Automation	Occupations	2019 Jobs Seattle MSA	Median Hourly Earnings	Exposure to Robotics (0-100)	Probability of Task Automation (0-1.0)
Low or Moderate Risk	Electricians	207,168	$34.47	67	0.15
	First-Line Supervisors of Construction Trades and Extractio..	194,558	$40.18	48	0.17
	Explosives Workers, Ordnance Handling Experts, and Blast..	6,881	$24.64	92	0.48
	Elevator Installers and Repairers	3,596	$56.82	98	0.39
	Pipelayers, Plumbers, Pipefitters, and Steamfitters			88	0.35
	Miscellaneous extraction workers including roof bolters and..			*	*
	Drywall Installers, Ceiling Tile Installers, and Tapers			47	0.62

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