EPiC Series in Built Environment
Volume 3, 2022, Pages 371–379
ASC2022. 58th Annual Associated Schools of Construction International Conference

A Taxonomy-based Approach to Analyze the impacts of Automation on Human Workers' Qualifications

Xi Chen and Mohammad Ilbeigi, PhD
Stevens Institute of Technology
Hoboken, New Jersey

The 4th industrial revolution is changing every aspect of the construction industry. However, recent studies indicated that, at least for the foreseeable future, most of the new automated technologies will have a complementary role that requires interaction and collaboration with human workers. Therefore, it is critical to prepare and train human workers to work with and alongside robots. Middle-skill workers must gain new skills, knowledge, and abilities to contribute to the industry effectively and stay employed during this technological revolution. To prepare, educate, and train middle-skill workers to embrace the unprecedented changes and get ready for their parts in the automation era, it is critical to, first, analyze and understand how new automated technologies change the work and required qualifications for human workers. This study aims to address this need by proposing a systematic approach based on three types of taxonomies: (1) taxonomy of the work and its tasks, (2) taxonomy of the robot and its functionalities, and (3) taxonomy of the human worker's qualifications. Using these taxonomies, the interactions between the functionalities of a robot, the work, and human workers' requirements are mapped to systematically identify the potential impacts of new technologies on middle-skill workers. The proposed approach is implemented for Hilti's Jaibot, a semi-automated robot for overhead drilling. The outcomes of this study will help experts systematically design strategic plans to prepare and train middle-skill construction workers to efficiently and successfully work in the digital era.

Key Words: Automation, Taxonomy, Middle-Skill Workers, Qualifications

Introduction

The 4th industrial revolution is changing the construction industry through a wide range of technological advancements, including artificial intelligence (AI), automation, robotics, and 3D printing, making construction works easier, faster, and safer (Leopold et al., 2016). These revolutionary advancements change the nature of work and the required qualifications for human workers. Recent studies indicate that most automated solutions will not substitute for human workers, at least for the foreseeable future (MIT 2019). Manyika et al. (2017a) argued that advanced technologies could entirely displace only 5 percent of tasks. The new automated technologies mostly have a complementary role that requires interaction and collaboration with human workers (Sachs et al., 2015). In this new environment, tasks that once only needed human workers now require interaction and collaboration between automated technologies such as robots and human workers. This complementary role changes human workers' qualifications. Human workers must gain new skills, knowledge, and abilities to contribute to the industry effectively and stay employed during this technological revolution. McKinsey Global Institute (2017) estimates that more than 2,000 work activities across 800 jobs are affected by automation. Leopold et al. (2016) point out that on average more than one-third of the skill sets that are currently required in many innovative industries including construction will change due to automation.

The MIT task force on the work of the future (2019) reports that middle-skill workers are the majority of the class of workers affected by the 4th industrial revolution. Recent studies (Aladbulkareem et al., 2018) point out that AI and automation drive labor employment disproportionately and increase middle-skill workers' exposure to skill shortages and job displacement. Thus, the middle-skill workers whose work and tasks have the highest potential for automation face a more complicated transition. The MIT report (2019) addresses that training and lifelong learning are effective ways to update the middle-skill workers' qualifications for the labor market challenges caused by ongoing technological change. As construction is continually evolving towards automation, it is essential to provide workers with training in technological innovation and prepare and retrain them to interact and collaborate with robots (Stern, 2019). To prepare, educate, and train middle-skill workers to embrace the unprecedented changes and get ready for their parts in the automation era, it is critical to, first, analyze and understand how new automated technologies change the work and required qualifications for human workers.

This study aims to address this need by proposing a systematic approach to identify the potential impacts of new technologies on human workers' required qualifications. The proposed approach is based on three types of taxonomies: (1) taxonomy of the work and its tasks, (2) taxonomy of the robot and its functionalities, and (3) taxonomy of the human worker's qualifications (i.e., abilities, skills, and knowledge). To better present the proposed approach and its implementation, we considered Hilti's Jaibot for overhead drilling and examined how it changes the work tasks and required qualifications for plumber helpers whose tasks involve a lot of overhead drilling. Jaibot is a great example of a semi-automated robot that directly interacts with a human operator.

The primary contribution of this study to the body of knowledge is to create a systematic method to analyze the impacts of automation on middle-skill workers' required qualifications and work tasks. The outcomes of this study will help experts systematically design strategic plans to prepare and train middle-skill construction workers accordingly.

In the remainder of this paper, after a brief overview of Jaibot's functionalities, we introduce the proposed framework. Next, we discuss the outcomes. Finally, we present the conclusion and potential future works.

Jaibot: A Semi-automated Robot for Overhead Drilling

Jaibot is a semi-autonomous construction robot designed for mechanical, electrical, and plumbing installation to support overhead drilling in concrete ceilings with a dust control system based on building information modeling data (BIM) or AutoCAD layout. Jaibot is able to locate itself on the jobsite with human's control. Its navigation capability allows it to position and orientate where needed to drill holes based on digital plans. The level of robot autonomy is shared control as the human worker monitors the robot's process and carries out this task together (Endsley & Kaber, 1999). Jaibot has a safety capability as it helps remove potential risks associated with overhead drilling for users and is environmentally friendly with a dust shroud. Since Jaibot acts as a complementary role that requires interaction and collaboration with the worker, the human role is categorized as an operator who directly controls and works alongside the robot. Therefore, the team is composed of a human operator and the robot. The form of input for communication channels is electronic, which indicates that Jaibot receives information through a control device from the operator and passes information back to the worker by visual communication (Hilti 2020). Physical proximity is classified as approaching, and temporal proximity is synchronous for the operator and the robot to share the same space and work closely together without physical contact (Huttenrauch & Eklundh, 2004; Yanco & Drury, 2004). Jaibot can work up to eight hours with full charge to drill numerous holes overhead for many physical, repetitive installation tasks. Figure 1 shows a Jaibot performing overhead drilling.

Figure 1. Jaibot performing the overhead drilling task (source from Hilti Corporation)

Methodology

To systematically understand the impacts of automation on middle-skill workers' required qualifications and work activities, our study develops a framework consisting of three types of taxonomies: (1) taxonomy of the work and its tasks, (2) taxonomy of the robot and its functionalities, and (3) taxonomy of the human worker's qualifications. The design of the robot's taxonomy and its functionalities is inspired by previous works that aimed to classify robots characterized from different perspectives including Yanco and Drury (2002), Yanco and Drury (2004), Beer et al. (2014), Onnasch and Roesler (2020), and Jahn et al. (2020). We created the other two taxonomies (i.e., human workers' qualifications and work tasks) based on the Occupational Information Network (O*NET) data developed by the U.S. Department of Labor (2021). The dataset consists of a comprehensive directory of occupations in different industries and their required qualifications, including skills, abilities, and knowledge. O*NET collects this information through continual surveys from subject-matter experts. The latest version of the dataset was published in August 2021. For each job, the database provided a list of work activities and required qualifications. The required qualifications include 35 types of skills, 52 types of abilities, and 33 types of knowledge.

The latest version of the O*NET database contains 93 construction occupations. 84 out of the 93 occupations are considered middle-skill jobs. Among these occupations, a job entitled "Helpers of Pipelayers, Plumbers, Pipfitters, and Steamfitters" (HPPPS) is one of the jobs that involve tasks that require overhead drilling. To present the proposed method in this study, we focus on this job.

After creating the taxonomies, we use them for mapping the interactions among the elements of the taxonomies and identifying the impacts of automation on the human worker's qualifications.

Analysis

Taxonomy of the Robot and its Functionalities

Taxonomy, initially invented in biology, is the science of classifying the characteristics of an entity through a hierarchical structure (Ohl, 2015). As robotics has become a popular research field in recent decades, the application of taxonomy is extended to sorting robots based on types, applications, capabilities, and implementations (Jahn et al., 2020). Previous studies have proposed different taxonomies from various perspectives. Yanco (2002) created a Human-Robot Interaction (HRI) taxonomy that includes team composition, required interaction, and space-time location. In another study, Yanco (2004) updated the proposed taxonomy by adding human interaction roles, task types, and human-robot physical proximity to reflect the changes in HRI and its tasks. Beer et al. (2014) proposed a taxonomy framework to draw a relationship between human-robot interaction (HRI) and human-automation interaction to understand human-related variables. Onnasch (2020) developed a new HRI taxonomy that adds the context of the HRI and its application to various HRI scenarios. Inspired by the existing taxonomies for robots, our study proposes a new and comprehensive robot taxonomy. In this study, we calibrated the taxonomy to Jaibot, its characteristics, and functionalities.

The proposed taxonomy of the Jaibot consists of two main parts: capabilities and tasks. The capability part consists of six subcategories: (1) navigation; (2) autonomy; (3) safety; (4) human-robot interaction; (5) energy efficiency; and (6) usability. The task part consists of four subcategories: (1) information exchange, (2) physical load reduction, (3) manipulation, and (4) cognitive stimulation. Jaibot takes over most of the strenuous and exhausting tasks based on digitization, reducing the human's physical workload (i.e., lifting, climbing, and walking). The manipulation task is drilling holes overhead and then marking them automatically. Jaibot can memorize the process and upload it to the Hilti Cloud for tracking purposes, defined as a cognitive task. The information exchange describes the robot's acquisition of information from the environment and transfers it to the human (Onnasch, 2020). Therefore, Jaibot's information exchange task is a visual display because the robot receives the information through digital plans and transfers this information to the human through implementing the drilling task.

Each one of the subcategories is divided into more detailed elements. For example, the HRI subcategory is further subdivided into the human role, communication channel, proximity, and team composition. These elements are also divided into further detailed subcategories. Next, the characteristics are nested directly under their related subcategories. For example, under the human role element, we put "operator." Figure 2 shows the complete taxonomy.

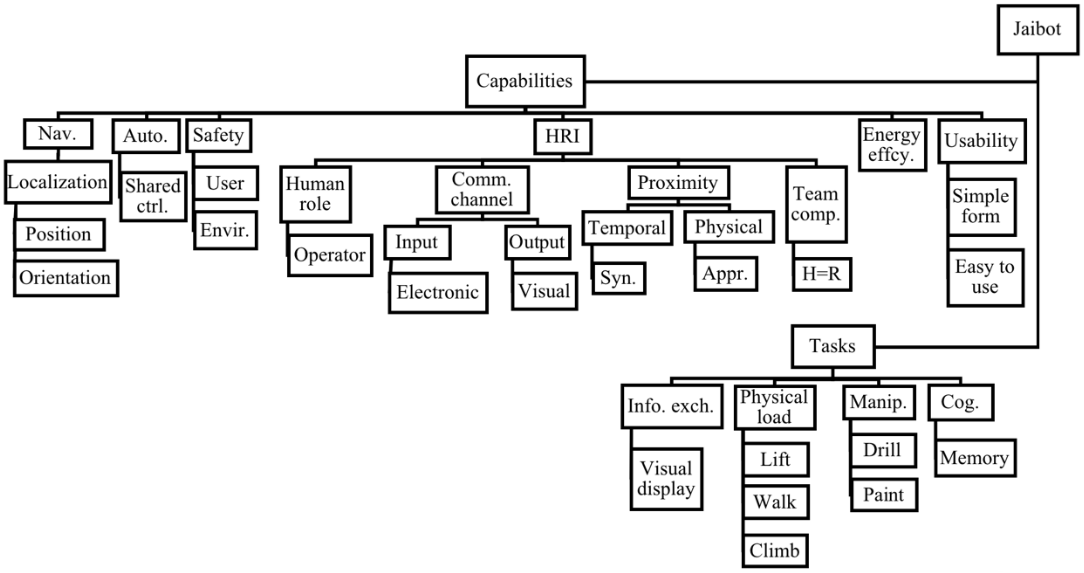

Figure 2. The proposed hierarchical taxonomy of Jaibot

Taxonomy of the Human Workers' Qualifications

As noted before, the taxonomy of human workers' qualifications is designed based on the O*NET database. Among the required qualifications for an HPPPS, we identified 15 skills, 9 knowledge areas, and 26 types of abilities linked to overhead drilling. Using these qualifications, we created the taxonomy that is shown in Figure 3. The required skills are classified into four categories: (1) basic skills; (2) social; (3) resource management; and (4) technical. The knowledge area does not have subcategories, but it contains the nine elements directly. The required abilities are also subdivided into four categories: (1) physical, (2) psychomotor, (3) cognitive, and (4) sensory.

After developing the taxonomy, the robot's capabilities should be mapped with the human worker's qualifications to identify the potential impacts of the new technology on the human worker's requirements. The human qualifications can be categorized into three groups: (1) those that are needed more when the worker uses the robot; (2) those that are needed less when the worker uses the robot; and (3) those that do not change. This process can be done by subject-matter experts. In this study, we did this based on inputs received from experts who have used the robot. We showed these groups in Figure 3.

Figure 3 shows that many human worker's qualifications that are linked to their physical characteristics will have a lower level of importance when Jaibot is used. For example, arm and hand steadiness under psychomotor abilities will not be that critical when a construction worker uses Jaibot for overhead drilling. Another example of qualifications that are needed less when workers use Jaibot would be near vision under the sensory abilities. Overall, most items under the ability category will have a lower level of importance when Jaibot is involved. On the other hand, some other qualifications, such as those under the technical skills category, will play a more critical role when workers interact with Jaibot. Examples include troubleshooting, operation and control, and equipment maintenance.

The importance level of a few qualifications may not change significantly when we use Jaibot. One example would be the management of material resources under resource management skills. In both cases of using and not using Jaibot, the user needs to make sure materials and equipment are ready for the job.

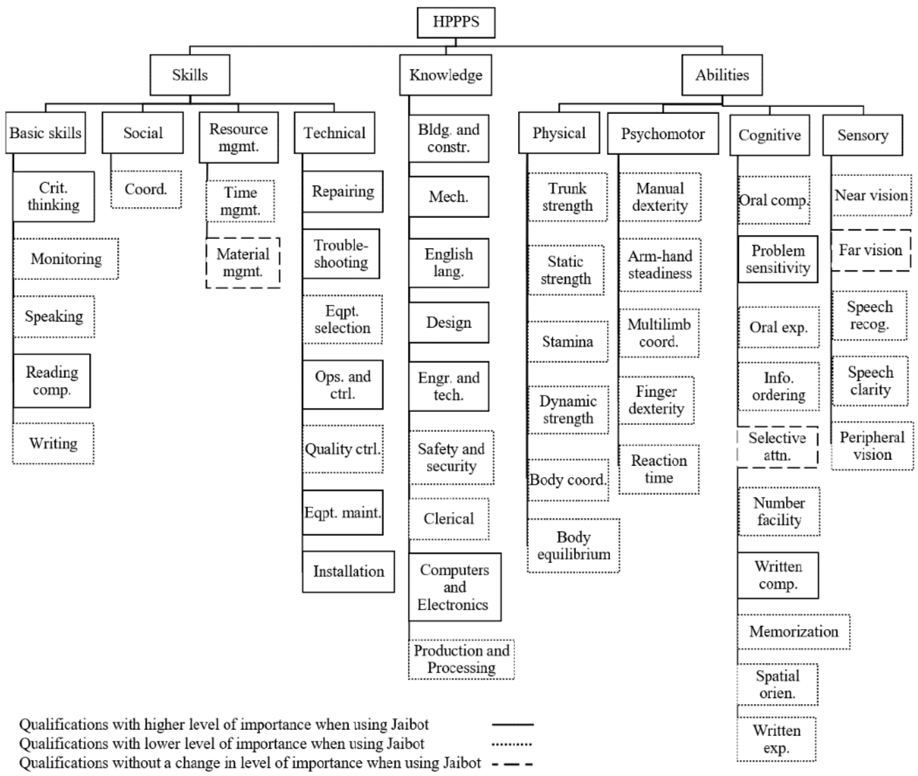

Figure 3. The taxonomy of the worker's qualifications

Taxonomy of the Work and Its Tasks

Not only do new technologies change the human worker's required qualifications, but they also may change the nature of the work and its tasks. The taxonomy of the work and its tasks help us systematically identify the changes. As noted before, this taxonomy is also designed using the O*NET dataset. The O*NET dataset lists 41 tasks for an HPPPS. Eighteen tasks, out of the 41, are related to overhead drilling. According to the O*NET classifications, we grouped those 18 tasks into four categories: (1) information input, (2) interacting with others, (3) mental processes, and (4) work outputs.

The information input category includes tasks related to inspection, getting information, quantifying, and process monitoring. The second category, interacting with others, involves communication with others and coordinating the work activities. The category of mental processes covers 7 tasks, including analyzing data and information. Finally, the fourth task, work output, includes tasks such as handling and moving objects.

Figure 4 shows the taxonomy of the work and its tasks. Similar to the taxonomy of human workers' qualifications presented in the previous section, we identified the tasks that change when Jaibot is used. The outcomes indicate that tasks that are linked to physical activities such as handling and moving objects and documenting will contribute less to what human workers do when Jaibot works. On the other hand, activities that need human judgments, such as repairing and maintenance of equipment, updating and using relevant knowledge, will play a more important role on the human side of the work when the robot is used.

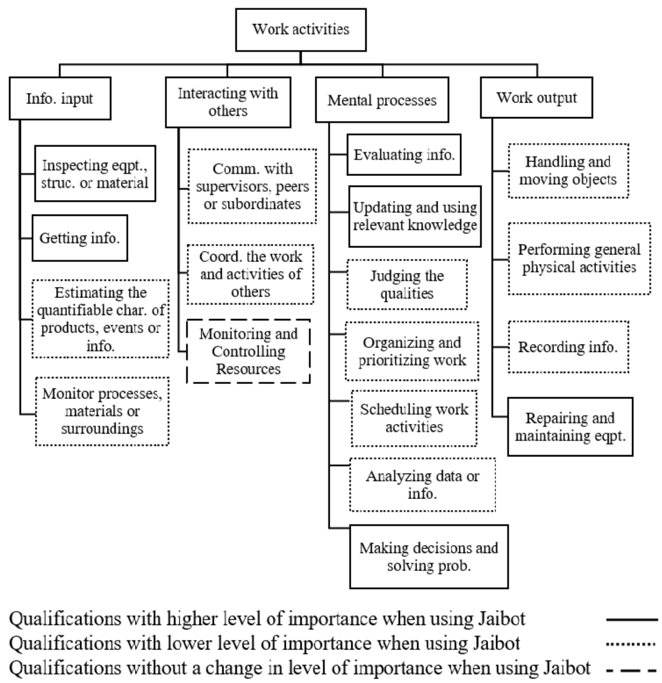

Figure 4. The taxonomy of the work and its tasks

Conclusion and Future Work

This study developed a systematic approach to analyzing how automation affects middle-skill workers' required qualifications and the work based on three types of taxonomies, namely the taxonomy of the work and its tasks, the taxonomy of the robot and its functionalities, and the taxonomy of the human worker's qualifications. To present and implement the proposed approach, we analyzed the impacts of the Jaibot robot by Hilti on the required qualifications that a plumber helper needs to have for overhead drilling.

We created the taxonomy of the Jaibot and its functionalities using a wide range of previous studies that designed robot taxonomies from different perspectives. To create the taxonomy of human workers' qualifications and the taxonomy of the work and its tasks, we used the O*NET database. We systematically mapped the robots' characteristics with human qualifications and the work tasks using the three taxonomies. The outcomes helped us systematically identify the changes that Jaibot creates in the human's required qualifications and work tasks.

Through the proposed framework, we identified the human worker's qualifications that may have a lower level of importance when Jaibot is part of the project team. Most of these qualifications are linked to the human worker's physical characteristics since the robot will take care of many physical aspects of the job. Examples include physical abilities such as strength and body equilibrium, psychomotor abilities such as manual dexterity, arm-hand steadiness, and multilimb coordination, and sensory abilities such as near vision and speech clarity. In addition, some cognitive abilities such as memorization may be less critical too, as the robot can record and keep all the data.

The required human qualifications that will be less critical is the positive side of employing new technologies. The challenge is the qualifications that are needed more when a human interacts with a robot. Using the proposed framework, we aimed to identify those factors too. Examples include repairing, troubleshooting, reading comprehension, and critical thinking.

In addition to the impacts of the new technology on human workers' qualifications, we also analyzed the impacts of the robot on work tasks. Using the proposed framework, we identified the tasks that will take a lower amount of time from the human when Jaibot is involved in the project and also those that will need more attention from the human side when they use the robot. For example, when workers use Jaibot, they may not need to perform general physical activities, move objects, and manually record data. However, they may need to do more equipment inspection, decision-making, and problem-solving tasks.

The primary contribution of this study to the body of knowledge is to create a systematic method to analyze the impacts of automation on middle-skill workers' required qualifications and their tasks. Although we focused on Jaibot to implement the proposed method in this study, the introduced method based on the taxonomy analysis can be applied to any other robot as well. The outcomes of this study will help experts systematically design strategic plans to prepare and train middle-skill construction workers accordingly. To the best of our knowledge, this study is the first effort to analyze potential changes of automated technologies on the qualifications of middle-skill workers and their work activities based on various taxonomies.

One of the limitations of this study is its dependency on the recency and accuracy of the O*NET database. The construction industry is a rapidly changing environment in which new tasks and qualifications are created, and it is critical that O*NET continuously captures these changes in its databases. Another limitation is that our study only considers skills, abilities, and knowledge as the worker's qualifications as we defined. However, other factors (i.e., personal interests and values) are not taken into account in this study. Addressing these limitations can be a basis for future studies. This study can set the stage for future research focusing on analyzing the impacts of automation on the middle-skill workers' qualifications and the work tasks during this technological revolution.

References

Alabdulkareem, A., Frank, M., Sun, L., Alshebli, B., Hidalgo, C. & Rahwan, I. (2018). Unpacking the polarization of workplace skills. *Science Advances*.

Beer, J.M., Fisk, A. D., & Rogers, W. A. (2014). Toward a framework for levels of robot autonomy in human-robot interaction. *Journal of Human-Robot Interaction*. *3* (2), 74-99.

Endsley, M. R., & Kaber, D. B. (1999). Level of automation effects on performance, situation awareness and workload in a dynamic control task. *Ergonomics*. *42*(3), 462-492.

Hilti Corporation. (2020). Hilti unveils BIM-enabled construction jobsite robot. Retrieved from https://www.hilti.group/

Huttenrauch, H., & Eklundh, K. (2004). Investigating socially interactive robots that give the right cues and make their presence felt. *The CHI 2004 workshop on shaping human-robot interaction.* 17–20.

Jahn, U., Heß, D., Stampa, M., Sutorma, A., Röhrig, C., Schulz, P., & Wolff, C. (2020). A taxonomy for mobile robots: types, applications, capabilities, implementations, requirements, and challenges. *Robotics. 9.* 109.

Leopold, T. A., Vesselina, R., & Zahidi, S. (2016). The future of jobs report in world economic forum. *Global Challenge Insight Report.*

Manyika, J., Chui, M., Miremadi, M., Bughin, J., George, K., Willmott, P., & Dewhurst, M. (2017a). Harnessing automation for a future that works. *McKinsey Global Institute.*

Massachusetts Institute of Technology. (2019). The work of the future: shaping technology and institutions. *MIT Task Force for Work of the future*.

McKinsey Global Institute. (2017). A future that works: automation, employment, and productivity. *MGI A future that works.*

Occupational Information Network. (2021). O*NET OnLine, https://www.onetonline.org/ (August, 2021)

Ohl, M. (2007). 4 Principles of taxonomy and classification: current procedures for naming and classifying organisms. *ResearchGate.*

Onnasch, L., & Roesler, E. (2020). A taxonomy to structure and analyze human-robot interaction. *International Journal of Social Robotics. 13*, 833-849.

Sachs, J., Benzell, S., & LaGarda, G. (2015). Robots: curse or blessing? A basic framework. *National Bureau of Economic Research.*

Stern, B. E. (2019). Addressing the workforce skills gap in construction and CRE-related trades. *NAIOP Research Foundation.*

Yanco, H. A., & Drury, J. L. (2002). A taxonomy for human-robot interaction. *AAAI Fall Symposium on Human-Robot Interaction.* 111-119.

Yanco, H. A., & Drury, J. L. (2004). Classifying human-robot interaction: an updated taxonomy. *IEEE International Conference on Systems, Man and Cybernetics. 3.* 2841-2846.