

## Chapter 2

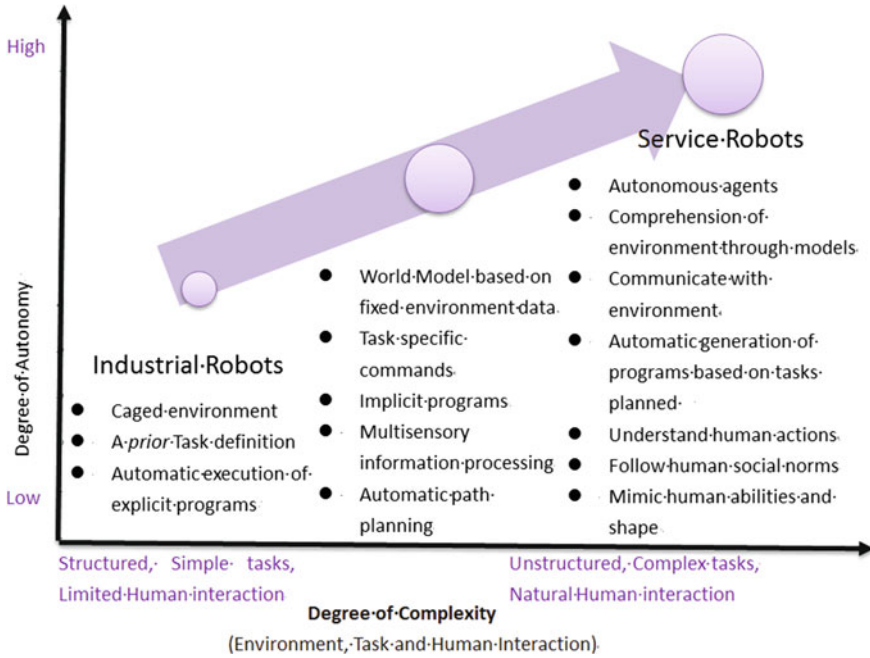
# Robots for the Construction Industry

**Abstract** Employing robots on building sites may have been considered an unattainable fantasy in the past or simply a futuristic dream. Many construction practitioners are fiercely opposed to the use of robots and are wary of losing their jobs when such creations are intelligent enough to replace human resources. In contrast, the prohibitively high costs of manufacturing, producing and using robots on-site, in comparison to the costs of hiring labourers, is a major concern thwarting the ideas of many construction practitioners who wish to try something new and innovatory. Hence, hiring a robot to work on-site is not an imminent threat to the workers. Nevertheless, the recent technological breakthrough has caused waves in the industry and excited interest. It is reasonable to foresee that robots will usher in a new era in the construction industry. In this chapter, we adopt the data and method triangulation approach to study the construction practitioners', academics' and tool providers' viewpoints with regard to the costs and benefits of robots on construction safety and the construction industry. The interview results show that academics and construction practitioners in different parts of the world worry that robots may take jobs away from manual labourers. Wearable robotics have recently been introduced to one of the companies in Hong Kong's construction industry, yet most workers and even safety officers have no knowledge of this advance. A focus group interview has been conducted with a PowerPoint presentation and some research participants have worn the wearable robotics and commented on the tools' usefulness and efficacy.

**Keywords** Robot • Wearable robotics • Construction safety

### 1 Introduction: A General Overview on Robots

Between the 1960s and 1990s, many robots were designed for industrial application. They were used to rationalise manufacturing production and were equipped with prior task definition to execute works according to predefined programmes.



**Fig. 1** Degree of autonomy and complexity from industrial robots to service robots (Haidegger et al. 2013)

Later on, robots were equipped with sensors to ascertain the working environment. Today, modern robots are ubiquitous. They have a certain level of artificial intelligence and can support, nurse and accompany humans (Haidegger et al. 2013; Li et al. 2016). Figure 1 illustrates the changes in robots over recent years.

In-depth research on robots suggests that they can autonomously react to any situation they encounter. For one example, they are able to open any type of door. Nevertheless, many of them can deal only with particular tasks in very specific situations (van Osch et al. 2014). Thus, it is often considered unrealistic to believe that a robot can fulfil some of the work tasks that have always been accomplished by human beings. Likewise, some construction practitioners do not wish to even consider the idea of adopting robots on-site for construction works at this premature stage.

No matter the perceptions, the reality or inconvenient truth is that robots are, in fact, slowly replacing some jobs originally conducted by humans. For example, some shopping malls use robots to replace ordinary security guards. A bank in China recruits a robot to act as receptionist “who” can handle customers’ enquiries

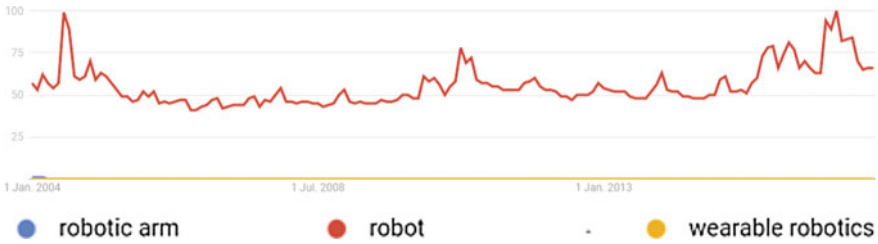
and persuade their potential customers to use their services. Recent research forecast that the US market will grow at 15% annually while the Chinese trade will increase by 17%. Service robots have become more significant throughout the first decade in the twenty-first century (Haidegger et al. 2013). As robots and other computer-assisted technologies take over manual labourers' tasks, there is rising concern about the future job market. By analysing the effect of the industrial robot usage from 1990 to 2007 in local labour markets in the United States, the research bolsters evidence that robots may reduce employment and wages. It is estimated that one more robot per thousand workers lowers the employment to population ratio by about 0.18–0.34% and wages by 0.25–0.5% (Acemoglu and Restrepo 2017).

## 2 Popularity in Robots, Robotic Arms and Wearable Robotic Searches as Reflected in Google Searches: A Big Data Analysis from 2004 to the Present

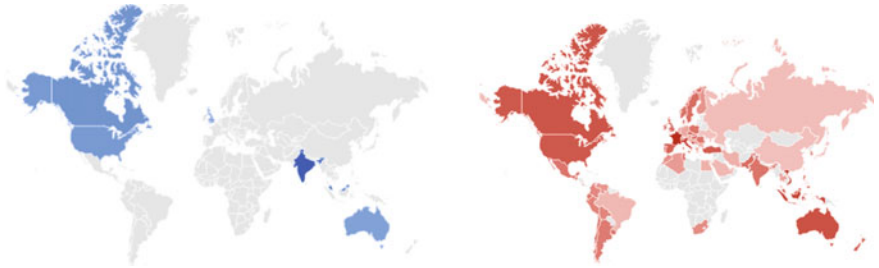
Whilst the subject of robots is discussed by many individuals, ranging from China to Peru, most of us may share the instinctive feelings that robots are envisaged as comprising two legs and arms only. In reality, there are three types of robots. The first is a traditional robot, with arms and legs, and able to move around freely. Smart home robots represent one of the very good examples. Another type is a robotic arm, which only processes arm-like movements (Fig. 2). Finally, there are now



**Fig. 2** Robotic arm designed for industrial use, preparing food (photo taken by the author)



**Fig. 3** Comparison with the number of searches between robot, robotic arm and wearable robotics from 1 Jan 2004 to 21 April 2017, in Google (2017)



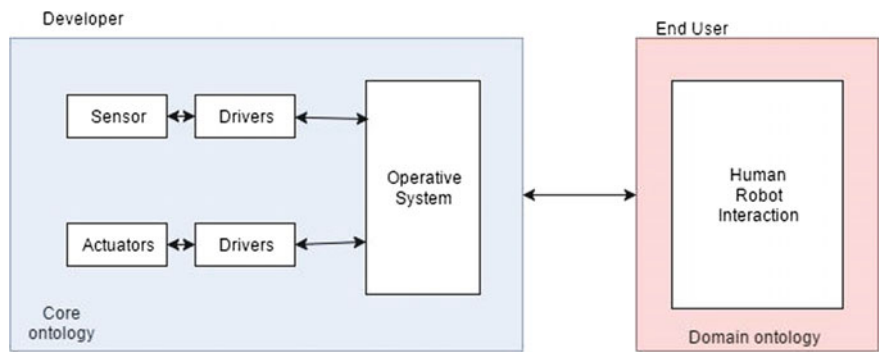
**Fig. 4** Comparison of the regions with most searches on robotic arm (*left*) and robots (*right*) (Google 2017). *Note* There is insufficient data to illustrate regions for wearable robotics searches on the map (Google 2017)

wearable robotics, which need to be worn by humans to provide extra strength and support. All of these can potentially be used on sites (Li and Ng 2017).

Following the big data analytics adopted by Li et al. (2016), the figures below show the comparison the relative popularity of robotic arm, robot and wearable robotics in Google searches. There are a lot more searches in robot as compared to wearable robotics and robotic arm. The three largest number of searches of robotic arm comes from India, the Canada, the United States and Australia indicated by darker blue colour. On the other hand, the largest number of searches for robots are France, Bosnia and Herzegovina and Vietnam (Google 2017) (Figs. 3 and 4).

### 3 Information Flow Between Robot and Human

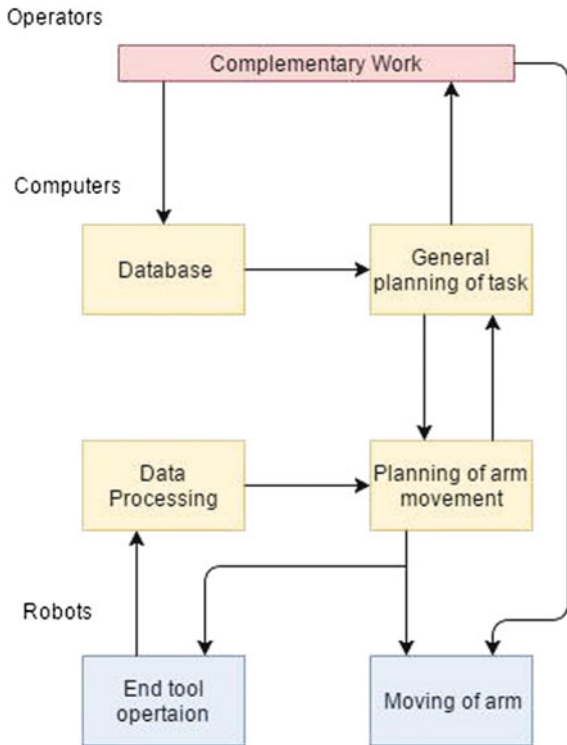
In general, there exists a core and domain ontology between developer and end user. The core ontology consists of sensors, actuators, drivers and operative systems and the end user domain ontology concerns the human–robot interaction. The



**Fig. 5** Core and domain ontology between developer and end user (Haidegger et al. 2013)

human–robot system consists of three elements: computer, operator and robot. Figure 5: Core and domain ontology between developer and end user (Haidegger et al. 2013). A human operator performs two complementary actions: preparatory and supplementary work. The preparatory work includes data input to the computer with regards to the task. The supplementary work includes preparing the materials,

**Fig. 6** The relationship between robots, computers and operators (Kahane and Rosenfeld 2004)



guiding the robot, placing it in the correct position, providing technical support and acquainting the robot with the work environment. Relying on its database, the computer plans the task at the workstation and presents the work plan to the operator, for feedback. After the operator revises and approves the plan, manipulator movements are initiated. Upon completion of the robot movements, the computer puts the sensors on the right track (Kahane and Rosenfeld 2004) (Fig. 6).

## 4 Robotics Application in the Construction Industry

Construction work usually takes place in a disorganised environment hosting many types and areas of danger. The idea of replacing construction workers with robots offers many advantages; for example, safety, quality and productivity improvement. Current trends in skyscraper towers, with accompanying escalations in labour costs and difficulty in hiring suitable workers, inevitably raises the need to adopt various robotic technologies in the construction industry (Jung et al. 2013).

The desire to move towards robot architecture has been developed through the current interest in constructing extremely high-rise buildings in Southeast Asia. Moreover, many of these structures do not take the form of traditional “straight up and down” designs but boast innovative typologies. Researchers have developed model-building robot systems that can construct 1:50 scale models. The model-building projects allow construction practitioners to envisage a new building’s appearance, structural stability and construction reality (Bloss 2014).

At present, robots are mainly used for dangerous and laborious jobs. Bricklaying and paving is repetitive and hence can be conducted by robots. Despite its repetitive nature, bricklaying can lead to construction accidents. Bricklayers’ workloads can be very high. The highest workload occurs when the bricks are loaded and unloaded via a wheelbarrow 0–50 cm above the floor. Anliker developed one of the earliest masonry automation systems that can build brick walls up to 8 m long. Lehtinen developed two masonry robots which utilise seam adhesive to glue the brick. Slocum and Schena produced a “Blockbot” that dry the stacks of concrete blocks. Pritschow et al. proposed a bricklaying robot that operates on-site to pick the bricks from prepared pallets, apply bonding materials and erect brickwork accurately, perform mortar plastering on the bricks and squeeze the brick onto the mortar (Yu et al. 2009). Figure 7 shows the process of making a bricklaying robot under the lens of Yu et al. (2009) and Table 1: Construction and infrastructure activities with the help of robots in the construction industry.

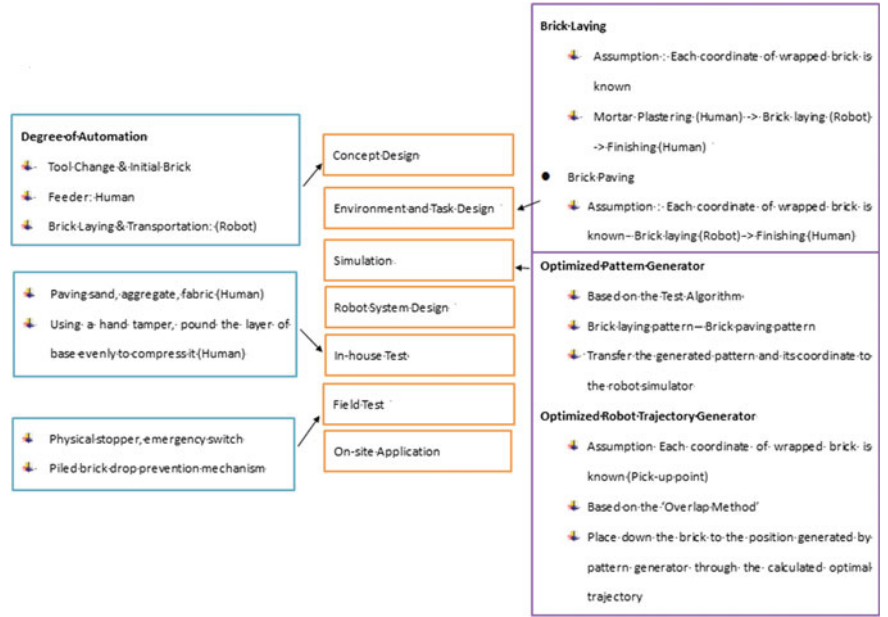


Fig. 7 The process of making a bricklaying robot (Yu et al. 2009)

Table 1 Construction and infrastructure activities with the help of robots (Bloss 2014)

Construction	Building services and maintenance
	Housing and building construction
	Construction in special areas, for example, deep sea, arctic zones, space and desert
Infrastructure	Bridge, container port, tunnelling and road construction
	Construction and deconstruction of power plants and dams

In view of these examples, gone are the days when robots could only be used in the design studio or laboratory. Many of the modern day robots address construction and fabrication issues on-site. These challenge the traditional construction approach and create new fabrication techniques for designers. In turn, this approach transforms architectural works by traditional construction techniques to feasible construction works on sites (Bloss 2014).

## ***4.1 Four Types of Robots in the Construction Industry***

### **4.1.1 Traditional Robots**

Controlled by computers or other kinds of stimulus on-site, robots are used to autonomously construct the superstructure of buildings. Different types of robots are used for different types on sites. For instance, climbing robots have been used for bridge, skyscrapers and highways maintenance. The underwater construction robot for heavy work is driven by a hydraulic system that is robust to external force. Traffic Marshal Robot with motorised hand movement conveys car users a clear message that there is road work ahead. Likewise, the installation of heavy building materials, such as exterior curtain wall panels, is often hazardous and complicated: traditionally, a large amount of manpower is often needed (Li and Ng 2017). Indeed, with the help of robots, however, a number of workers who need to work on sites can be reduced. For example, PN Safety Industries (2017) has developed a Traffic Marshal Robot with motorised hand movement for road safety.

### **4.1.2 Wearable Robotics**

The AWN-03 provides back support, senses a worker's motion and sends a signal to motors, which rotate the gears. The Suit AWN-03 embraces the user's shoulder, waist and thigh. In essence, it assists construction workers' movement when they lift and grasp heavy items. It raises workers' upper body support, pushes their thighs and lessens lower back stress by 15 kg. The battery power pack of AWN-03 lasts for six hours and each of the robot suits is sold for approximately US\$8100. It is expected that there will be an increase in demand for AWN-03 amid the labour shortage problems and the ageing workers in the construction industries (Li and Ng 2017).

FORTIS, another wearable exoskeleton, enhances users' strength and work clothing. Similar to Iron Man, the tool is unpowered and light in weight. The external structure enhances the user's endurance. It aids workers in lifting heavy loads, such as reinforcing bars, and while using industrial tools. It transfers loads to the ground via the exoskeleton when the construction workers stand or kneel. It creates a weightlessness sensation when wearers are carrying or manoeuvring heavy objects. The exoskeleton's ergonomic design moves naturally with the wearer and is able to adapt to various different body heights and types. Capable of supporting up to a thirty-six-pound instrument, it is designed like the bucket of a cherry picker or a man lift. It is used to support large tools which may be tiring to



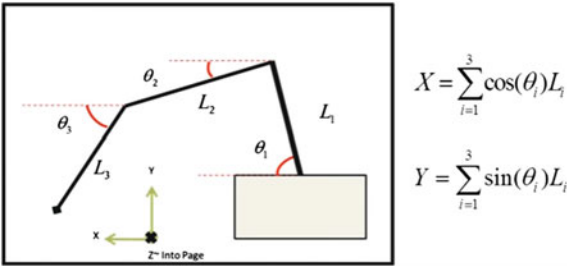
operate overhead and horizontally, such as grinders, demo hammers, rivet busters, etc. (Li and Ng 2017).

4.1.3   Robotic Arm

Robotic arms are usually discussed together with robots as their size is relatively small but they can carry out all types of work conducted by robots. For example, a robotic arm is constructed with servo brackets, which are made of aluminium due to its lightweight properties but are stiff, to mimic a human arm. Similarly, the robot gripper is also made of aluminium for the same reason (Candelas et al. 2015).

Figure 8 shows the design of a typical robotic arm. A robotic arm includes an infrared sensor to determine radial distance, a USB camera to detect the necessary accelerators, angular orientation to provide feedback for angles and force sensors to determine whether the arm can grab an object. The constraints of the robotic arm can be solved by Optimisation Toolbox in Matlab via fmincon and other software. Table 2 demonstrates the sensors required to operate the robotic arm, and Fig. 9 shows the typical mini-robotic arm with gripper, servos (to alter the direction of the robotic arm) and Arduino board (acts as the “brain” of the robotic arm) (Li 2017, forthcoming-b).

**Fig. 8**   Design of robotic arm  
(Li 2017, forthcoming-b)



**Table 2**   Sensors required for making the robotic arm (Li 2017, forthcoming-b)

Sensors needed	Reasons
Two infrared sensors	To determine the radial distance between the object and the arm
USB camera	To detect the angular orientation of the object
Accelerators	To provide feedback for angles $\theta_1, \theta_2, \theta_3$
Force sensor	To determine if the arm grasps something

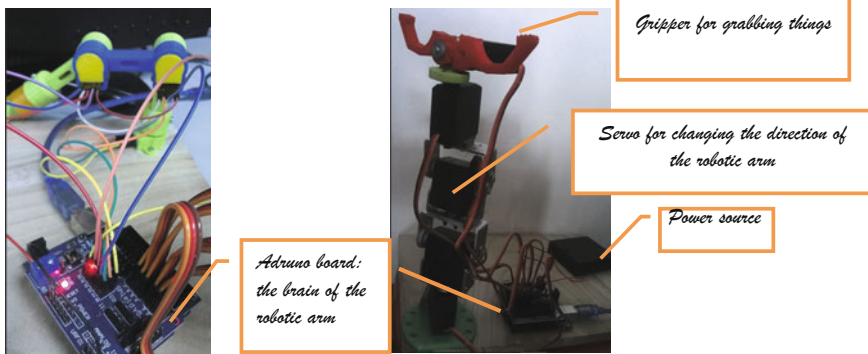


Fig. 9 A robotic arm made by the author (author's photo) (Li 2017, forthcoming-b)

## 5 Monetary Benefits of Using Robots on Sites

"A penny saved is a penny earned." When making decisions to purchase materials that are new to the market, most companies need to recognise the benefits they will incur when they make any groundbreaking decision. Robot purchase is no exception. Senior management personnel need to be certain that such purchases make economic sense for the future of the company.

Revisiting the issue of the nature of the construction site and the inherent labour shortage, a clear picture emerges regarding why robots are adopted. The construction industry has always been considered as dangerous. The heat of summer and the cold winter months worsen the work environment in the cities and deter many workers from seeking employment in the industry. In view of the labour shortages, manual labourers' costs are inexorably rising around the globe. For example, a 27-year-old concrete worker toils at least 18 h per day and earns HK \$160,000 (about US\$20,513) per month. Many of the workers even earn HK \$110,000 (about US\$14,103) monthly in Hong Kong (see Table 3). The high labour costs, coupled with possible compensation payouts, have become two of the major reasons why construction industry practitioners are exploring different outcomes through employing robots on sites.

**Table 3** Construction workers' salaries in different trades in Hong Kong (Yu 2016)

Types of work	2015/2016 (HK\$ per day) (HK\$7.8 = US\$1)	2016/2017 (HK\$ per day) (HK\$7.8 = US\$1)
Plasterer	\$1350	\$1450
Carpenter	\$1130	\$1230
Painter	\$1120	\$1170
Plumber	\$1250	\$1350
Formworkers	\$2050	\$2500
Steel fixer	\$1930	\$2150
Concreter	\$2300	\$2500
Scaffolder	\$1700	\$1800
Surveyor	\$1200	\$1300
Electrician	\$1150	\$1210
Metal Scaffolder	\$1150	\$1250
Metal worker	\$1080	\$1150
Mason worker	\$1100	\$1150
carpenter	\$1130	\$1230
Ceiling and Partition labourer	\$880	\$1000
Pile driver	\$1300	\$1350

## 6 Are Robots Safe to Use? Safety Issues in Using Robots

Asimov mentioned robot safety as early as 1942. However, Asimov's three laws are insufficient to cope with today's robots' behaviour. Modern industrial robot standards provide guidelines for robots and their working environment. ISO 10218-1 (2011) and ISO 10218-2 (2011) standards delineate the requirements to lessen critical hazards. Project teams need to consider the trade-off between technical attributes and pertinent safety requirements, due to the emerging issue of the robot. Interlocks and guards protect people who work with robots. For years, industrial robot safety has been considered as a problem, in use, and has resulted in laws and regulations which keep users away from robots. Well-defined operations, such as programming, repair and teaching, are difficult (Mitka et al. 2012). The American National Institute of Standards and Technology classifies three levels of safety zones for robots (Mitka et al. 2012) as shown in Fig. 10. Figure 11 demonstrates the risk assessments and reductions for robots on construction sites (Mitka et al. 2012).

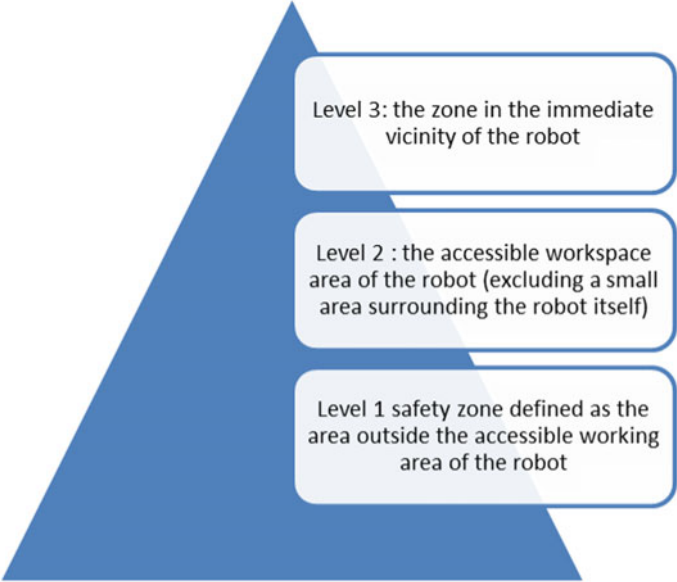


Fig. 10 Three levels of safety zones for robots (Mitka et al. 2012)

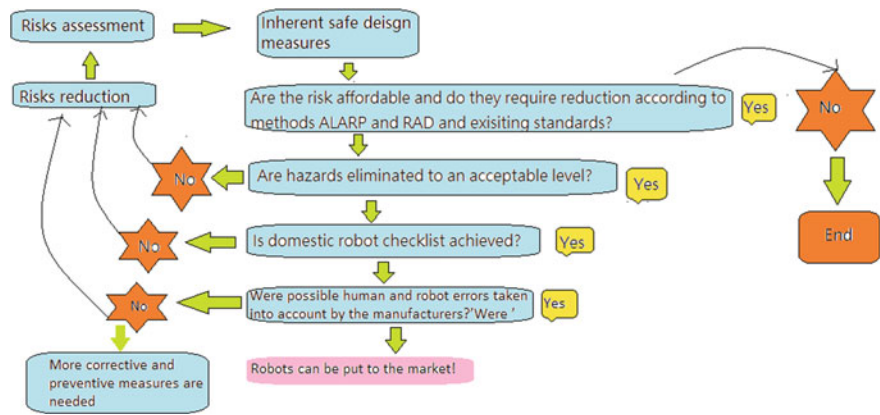


Fig. 11 Risk assessments and reductions for robots on sites (Mitka et al. 2012)

## 7 Research Method

In this chapter, we adopt data and method triangulation to study various stakeholders' viewpoints on robots, robotic arm and wearable robotics' implication on construction safety. Previous research results suggest that different research methods have their weaknesses and strengths. Method triangulation research (a combination of different research methods, between two or more) enhances accuracy and validity (Li 2015).

We first conduct an in-depth interview with construction practitioners. Following that, we conduct a case study. As some of the robotics, such as robotic arms and wearable robotics, had not yet been introduced to Hong Kong by the time we conducted the case study, focus group interviews where the interviewees can try the tools and presentations are particularly useful in studying the practitioners' viewpoints and perceptions.

## 8 Practitioners Viewpoints on Robots

In Hong Kong, many of the interviewees are aware that the usage of robots on sites is imminent. An innovation manager in a large-scale construction company mentions that his company has used robots for installing window panels. One of the CEOs of a construction firm suggests that their company has adopted the robots for laying pipes on construction sites, as it is difficult for workers to do so underground. A safety officer in a gas company suggests that when the existing gas conduit for the construction sites is repaired, his company does not want to dig the ground and repair it. Robots can be used for repairing the existing gas conduit without causing much disruption to the nearby neighbours. Thus, we may conclude that in Hong Kong, most of the robots are used to perform varying jobs that prove difficult for manual workers to undertake, such as underground work and heavy-duty works, including window panel installation.

The benefits of robots may be addressed by the question posed by a CEO in one of the largest construction companies in Seattle: "*[the question that we have in the construction industry is] how do we leverage people? We have so many repetitive [tasks] that need to be done manually...*" A section chief for a construction company in Fujian, China, suggests that robot manipulators enable large-scale factory automation of simple and repeated tasks. A project manager, currently stationed in Shanghai, agrees that robots can save time and offer high efficiency.

### 8.1 Implications of Robots on Construction Safety

Most of the interviewees agree that the reason why the employment of robots must lead to fewer accidents is prominently due to their ability to replace manual

workers. For example, a structural engineer in Hong Kong suggests that *“it is in no doubt that a robot is helpful in construction. Robots play an important role in taking down a wall, which can replace construction workers and reduce the injury rate. Also, it can forecast the difficulties when constructing a building”*. A labour union chairman in Hong Kong suggests that *“robots can replace workers in collecting and putting the safety cones in the road. As many of the recent construction workers were killed or injured due to reckless drivers carelessly hitting the workers, replacing the manual work by robots can reduce safety risks. Likewise, the robots can also work underground where the confined space is so small that there is no room for humans to work and unknown toxic gases may cause accidents”*. A CEO of a safety investigation company suggests that *“robots can work at hazardous jobs; for example, they can work in environments with asbestos”*. He also quoted an example of when a fire exploded in a warehouse in Hong Kong, causing the death of two firemen. A client of his asked if their company could send their robots to take photos. Thus, he considers that robots can act as helpful assistants in planning ahead for some of the dangerous jobs. Nevertheless, he also agrees that not all work can be replaced by robots, despite the safety perspective. For example, we need to hire a worker to monitor the robots. It is hard to hire a robot to monitor the robots. With given and limited resources, humans have to make their own judgements on whether robots can be used for the sake of safety and other concerns.

An academic researcher (also working as an architect) from Hong Kong shares similar thoughts and suggests that the ability of robots to reduce construction accidents is mainly due to the fact that *“the dangerous work or work with high risk could be carried out by [them]”*. Two professors from different universities in the United States are also in agreement. One of them suggests that *“the costs will be high but the benefits could save lives”*. Another professor proposes that *“as there are fewer humans on sites, there will be lower chance for human injury”*.

## 8.2 Costs of Using Robots

Most of the construction practitioners are sceptical about adopting robots on sites. Some of them consider that the major drawbacks for robots are the financial considerations. They are of the view that the costs for adopting robots on sites are higher than other automated tools, such as virtual reality and additive printing. An academic professor from Melbourne reveals that the *“costs include robots, software and hardware engineers for customised applications for the robots”*. A university professor in the United States who still holds an industry position in Iran concedes that a *“robot is expensive technology and needs training and expertise”*. A CEO of a construction company in Guangdong added *“the cost is the price and technology. The price of making the robot in a safe way is very expensive. Also, it needs in-depth technology to maintain the safety”*.

A senior management from a construction company in Seattle, however, does not agree with them. He holds an optimistic view on this issue as his company is now investing a large amount of resources in developing artificial intelligence, meaning that the robots can have their own “thoughts”, making the best decisions for the building processes, saving time and money for the construction company. Thus, they consider what they are doing now is a good investment. A robot provider suggests that *“despite the costs of buying robots, it saves the labour costs a lot, with higher efficiency since it does not need a break; just needs electricity then it works 24/7”*. A senior management member of a safety investigation company in Hong Kong is of the view that the costs are only high at the initial stage but will reduce as the tool becomes mature and more widely used.

A top construction journal editor in chief in the United States also throws light on artificial intelligence of robots *“robots are mostly used for surface furnishing, simple for robots to do, but dangerous for humans to do. Robots must have artificial intelligence to accomplish the tasks. Nevertheless, if that has too much AI, they are very expensive. Most robots have to be as cheap as possible with less AI and accomplish the work”*.

### **8.3 Robots Replacing Manual Workers on Sites Is Simply a Fantasy**

A CEO of a construction firm in Hong Kong keeps things in perspective and suggests that *“robots can hardly replace human work, because the robots cannot climb as a human climbs. On the other hand, the robots are so heavy that the scaffolding cannot support [the heavy robots] and robots cannot work well with some of the small tools”*. Another safety officer who works for one of the largest contractors concedes that *“the robots cannot replace human beings, as artificial intelligence is not that well-developed”*.

I think robots are difficult to work on site. Factory-like production can be done by robots as works are fixed and can be easily standardised. Nevertheless, it is quite difficult to use them on sites when works are not fixed. Every single piece of work can have errors: we have to make sure everything is in a correct place. You cannot make a minor mistake as you cannot pass the standard if there is any error.

Because a construction site is not flat enough, robots may not work well. When it comes to building flats, it will not even be flat. This is because there will be more job mud. When we build flats, there will be more materials needed. When there are over 20 different types of material on sites, it will be more difficult.

A safety officer in Macau suggests *“I think this can have a use in planning or method statements, such as for display. For example, we can use robots to show the installation of buildings, which can be used in the long-term or existing situations. I think using a robot is the most useful”*.

A structural engineer thinks that robots cannot replace all the manual labourers' work: *"There is still a question if the robot is an end solution, since its price is too high and it is in doubt whether today's technology can deal with a variety of jobs on sites... Whether robots [are useful or not for construction works] depends on the [nature of the] job. Some manual work is impossible to be replaced by robots. For example, it is hard to find a robot to carry the tool and weld for you"*.

A professor from the United States with over thirty years of research in robotics comments *"the number one reason for not using robots is construction law preventing [robot] from happen. Nobody wants to be number one in the industry. Everybody wants to be number two. They know all the risks. Risks mean we have product liability, you have insurance policies for contract design...if you going to use this technology, we (insurance) are not going to cover it. It is unproven, it is untested and therefore you are entering to construction liability and product liability. And there is professional liability...Legal liability besides contract law that the unproven technology cannot be used in a given site. You have professional liability that extends to people who make decision, either from design to those who take decision"*.

#### **8.4 Are Robots Threats to Construction Workers?**

Adopting robots for various kinds of jobs should come as news to no one. One of the traditional explanations for why we do not adopt robots for work is due to everyone's natural fear of losing jobs. Thus, wider adoption of robots on sites is still a moot point. Some interviewees consider it is impractical and unworkable to use robots on sites and that the idea has no merit. A researcher working in Switzerland is worried that robots will worsen the current high unemployment rate in Europe: *"If I am an employer, I cut costs to [reduce] intensive labour: it is ok in one enterprise or so. If we all do that, it can be problematic. If we put drones in as well, they do the most dangerous work. People do not need to do the risky work. The big picture...many people will be unemployed if digitalisation can be shared by the population as a whole"*.

In Spain, 25% are unemployed. Actually more than this. They have difficulty finding a job in the market. Some employed subsidise those who are unemployed. Limited extent of migrants and very controlled. If you find the way to distribute a mining site, digging out ... generate some wealth at least to a minimum, to lose the job, it's better to have robots to work for digging something in the sea. The question is how to deal with the issue. That's better. Look at Arab Spring who don't see the chance in the labour market riots and social unrest.

Thus, he suggested that the major hurdle in hiring robots lies mainly in Trade Unions. *"The trade union is very powerful and manages to put some limits on*

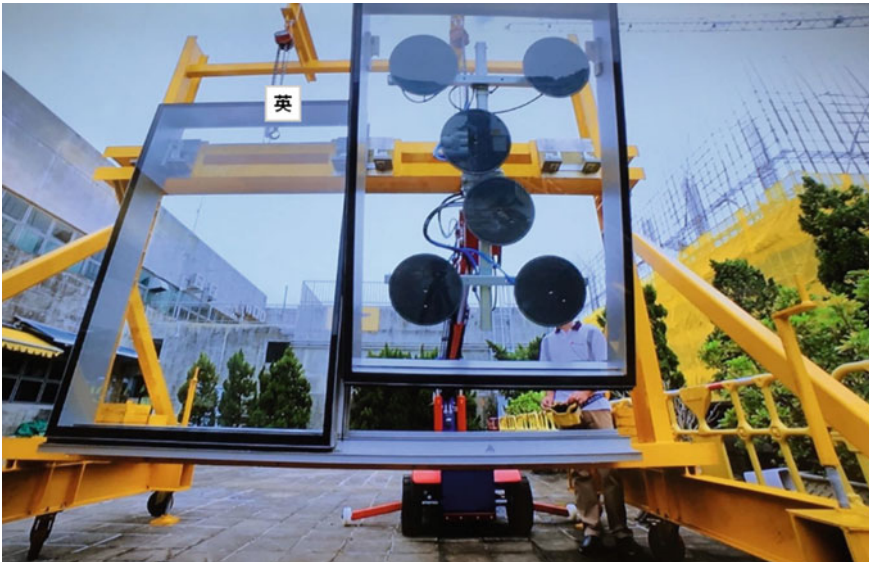


*technological change. They have strong working hours and we work more on developing countries. You don't need so much support. If in a market approach, private companies will try to cut costs as much as possible. I don't know whether we should stop it. The private companies are investing but Switzerland is a small country. The economy is not growing fast. They benefit from international. Everybody will be employed. The question is what happens if the welfare is not there. That's a question we need to answer together. What happens if Europe subsidises those who do not work. The number of unemployed is growing.*

## 9 Modern Application of Robots, Robotic Arm and Wearable Robots on Sites

### 9.1 Application of Robots on Sites

One of the largest Hong Kong local construction firms has adopted robots to reduce the number of workers and to enhance productivity and safety. In one of the hotel redevelopment projects, the presence of robots reduced the number of workers on-site by 25% (Figs. 12 and 13).



**Fig. 12** Large window panels are installed with the help of robots (author's photo)



**Fig. 13** Large window panels are installed with the help of robots (author's photo)

## ***9.2 Application of Wearable Robotics***

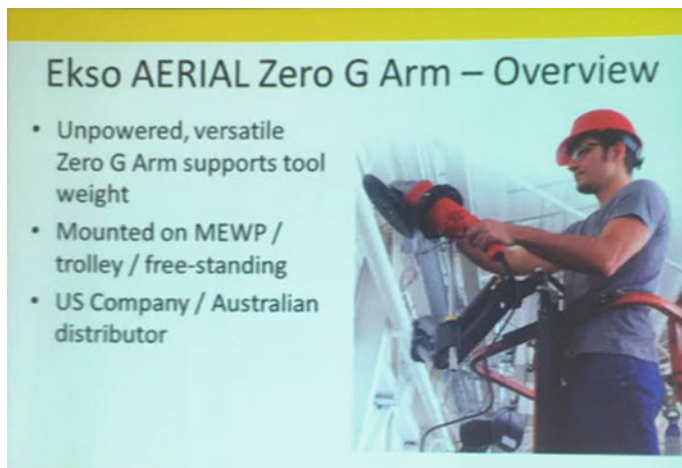
This construction company has also purchased two sets of exoskeletons, a kind of wearable robotics from Japan that protects their workers, improve their efficiency and reduce risk. According to the company's safety officer, it is used to protect workers' backs and waists. This is particularly useful when they work for a prolonged period. However, the cost of this technology is high: it is difficult for a small-size company to use such innovations (Li and Ng 2017).

As wearable robotics, such as exoskeletons and robotic arms, reduce strain and lighten heavy loads, they inevitably benefit older workers. As robotics technology continues to develop, coupled with the rapid progress in programming and robot maintenance techniques, this certainly opens up new opportunities for younger staff, who are often considered to be the best age group to welcome modern technology the most and who often look for innovative applications, such as wearable robots. Nevertheless, some workers worry that robots will eventually take jobs away from them or lead to some of the scenarios from a science fiction film. Yet, many countries and cities in the developed world experience the problem of labour shortage as fewer people enter the industry. Therefore, robots are simply doing their jobs in filling the gap left by a dwindling workforce (Li and Ng 2017).



**Fig. 14** Panasonic ActiveLink AWN-03 (“Ekso works,” 2016) (author’s photo)

In Hong Kong, using the robot’s motor assists with human body mechanics, minimising the risk of human error. It reduces physical strain during human work, assists lower back body movements, detects the user’s motion in the lower back when lifting and holding heavy objects and then sends a signal to the motors to rotate the machine’s gear. It raises workers’ upper body whilst pushing their thighs, lowering the user’s stress at the back by 15 kg. Users can wear the tool by themselves and do not require extra help from others. Thus, it is easy to use. It has three major features: an auto assist mechanism, it is easy to put on and the battery can last for 8 h. <https://www.youtube.com/watch?v=zGmymin7d0o> (Figs. 14, 15 and 16).



**Fig. 15** Ekso Aerial Zero G Arm (author's photo)



**Fig. 16** Ekso Aerial Zero G Arm (author's photo)

**9.3 Focus Group Interview Results of Practitioners’ Perspectives on the Exoskeleton**

In this research, we were grateful to have the opportunity to attend the lunch meeting offered by a construction company to conduct a focus group interview. The meeting began with a detailed PowerPoint introduction on wearable robotics; i.e. various types of exoskeleton presentation. After that, workers and our research assistants tried to use the tools.

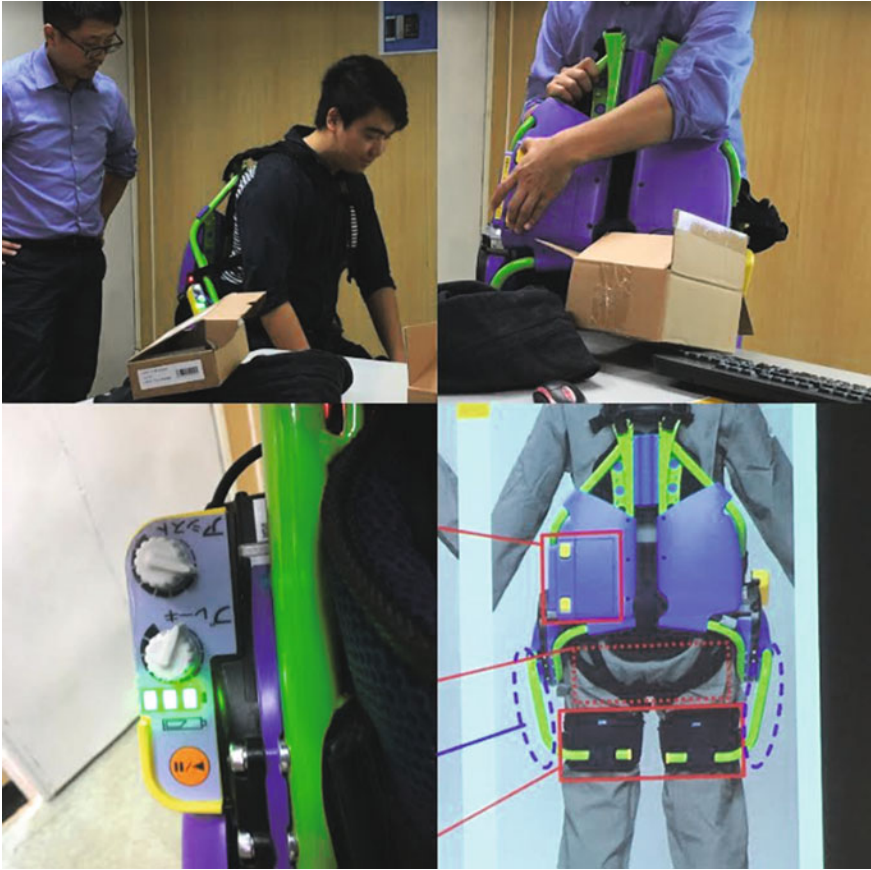
Worker A suggests that the company may purchase some exoskeletons: when the workers need the tool for one particular procedure, they can get one from stock. The costs are quite high currently but will soon decrease when they gain popularity. Worker B recalls that at the very beginning, the costs of mobile phones were quite high. The costs of the exoskeleton may also reduce substantially, later, but he thinks that will take a very long time. At the meeting two workers were also invited to wear the exoskeleton.

Worker C, a well-built man, suggests that the tools should be able to help him in moving heavy equipment. Nevertheless, another worker states that the person who wears the exoskeleton can only help him in moving heavy materials if his hand is



**Fig. 17** AWN-03 robotic (author’s photo)

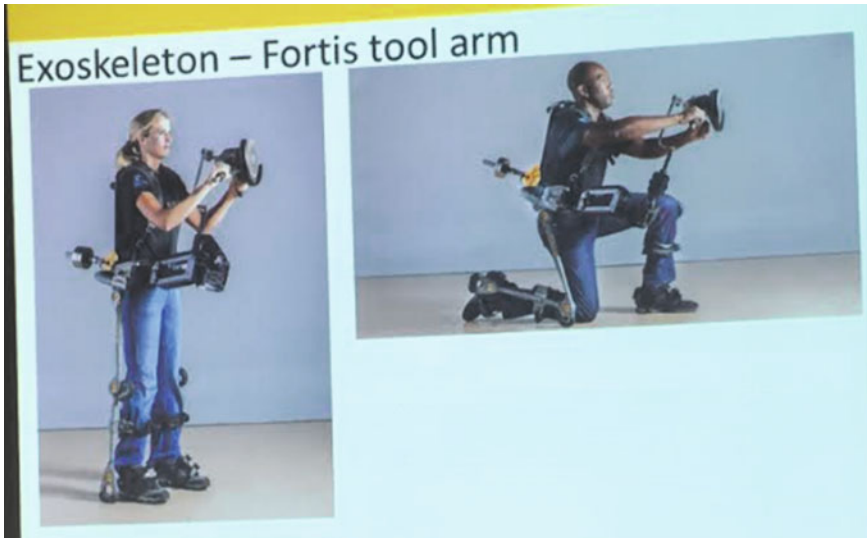




**Fig. 18** Panasonic ActiveLink AWN-03 (author's photo)

really strong. If the workers' hand is not strong enough and the exoskeleton helps him move up his body with the load, he may damage his hands.

Thus, we invited a slightly built worker (D) to try to use the exoskeleton and he also conceded that the exoskeleton could help him in carrying heavy blocks. Even the worker himself can wear the exoskeleton, once he is familiar with the procedure. A worker only needs help when they use the tool for the very first time. Most of the workers agree that it would be advantageous if the exoskeleton can further develop with upper arm section. It can help workers who are not currently strong enough to move heavy materials on-site (Figs. 17 and 18).



**Fig. 19** Exoskeleton Fortis tool arm (author's photo)

With regard to the Fortis tool arm, Worker A considers that the arm can help to do such work as drilling, when the activity must be sustained for a long period. This can provide much extra arm strength and prevent fatigue (Fig. 19).

## 10 Conclusion

Among the many companies that engaged in the interviews, only the largest scale companies have adopted robots for works on sites. Usage of robots sounds as though they represent status symbols for wealthy, large-scale construction companies. Full automation by robots on sites is still work-in-progress. This may be due to the relative high costs at present. Whilst the costs of making robots are not that expensive (sensors, motors, electric wires are relatively cheap), there are quite high costs incurred in doing research and development before robots can be usable on sites. Nevertheless, it is reasonable to foresee that the number of construction companies adopting robots on sites will increase. This is particularly true when the costs of hiring manual labour increase but the costs of robots decrease due to mass production. Thus, is it worth taking the decision to invest in such an innovative approach? Whilst some of the stakeholders may consider this whole development as a new technology currently in its very early stages, the outcome should be positive in the near future.

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