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Robotics in the Construction Industry

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ABSTRACT

The construction industry is one of the largest and most labor-intensive industries in the world. It is currently grappling with issues related to quality, timelines, safety, and complex environments. The industry is on the verge of a digital revolution, using technology to tackle issues like productivity, safety, labor shortages, and collaboration. It is ready for more changes ahead, emphasizing digital transformation and the integration of new technologies to meet the evolving needs of society. The integration of robotics technology in construction facilitates construction professionals with quality-assured outcomes and reduced human errors. The modern robotic technology has the potential to revolutionize and provide numerous advantages to the construction professionals. In this paper, we will explore how robotics is making sweeping changes in the construction industry.

KEYWORDS: *robotics, space robotics, construction, construction industry*

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INTRODUCTION

The construction industry is one of the most important industrial sectors in North America. It has huge economic importance. The construction industry is a labor-intensive industry and is one of the least automated industries of all. It is highly complex, with a construction project usually including hundreds of tasks and multiple phases. The construction industry, traditionally seen as slow to embrace technological change, is undergoing a remarkable transformation. This transformation is not about replacing human labor; it is about augmenting and enhancing human capabilities, opening up new possibilities in building design and construction methods. Figure 1 shows a typical construction site [1], while Figure 2 shows some construction workers [2].

Traditionally, construction works of the large building were performed by human labor in an uncomfortable working condition for a long duration. Today, construction demands more precise, faster, and cost-effective methods to build increasingly elaborate designs. To be effective requires computer-assisted planning, engineering, and a flexible automation process. There is where robots come in.

Robotics is the branch of engineering that integrates computer science with mechanical and electrical engineering. It is now finding its way into the construction industry. Robots usually speed up production and eliminate the cost of labor. Imagine a team of robots working along with laborers on a construction site to transform the landscape.

WHAT ARE ROBOTS?

The word "robot" was coined by Czechriter Karel Čapek in his play in 1920. Isaac Asimov coined the term "robotics" in 1942 and came up with three rules to guide the behavior of robots and later added the zeroth law [3]:

- Law 0: A robot may not injure humanity or through inaction, allow humanity to come to harm.
- Law 1: Robots must never harm human beings,
- Law 2: Robots must follow instructions from humans without violating rule 1,
- Law3: Robots must protect themselves without violating the other rules.

Robots are becoming increasingly prevalent in almost every industry, from healthcare to manufacturing. Figure 3 indicates that robotics is one of the branches of artificial intelligence.

Although there are many types of robots designed for different environments and for different purposes/applications, they all share four basic similarities [4]:

1. All robots have some form of mechanical construction designed to achieve a particular task;
2. They have electrical components which power and control the machinery;
3. All robots must be able to sense its surroundings; a robot may have light sensors (eyes), touch and pressure sensors (hands), chemical sensors (nose), hearing and sonar sensors (ears), etc.
4. All robots contain some level of computer programming code.

Programs are the core essence of a robot since they provide intelligence. There are three different types of robotic programs: remote control, artificial intelligence, and hybrid. Some robots are programmed to faithfully carry out specific actions over and over again (repetitive actions) without variation and with a high degree of accuracy.

Robotics is an interdisciplinary field that involves the design, construction, operation, and use of robots. It is a branch of engineering and computer sciences that includes the design and use of machines that are capable of performing programmed tasks without human involvement. The field develops machines that can efficiently carry out various tasks, can automate tasks, and do various jobs that a human might not be able to do. Robots could someday be our drivers, companions, collaborators, teachers, specialists, and exploration pioneers [5].

CONSTRUCTION ROBOTS

With rising global populations and the consequent demand for infrastructure, the construction industry faces challenges that require solutions beyond traditional practices.

Robotics is poised to revolutionize construction methodologies, ensuring projects are not only completed faster but also with a level of precision hitherto unseen. Labor shortages, the quest for perfection, tight project timelines, and heightened safety standards have all accelerated the need for automation and robotics.

Construction robot refers to robotic devices that are developed for specific construction-related activities. We are living in the booming era of construction robots. Robots come in different types and sizes, but not all robots are suitable for construction. Construction robots can be roughly divided into three categories based on the controlling mechanism: programmable robots, teleoperated systems, and fully autonomous robots. They can also be classified based on several factors such as power source, shape, size, type of application, mechanical structure (mobile or fixed), workspace geometry, motion characteristics, and levels of autonomy. The following types of robots are commonly used in construction [6,7]:

1. *Demolition Robots*: Using robots for demolishing large structures and buildings can accelerate the demolition process, improve efficiency, and save both money and time. Robots make it easy to break down walls, collect debris, and crush the concrete in confined places. Using robots allows the operator to operate by staying at a safe distance from the contaminants, debris, and crushing concrete, making it a safer option for human workers. They allow removing workers from some of the most dangerous activities due to the presence of noise, dust, and the risk of collapse or explosions. A demolition robot is shown in Figure 4 [8].
2. *Bricklaying Robots*: Bricklaying is the most monotonous and tedious task in the construction process. This increases the possibility of error. The bricklaying robots, however, enable us to execute such monotonous tasks efficiently. They can precisely place each brick, ensuring consistent quality and reducing the likelihood of human error.

   Most of the bricklaying robots utilize arms of industrial robots to assemble the masonry structure of the building, while other human-operated robot mixes bonding agent or cement. The major advantage is efficiency and reduced construction time. Bricklaying robots can lay thousands of bricks in a day, ensuring that walls are straight and of consistent quality. These robots, guided by CAD designs, can adapt to changes in real-time, ensuring that any design modifications are immediately incorporated. The first bricklaying robot, named "Motor Mason," was patented in 1904. It required three people for operating. It was considered as five to 10 times faster than humans were.
3. *Welding Robots:* Robotic welding is critical to construction for high-quality welds in shorter cycle times. Robots can perform precise welding and maneuver easily in difficult locations. They are expensive to purchase, which means that an average business cannot afford one.

4. *Exoskeleton*: Exoskeletons, as the name suggests, are external skeletal systems that can be worn by humans. The exoskeleton is an extremely helpful device for a construction worker. It is basically a metallic framework that can be worn by a person. An exoskeleton assists a worker in lifting heavy loads, maintaining the body balance of that person. This mechanical suit can exponentially increase the strength, speed, and agility of an average worker. It allows any worker to lift and carry heavier objects than an average person.

   The downside of this technology is the bulkiness, and most of them lack speed and agility. Due to the use of electric motors and heavy materials, exoskeletons are usually expensive, cumbersome, heavy, and uncomfortable to wear for a long period.

5. *Drones:* Drones are actually unmanned robots controlled remotely by operators to accomplish various complicated tasks. They can create real-time aerial images from the building objects and reveal assets and challenges presented by the terrain. They can provide convenient and smart ways of site supervision and management and result in better operations, planning, and effective on-site adjustments. They can improve safety and monitor project progress on construction sites. Flying mobile robots provide a significant advantage in construction by eliminating constraints associated with ground-based movement and the need for scaffolding. Figure 5 shows a typical drone [9].

6. *Robotics Arms*: These are the backbone of manufacturing, machinery, and industrial automation. These are the most widespread robots in construction. Their main tasks include welding, handling materials, thermal spraying, painting, drilling, and waste separation.

7. *Mobile Robots*: Mobile robot construction systems provide cutting-edge solutions for accelerating construction. They can construct structures larger than their size, and their advantages on uneven terrain make them essential for numerous applications.

8. *Swarm Robots:* Swarm robots enable cooperation and simultaneous task execution, making them a cutting-edge solution. In construction, swarm robots are made up of many small robots to build a design without any guidance.

9. *Teleoperated Robots*: These robots assist humans in a variety of tasks from a distance. Unlike autonomous robots, teleoperated machines rely on some degree of human interaction to function. Teleoperation allows construction robots to be remotely controlled from a safe distance, whether from within the same city, across states, or even from other countries.

10. *Finishing Robots*: Among the different activities involved in building construction, finishing tasks such as plastering, panting, or coating application have seen little development in the field of on-site automation in the last years. Although these operations are characterized by high repetitiveness, they require an advanced ability to adapt to different scenarios, As such, viable finishing robots are commonly equipped with advanced 3D scanning cameras to detect their surrounding and execute their actions accordingly. A finishing robot is displayed in Figure 6 [10].

APPLICATIONS OF CONSTRUCTION ROBOTICS

Robotic solutions within construction can automate heavy equipment and fleets for excavation, transportation, load lifting, concrete work, and demolition. The applications of robotics in construction are vast. Common areas of applications of robotics in construction include the following [11]:

- *Automation*: The construction industry stands at the threshold of a remarkable revolution, fueled by rapid advancements in automation and robotics. The automation of construction processes refers to the use of digital manufacturing techniques, including formative, subtractive, and additive methods, and of robots and autonomous or teleoperated vehicles to automate specific tasks or processes in both on-site and off-site fabrication activities. Physically demanding, repetitive installation tasks that are suitable for robotic automation include overhead drilling, electrical, and plumbing fixtures. A concrete construction operation that lends itself to robotic automation is positioning and tying of reinforcing bars, which is characterized by repetitiveness and labor strain and is usually prone to accidents as workers walk on irregular mats of rebar. Figure 7 shows robotic automation [12].
- *Paving:* This involves covering excavated land with various materials in different areas of construction sites. Robotics play a key role in this construction phase, with common uses including data identification through radars, area reading, and 3D modeling. Some robots are even designed specifically for automatically paving roads.

- *Project Management:* Drones can play a pivotal role in project management. Numerous companies already leverage drones for diverse tasks, spanning from 3D modeling that provides insights into project landscapes to advanced spatial detection capabilities, drones are reshaping the project management landscape.
- *Demolition:* Using robots to handle large-scale demolitions can make the process faster, safer, and more efficient. Operators can also control the demolition from a safe distance. Demolition robots allow job managers to reduce time and costs because they are able to dismantle structures in record time.
- *Bricklaying:* One of the most popular applications of construction robots is bricklaying. Bricklaying, either for load bearing and nonload bearing walls or for brickwork facades, is a construction activity that is extremely repetitive and physically taxing, as it implies frequent pick-up of heavy objects and may require labor to work on insecure ladders or scaffolding for long stretches of time. Bricklaying robots are highly skilled at stacking bricks or blocks to construct walls, facades, and other structural parts. Figure 8 shows a robot performing bricklaying [13].
- *Welding:* Some robots are used for various welding jobs. Polar robots, in particular, are great for creating strong and reliable connections between metal parts, such as steel beams. Figure 9 depicts a welding robot [10].
- *3D printing:* In recent years, additive manufacturing (AM), also known as 3D printing, has grown rapidly in the construction industry. This refers to creating 3D objects by depositing materials using a computer-controlled process. What used to take months to build with traditional methods can now be done in a day or two using 3D printing technology. Some construction robots now have this capability, creating intricate shapes and structures layer by layer using materials like concrete or plastic by following digital designs. AM has been adopted in the construction sector to enable greater flexibility in the geometry of structural elements, reduce material consumption and wastage, and improve worker safety.
- *Site Inspection:* Construction robots, like drones, are equipped with cameras, sensors, and measuring devices that can check structures and keep an eye on construction progress. By using these robots, contractors can quickly identify problems or areas that need attention.

BENEFITS

Construction has always been known for being physically demanding and time-consuming. But due to the integration of robotics in the construction industry, things are changing for the better. Construction robots have the potential to significantly revolutionize the industry. They are here to speed up tasks and reduce human errors and fatigue-related setbacks. Since construction is one of the most dangerous jobs, robots can eradicate the need for laborers in unsafe and hazardous conditions. Here are some other benefits of robotics in construction [7]:

- *Increased Efficiency:* Robots and automated machinery do not experience human symptoms such as fatigue, burnout, or a lack of interest in a repeated process. Therefore, robots can be more efficient in handling repetitive or mundane tasks, allowing human workers to concentrate on more essential and complex jobs. This translates into cost savings and ensures that projects are completed on schedule.
- *Lower Costs:* In construction, labor accounts for 25-30% of total expenses. However, construction robotics play a significant role in lowering these costs by automating labor-intensive tasks. It is well known that many construction projects overshoot their budgets and timelines because of unforeseen challenges. Construction robots can help in this case by minimizing the need for rework and human errors. More work in less time calls for less operational costs and associated expenses. Since robots can operate for much longer and at higher levels of precision than human workers, this benefit is intrinsic.
- *Improved Safety:* Safety is essential in construction, but accidents can still happen even with extensive training and precautions. Robots can take over dangerous jobs, removing or reducing the risk of injury for humans. A more controlled environment means less injuries at a jobsite. The construction industry has long been one of the most dangerous due to the nature of the job: heavy lifting, hazardous elements, and somewhat perilous terrains or platforms. The implementation of construction robots can result in a significant reduction of injuries on construction sites.
- *Better Sustainability:* Robotic innovations have helped to usher in an era of sustainable building practices, significantly reducing waste and the environmental impact of construction processes. Robots can optimize resources by accurately measuring and cutting materials, recovering recyclable or valuable items, and extending

material lifespan and utility, thus promoting a circular economy. The automation capabilities of robots can lead to faster project completion and lower energy consumption, thereby minimizing the environmental carbon footprint of construction activities.

- *Overcoming Labor Shortages:* The biggest challenge the construction industry faces is a shortage of skilled workers. However, introducing robots can help ensure that work progresses steadily, especially for repetitive tasks.
- *Better Quality Control*: The precision of construction robots ensures that every task, from bricklaying to welding, is done with consistent accuracy. This consistency leads to higher-quality work and fewer defects. It also allows leaders to spot and address quality issues on the spot, leading to better outcomes and higher client satisfaction.
- *Increased Productivity*: Robots in construction significantly boost productivity. They can work consistently without getting tired, allowing more work to be completed in a shorter period. The precision of robots ensures high-quality work, reducing the need for rework and further enhancing overall productivity.
- *Enhanced Accuracy:* Compared to human labor, robots are highly accurate. The incorporation of robotics technology eliminates the probability of human errors, delivering highly accurate results. Robots, with their efficiency and accuracy, are at the forefront of the shift towards sustainable construction.
- *Return on Investment:* While the initial costs associated with robotic integration in construction are substantial, the return on investment (ROI) over time can be equally impressive. Robots, with their ability to work round the clock, can drastically reduce project timelines, ensuring faster completions. The precision and consistency brought about by robots mean reduced wastage, leading to cost savings in terms of materials. When these benefits are quantified over the lifespan of the robots, the ROI becomes evident.

Some of these benefits are illustrated in Figure 10 [9].

CHALLENGES

While promising a plethora of benefits, robotics also brings with it a set of challenges and concerns. The construction project's requires people of different skills, equipment, materials, and machinery for every activity as result of which the construction process becomes complicated. Humans are able to surpass robots when dealing with decision-making in an unfamiliar situation. Urbanization, coupled with population growth, has led to a surge in infrastructure demands. Meeting this demand requires efficiency and precision, something that traditional construction practices often struggle with. Other challenges include the following [12]:

- *Resistance to Change:* The construction industry has traditionally relied on manual labor, which can cause resistance to adopting new technologies. Skepticism, fear of job displacement, and lack of awareness about the potential benefits of automation may hinder the acceptance and implementation of automated solutions. Automation is coming, whether companies like it or not, and success will depend on recognizing and overcoming this resistance.
- *Labor Shortage:* Basic knowledge of construction software and hardware are becoming increasingly prevalent on construction sites, establishing a new baseline of expectations for skilled workers. According to the Association of General Contractors of America, 80% of contractors have difficulties finding enough skilled workers to satisfy demand. As a labor-intensive industry, construction is the ideal field for a robotic revolution to take place.
- *Safety Concerns*: Safety, or the lack thereof, has been a long-standing issue in the construction industry. Construction sites, with their heavy machinery, high structures, and complex operations, are inherently risky. Integrating robots leads to substantial improvements in site safety. Construction robotics can offer real-time monitoring and safety alerts, as well as enhance site visualization for construction team members.
- *Lack of Flexibility*: Construction projects often involve unique and customized tasks that require flexibility, as well as collaboration and teamwork among various trades and skilled workers. Some construction professionals fear that automation cannot achieve the level of flexibility and improvisation required in complex construction environments. However, the opposite is true. By automating layout, construction professionals can be even more flexible with what is included in layout.
- *Collaboration:* There is a need to work closely with automated solution providers who have expertise in the construction industry. These partnerships ensure that the adopted automated systems are suitable for construction tasks and

can effectively address the specific challenges faced by the industry.

- *Fear of Unemployment:* The integration of robotics in the construction industry, while promising a plethora of benefits, also brings with it societal concerns, primarily related to job displacements. There is a fear of unemployment among laborers. Robotics and automation have started replacing a notable amount of the workforce in the construction business, eliminating the manual processes.
- *Maintenance:* Like any other technology, robotics requires maintenance to maintain its efficiency. Maintaining several robots can result in higher expenses.
- *Project Complexity:* The modern world demands infrastructure that is not just functional but also sustainable, aesthetically pleasing, and equipped with the latest technologies. This demand has led to an increase in project complexity. This complexity is not limited to buildings. Mistakes or misalignments, which might have been minor issues in simpler projects, can lead to significant complications, necessitating expensive rework.

CONCLUSION

The construction industry is undergoing a robotic overhaul. Robotics is giving the construction industry the massive potential to reach its prime. With an incredible amount of potential for productivity, safety and efficiency, autonomous robots are changing construction. The ability to work 24/7 and error-free make robots more appealing than human workers for the future. Unlike humans, robots do not feel fatigue and are able to perform the same task with high precision and consistency. Though the construction industry is highly unautomated, several different robots are already on the market for assisting construction professionals.

Robotics is poised to redefine the construction landscape, making it more efficient, precise, and sustainable. Robotics for construction are only going to be getting better. In the coming decade, we will be able to witness several different inventions in the field of construction automation and robotics that will completely revolutionize the construction business. Robots are important part of the future of construction. More information on robotics in the construction industry can be found in the books in [14-17] and the following related journals:

- *Robotica*
- *Robotics*
- *Robitics and Autonomous*
- *Robotics and Computer-Integrated Manufacturing,*
- *Advanced Robotics*
- *Autonomous Robots*
- *Automation in Construction*
- *Journal of Robotics*
- *Journal of Robotic Systems*
- *Journal of Robotic Surgery*
- *Journal of Robotics and Mechatronics*
- *Journal of Intelligent & Robotic Systems*
- *Journal of Mechanisms and Robotics-Transactions of the ASME*
- *Journal of Automation, Mobile Robotics and Intelligent Systems*
- *Journal of Future Robot Life*
- *IEEE Robotics and Automation Letters*
- *IEEE Transactions on Robotics*
- *International Journal of Medical Robotics and Computer Assisted Surgery*
- *International Journal of Robotics Research*
- *International Journal of Social Robotics*
- *International Journal of Humanoid Robotics*
- *International Journal of Advanced Robotic Systems*
- *Science Robotics*
- *Soft Robotics*

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Figure 1 A typical construction site [1].

Figure 2 Construction workers [2].

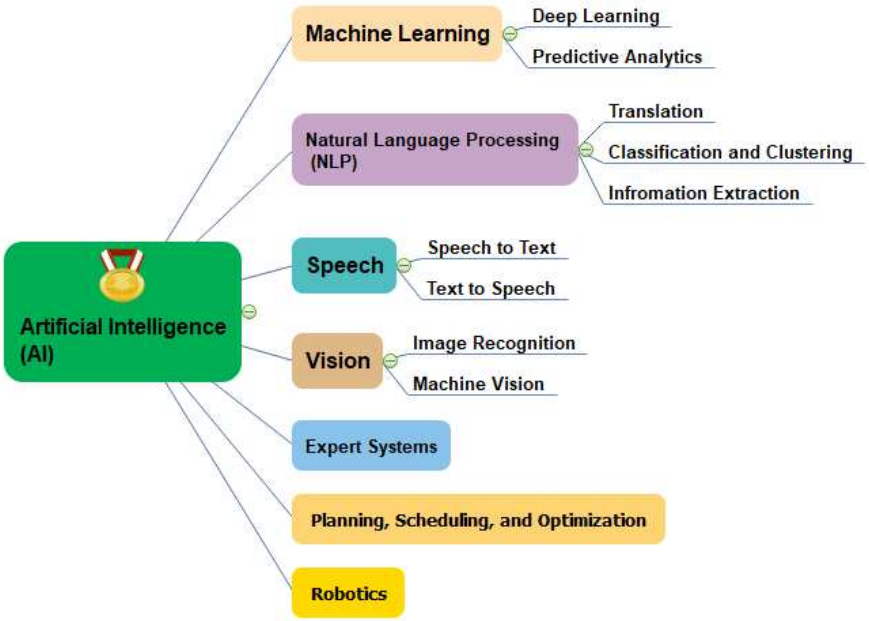

Figure 3 Robotics is one of the branches of artificial intelligence.

Figure 4 A demolition robot [8].

Figure 5 A typical drone [9].

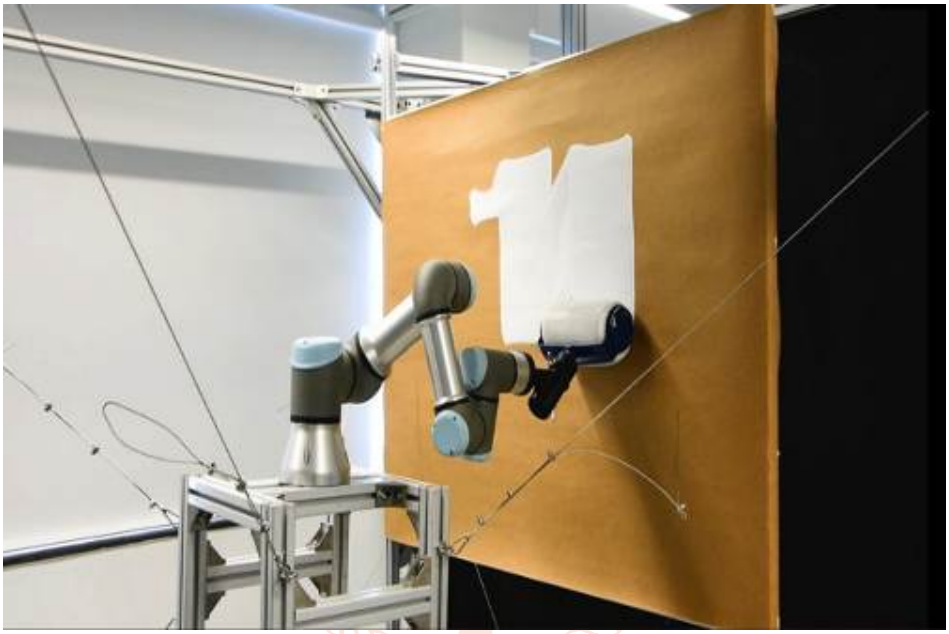

Figure 6 A finishing robot [10].

Figure 7 Robotic automation [12].

Figure 8 A robot performing bricklaying [13].

Figure 9 A welding robot [10].

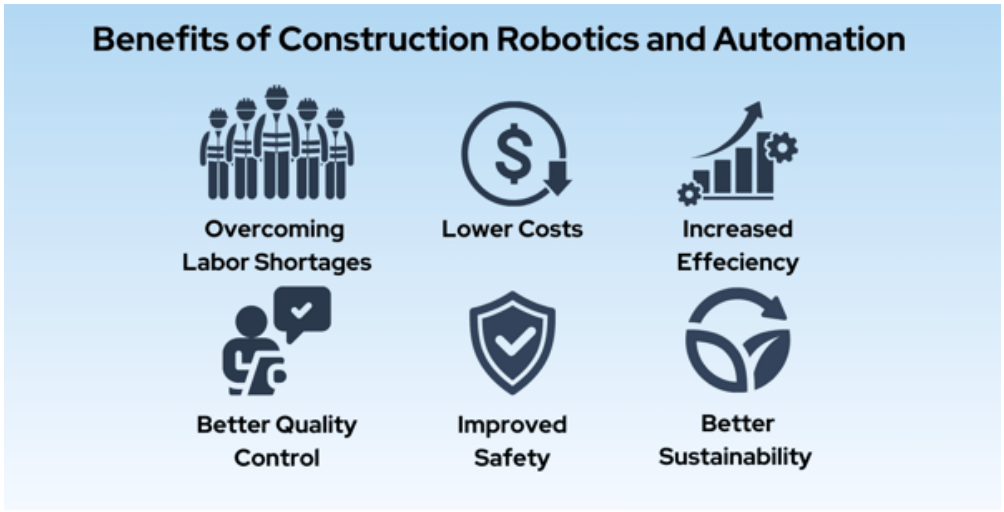

Figure 10 Some benefits of construction robotics [9].