Council on Tall Buildings and Urban Habitat Korea

International Journal of
High-Rise Buildings
www.ctbuh-korea.org/ijhrb/index.php

International Journal of High-Rise Buildings
December 2023, Vol 12, No 4, 343-350
https://doi.org/10.21022/IJHRB.2023.12.4.343

Construction Automation and Robotics: Innovative Challenges and Opportunities

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Abstract With the advent of the recent Fourth Industrial Revolution, efforts are vigorously underway to comprehend the new paradigm of Construction 4.0, following in the footsteps of Industry 4.0, and to establish novel production systems. The necessity and significance of technological advancements in the field of construction automation and robotics, a pivotal component for Construction 4.0, are being emphasized. This paper aims to discuss the concept of construction automation and robotics, encompassing its past, present, and future prospects. Particularly, it reviews the six relevant papers featured in the June 2022 special issue of IJHRB, along with discussions on the integration of cutting-edge ICT technologies and R&D in the realm of automation and robotics. With the progression of ICT technology, the domain of construction automation and robotics is anticipated to play a substantial role in the realization of Construction 4.0 and smart construction through more dynamic convergence in technological development.

Keywords Fourth Industrial Revolution, Construction Automation and Robotics, Construction 4.0, Smart Construction System, ICT technology

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1. Introduction

The main objective of this paper is to discuss past, recent trends and future prospects in the fields of construction automation and robotics. Furthermore, a concise summary and analysis of the six articles featured in the June 2022 special issue of "Construction Automation and Robotics" is discussed. The present article aims to elaborate on the significance, importance, and implications of construction automation and robotics as a pivotal technological element for the establishment of recent advancements such as Construction 4.0 and smart construction systems. It also seeks to address the integration of these fields with cutting-edge technologies.

2. Construction Automation And Robotics

2.1. Current State of the Art

Construction automation (Building automation) refers to the technology aimed at enhancing the productivity and safety of construction through the improvement of existing construction equipment, materials, and production systems, or the development of new forms of robotic equipment. This involves the integration of hardware technologies such as automated equipment and robots with software technologies like BIM, AR/VR, AI, and Big Data. By combining these software technologies with automation hardware, construction automation achieves the automation of construction sites (Seo, 2022).

From the late 1980s to the 1990s, active progress in the field of construction automation and robotics took place in Japan, the United States, and Europe. Japan primarily focused on the establishment of high-rise automated construction systems and the unmanned operation of construction equipment. The United States developed single-task robots for road construction as well as building projects, and automated construction equipment. Europe also centered its research and development on single-task robots for tasks such as material handling, masonry, welding and more. In the early 2000s, due to factors like the global economic crisis and resistance from labor unions, research and development in the field of construction automation slowed down. However, with the advent of the Fourth Industrial Revolution and the emergence of smart construction in the 2010s, there was a renewed emphasis on promoting construction technology innovation, leading to a resurgence of interest in the fields of construction automation and robotics.

The construction is one of the largest industries in the global economy. However, due to the conservative nature of the construction industry, it has been one of the slowest to initiate on the path of automation and digitization. Therefore, the integration of robotics in the construction field has lagged behind compared to other sectors. This is primarily attributed to factors such as labor costs and insufficient process planning. Although facing these

challenges, recent statistics suggest a hopeful future lies ahead. According to the Next Move Strategy Consulting group, the global construction robot market is expected to increase in size from 85.3 million U.S. dollars in 2021 to 242.4 million U.S. dollars by 2030.

In essence, construction automation and robotics align with the goals of the Fourth Industrial Revolution by leveraging cutting-edge technologies to make construction processes smarter, more efficient, and adaptable. These technologies are essential in addressing challenges, exploiting opportunities, and building a sustainable future for the construction industry. Construction automation and robotics offer numerous benefits that address key challenges and opportunities in the construction industry. In a more specific context, construction automation and robotics address vital challenges related to technology-intensive industrial transformation through technological advancement within the industry, and they offer opportunities to enhance efficiency, safety, quality, and sustainability by addressing data-driven decision-making and automated delivery processes.

2.2. Further Challenges and Opportunities

From the perspective of technological convergence, construction automation and robotics involve the integration of automated systems and robotic technologies in the field of construction. Such cutting-edge integrated technologies have the potential to transform the traditional production methods within the construction industry. Leveraging advancements in robotic technology, artificial intelligence, sensors, and computer control systems, tasks that were traditionally performed by human labor can be automated, particularly in repetitive, time-consuming, or hazardous environments.

The Fourth Industrial Revolution, often referred to as Industry 4.0, is characterized by the integration of digital technologies, automation, data analytics, and artificial intelligence into various industries. In the context of construction, automation and robotics play a significant role in reshaping how projects are planned, executed, and managed. Construction automation and robotics contribute by optimizing resource usage, minimizing waste, and enabling the integration of eco-friendly materials, thus aligning with the broader goals of sustainable development. Martinelli et al. (2019) have identified six enabling technologies of the Fourth Industrial Revolution, which include AI, Big Data, Cloud, IoT, 3D Printing, and Robotics. Bigliardi et al. (2020) have designated digital technologies including CPS, IoT, cloud computing, big data analytics, machine learning, advanced manufacturing technologies with sensors, decentralized agent-driven control, advanced robotics, AR, advanced tracking and tracing technologies, and additive manufacturing as the enabling technologies of the Fourth Industrial Revolution. PwC (2017) has identified 10 emerging technologies such as advance materials, cloud technology including big data,

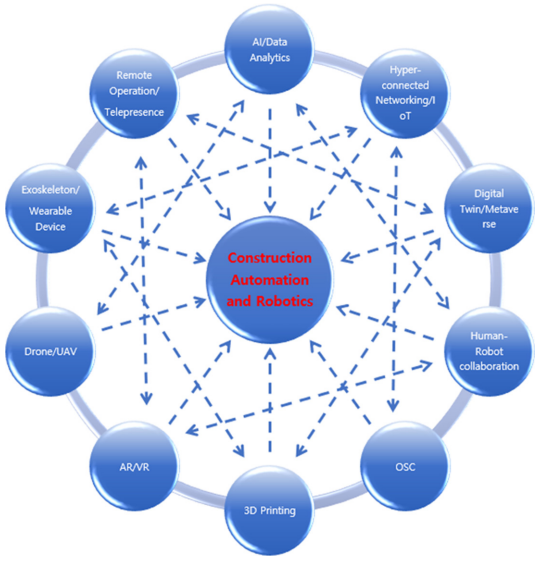


Figure 1. Integrated Construction Automation and Robotics Technology.

autonomous vehicles including drones, synthetic biology, virtual and augmented reality, AI, Robots, Blockchain, 3D Printing, and IoT for a sustainable Fourth Industrial Revolution. Based on the enabling technologies identified in previous researches for the manufacturing sector within the Fourth Industrial Revolution, a set of 10 enabling technologies necessary for Construction 4.0, which encompasses construction automation and robotics, are selected (Figure 1).

① AI and Advanced Data Analytics: Construction automation and robotics generate vast amounts of data through sensors, cameras, and other devices. The Fourth Industrial Revolution's emphasis on data analytics and artificial intelligence allows this data to be processed and analyzed for insights that can optimize construction processes, predict maintenance needs, and enhance decision-making.

② Hyper-connected Networking and IoT Integration: Enabled by technologies such as the internet, cloud computing, and the Internet of Things (IoT), this phenomenon emphasizes real-time data sharing and interaction between individuals and devices. In construction, IoT-enabled sensors on equipment, machinery, tools, and materials can provide real-time information, enabling remote monitoring, predictive maintenance, and overall project coordination.

③ Digital Twin and Metaverse Technology: A digital twin is a virtual representation created by modeling the physical attributes of real-world objects in a digital form. For instance, it involves replicating physical entities like buildings, manufacturing processes, and products in digital format to collect and analyze various data and information. It is utilized for simulations, predictions, and optimizations. Digital twins are employed as tools to monitor and

enhance the operation and state of actual objects. On the other hand, the metaverse refers to a virtual or digital world—a blended space where reality and the virtual realm converge, allowing users to engage in various activities within a virtual environment. This is formed through the utilization of diverse digital platforms and technologies such as virtual reality (VR), augmented reality (AR), online games, and social media. Construction automation and robotics allow real-time data from the field to be fed into digital twins, enabling dynamic monitoring, simulations, and performance analysis, leading to improved project planning and management. For Digital Twin and Metaverse technologies to gain utility in construction projects, architectural drawings need to be constructed as 3D BIM models, seamlessly integrated with them.

④ Human-Robot Collaboration: The form of robotics that is prominently emerging is the collaborative robot, often referred to as a "cobot" in the context of the Fourth Industrial Revolution. In construction, these cobots can work alongside human workers, handling repetitive tasks, heavy lifting, and hazardous jobs, thereby improving safety and efficiency.

⑤ OSC (Off-Site Construction): Offsite construction, also known as modular construction or prefabrication, is a construction method where components of a building or structure are manufactured in a controlled environment away from the actual construction site. These components, often referred to as modules, are then transported to the site and assembled to create the final structure. Robots and automation are used to fabricate these components with high precision, ensuring they fit together seamlessly during assembly.

⑥ 3D Printing (Additive manufacturing): 3D printing is transforming construction by enabling the creation of complex structures with greater precision and speed. This technology aligns with the Fourth Industrial Revolution's focus on innovative production methods, sustainability, and customization. Undoubtedly, the development of 3D printing materials for construction holds a significant importance as well.

⑦ Augmented Reality (AR) and Virtual Reality (VR): AR and VR technologies enhance visualization, training, and remote collaboration. In construction, these tools help architects, engineers, and workers visualize designs, simulate construction processes, and troubleshoot issues, aligning with the Fourth Industrial Revolution's emphasis on immersive experiences and connectivity.

⑧ Drones and UAV (Unmanned Aerial Vehicle): Drones are being widely used for site surveys, progress monitoring, and inspections. They can provide accurate and up-to-date visual data of construction sites, helping project managers make informed decisions. Some drones are equipped with LiDAR (Light Detection and Ranging) technology for creating detailed 3D maps of construction sites.

⑨ Exoskeletons and Wearable Technology: While not entirely robotic, exoskeletons and wearable devices are being developed to assist construction workers in lifting heavy objects and reduce physical strain.

⑩ Remote Operation and Telepresence: Some construction equipment can be operated remotely using advanced control systems. This technology allows skilled operators to control machinery from a distance, which can be particularly useful in hazardous or challenging environments.

These ideas explain how construction automation and robotics are tightly intertwined with the principles and technologies of the Fourth Industrial Revolution.

2.3. Level of Automation

Automation and robotics in construction can be categorized into different levels based on their degree of autonomy and human involvement. It is classified into three levels such as machine guidance, machine control, and autonomous robots.

① Machine Guidance: Machine guidance refers to the use of technology to assist human operators in performing construction tasks with increased accuracy and efficiency. In this level, technology provides guidance and real-time data to human operators, helping them make informed decisions and execute tasks more precisely. As an example, GPS-based machine guidance is commonly used in construction equipment such as bulldozers, graders, and excavators. These machines are equipped with GPS receivers that receive signals from satellites to determine their precise position on the construction site. The data is then used to guide the operator in achieving accurate grading or excavation, minimizing errors and reducing the need for manual measurement.

② Machine Control: Machine control takes automation a step further by allowing construction equipment to perform tasks more autonomously, guided by pre-programmed instructions and sensor feedback. In this level, human operators are still involved in overseeing and initiating the tasks, but the equipment has a greater degree of autonomy. Robotic total stations can be used in building layout and surveying tasks. These robotic instruments can automatically measure distances and angles, making it easier and faster for construction workers to lay out foundations and other key points accurately.

③ Autonomous Robots: Autonomous robots operate with a high level of independence, often without direct human intervention. These robots are capable of making decisions and performing tasks based on real-time data and program-ming, without requiring constant human guidance. Autonomous bricklaying robots are practical example, designed to place

bricks with precision and speed. These robots are equipped with sensors to measure brick sizes, mortar consistency, and wall alignment. They can autonomously pick up bricks, apply mortar, and place them in the correct position, reducing the need for manual bricklaying.

In summary, these three levels represent a progression from human-guided assistance to more advanced automation and autonomy in construction tasks. The adoption of these different levels of automation depends on factors such as the complexity of tasks, available technology, safety considerations, and the willingness of the construction industry to embrace new technologies.

In the future, the field of construction automation and robotics is expected to advance in conjunction with the technological progress in the ICT sector, encompassing areas like information, communication, networking and sensing technologies. This progress will be aligned with advancements in hardware technologies such as wearable devices, construction equipment, machinery, and robots. Ultimately, the convergence of these technologies is expected to be a challenging endeavor for the establishment of innovative construction delivery systems through the integration of construction automation and robotics systems.

3. Brief Review Of Special Issued Papers

With the advent of the Fourth Industrial Revolution, new business models driven by technological innovation are being developed across all industries. In the construction industry, automation and robotics are also experiencing active global research and development as part of this trend. In particular, this paper introduces a brief overview of six (6) construction automation and robotics-related papers from the United States, Germany, China, Japan, and South Korea, which were featured in the June 2022 special issue of IJHRB. The six papers prominently highlight the fusion of cutting-edge ICT technologies such as information technology, sensing, and AI in the development of construction robots.

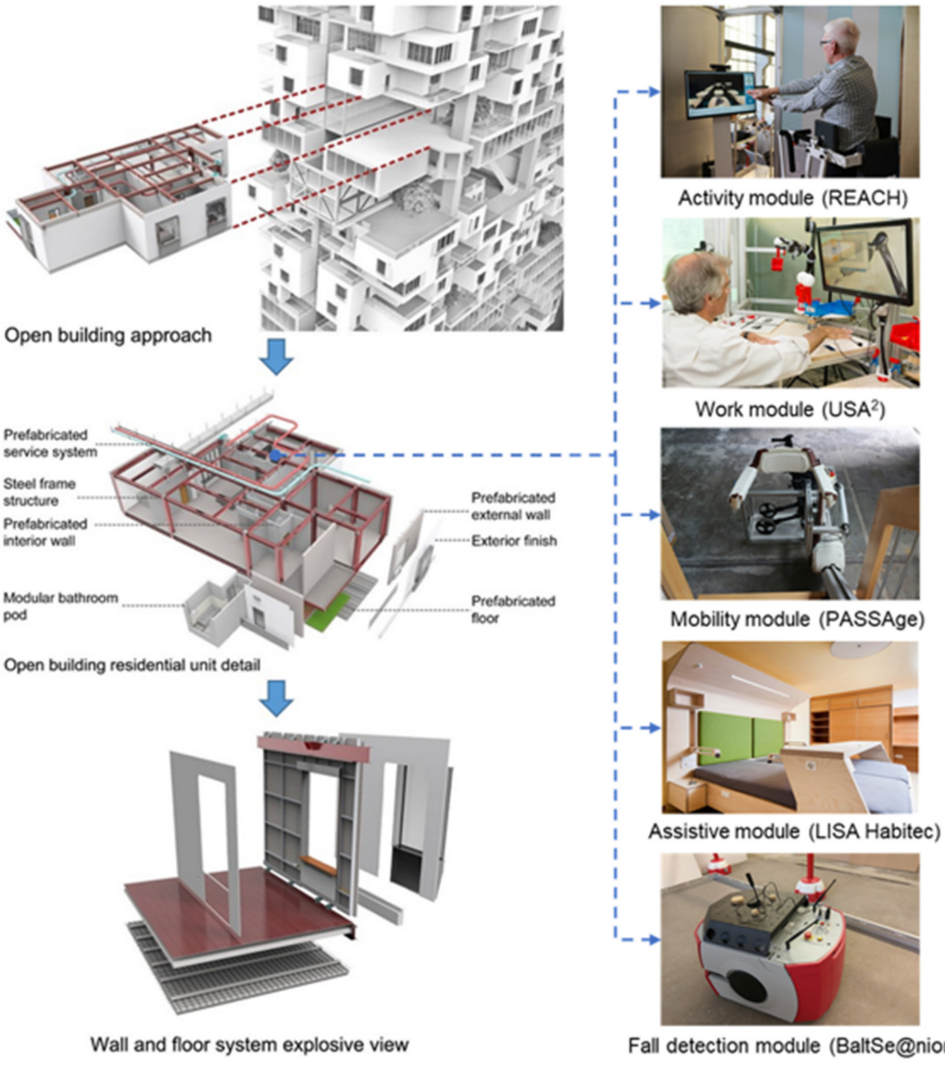


Figure 2. Open Building system in DVU. (Thomas Bock et al., 2022)

3.1 Automated Deployment and Transformation of High-Rise Buildings to Mitigate Social Challenges by Thomas Bock et al. (2022)

This paper analyzes the technological readiness and innovations in the field of construction automation and robotics, providing insights into the future direction of automation and robotic technologies for the construction of future vertical cities, with a focus on high-rise buildings as representative structures. The robots designed for high-rise buildings encompass single-task construction robots, automated on-site construction factories, and ambient assisted living technologies.

The progression of construction automation and robotic technologies, which has been ongoing since the 1980s, enables the realization of future vertical cities that can continuously grow and transform in terms of form and function. Lastly, the paper introduces a visionary archetype termed "dynamic vertical urbanism (DVU)." This concept, facilitated by advanced architectural technologies, enables easy vertical and horizontal expansion, ensuring instant availability and full lifecycle resilience. The integrated system structure of various components is shown in Figure 2.

The paper presents challenging and innovative ideas regarding the future of automation and robotics, extending from robotic technologies for high-rise buildings to the construction of vertical cities.

3.2. Toward the Future of Mechanized Construction Introduction and Future Prospects of Mechanized Constructions Using Digital Information by Makoto Kayashima et al. (2022)

This paper discusses the future of construction automation and robotics in Japan, particularly focusing on the prospects of automation utilizing digital information. Currently, Japan is experiencing rapid population aging and is entering a phase of population decrease, while global population growth continues. Consequently, the construction market is expected to contract, but the labor shortage situation is anticipated to worsen due to the aging of construction workers and the inability to secure new, younger labor force. To address labor shortages, it is crucial to implement mechanization, automation, labor-saving practices, and efficiency improvements by effectively utilizing information at each stage of the planning, design, construction, operation, and dismantling process.

New efficiency enhancement techniques that leverage building information are necessary to maintain and expand the construction market. Currently, fundamental technologies utilizing Building Information Modeling (BIM) are being developed through digitization at each phase. Digital transformation (DX) in the construction industry can be realized through matured technologies and continuity(Figure 3). This is expected to evolve into unprecedented new methods. Taisei Construction's status in BIM and mechanized construction is introduced by showcasing advanced technologies applied in actual projects and discussing future prospects. The importance of an integrated system involving digital technology, robot construction, and mechanized construction is emphasized as a future technology.

3.3. Design and Application of Self-Lifting & Slewing Multi-Cranes Platform by Kun Zhang et al. (2022)

This paper presents an automation study of tower cranes, which are essential for material handling in the construction of high-rise buildings. The objective of the paper is to develop a crane slewing platform to facilitate

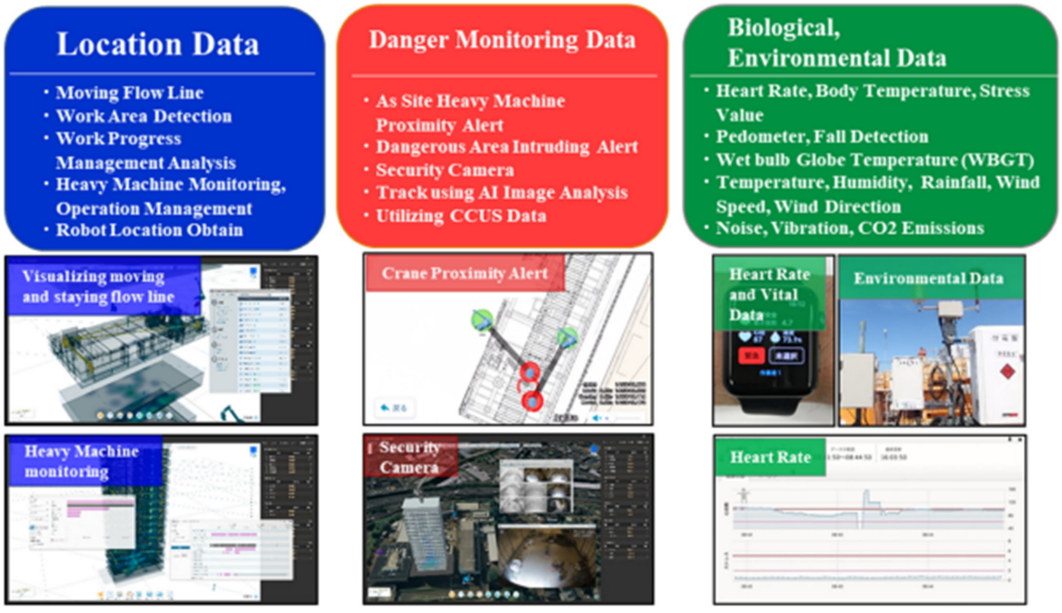


Figure 3. Examples of utilizing various digital data. (Makoto Kayashima et al, 2022)

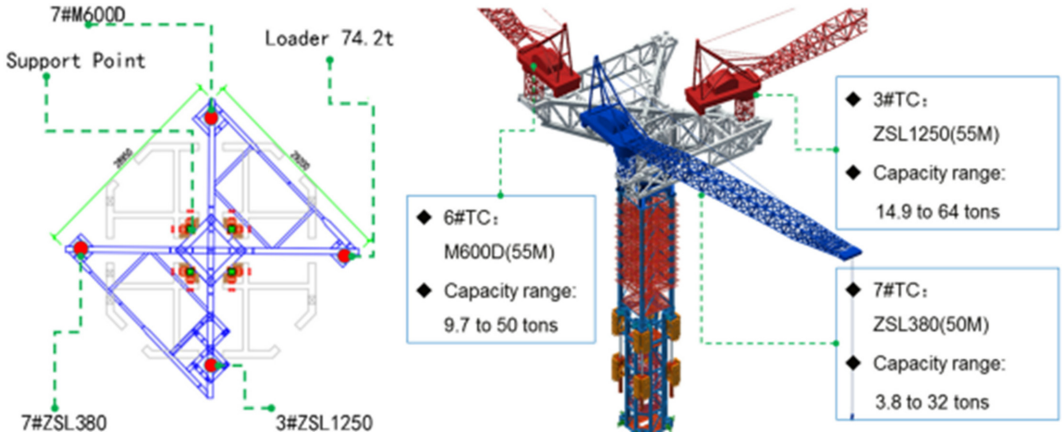


Figure 4. Arrangements of cranes on slewing platform. (Kun Zhang et al, 2022)

smooth crane operations. The self-lifting and slewing multi-cranes platform, also known as the crane slewing platform, holds significant importance in the construction of high-rise buildings (Figure 4). It was developed to optimize the configuration of multiple tower cranes, address collaborative operation conflicts among various cranes and construction equipment, and mitigate challenges related to climbing and occupation during different construction phases.

To achieve the research objective, the paper encompasses the design, simulation, on-site testing, and performance analysis of the slewing platform. By applying the slewing platform in the construction of the Chengdu Greenland Center super high-rise building project, key technologies such as crane configuration, platform installation, construction, and lifting were implemented and validated. Up to this point, the slewing platform has been safely lifted 98 times during the Chengdu Greenland Center project construction, showcasing not only technological achievements but also social and economic benefits. This underscores the substantial impact of construction automation and robotics, demonstrating both technical value and broader societal and economic implications.

3.4. Development of Automated Welding System for Construction: Focused on Robotic Arm Operation for Varying Weave Patterns by Doyun Lee et al. (2022)

The purpose of this study is the development of a welding robot system. The composition of the automated welding robot system consists of a welding machine, unmanned ground vehicle (UGV), robotic arm, and visual sensors as shown in Figure 5.

For automated welding operations, a microcontroller is utilized to control the switch, which is physically modified and added to the welding torch. Various weaving patterns are mathematically programmed. Automated weaving is tested using a brush pen and a ballpoint pen to clearly visualize the patterns and detect changes in the vertical

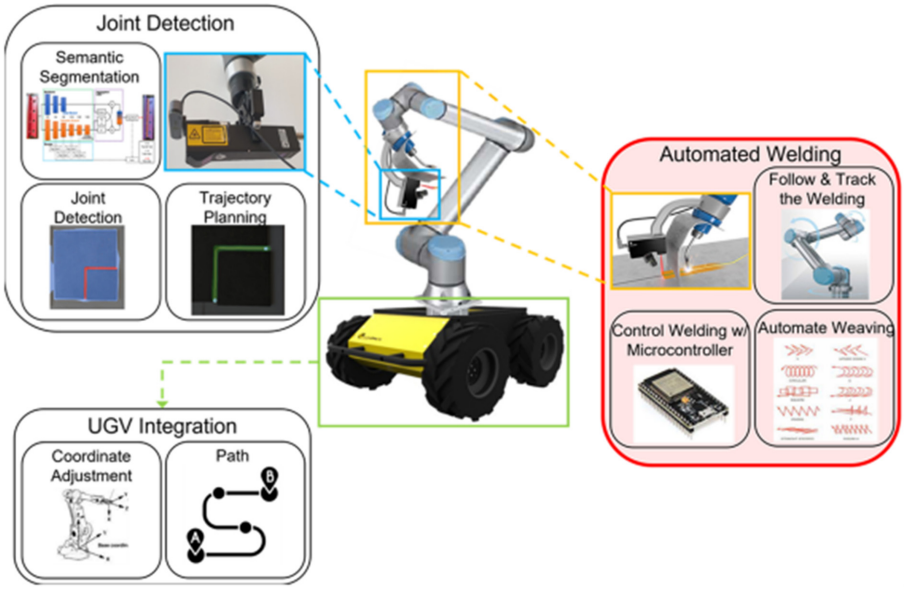


Figure 5. Arrangements of cranes on slewing platform. (Doyun Lee et al, 2022)

force of the arm. The results demonstrate that the weaving patterns exhibit sufficient consistency and precision for utilization in actual welding. Real welding operations are performed, and the corresponding outcomes along with performance evaluations are presented. This study presents a robotic system aimed at automating a specific task, focusing on welding robots, and involves the development and experimentation of hardware and software that enable task execution, control, and feedback. Welding tasks require a high level of skill to ensure uniform quality and are prone to safety incidents, making the introduction of robots crucial. Therefore, this study holds significant importance in addressing these challenges.

3.5. Lifting Load Recording and Management Method of the Lift for Construction based Sensing Information by Taekyu Ko et al. (2022)

This paper discusses the application of automation technology to efficiently manage the frequency and load of construction lifts used in the construction of super high-rise buildings. While buildings these days are becoming taller and larger, various challenges arise during construction management. Particularly, as the vertical movement of manpower and materials during construction becomes more extensive, leading to increased lifting frequency and load, the need for effective lifting management practices is also growing. Therefore, this study introduces a real-time lifting performance monitoring system that can store and manage lifting records for construction management (Figure 6).

Through literature review and prior studies related to construction lifts, concepts and operational management were understood. Building upon this understanding, a system was developed to monitor lifting operations and performance information. This system enables rapid measurement of lifting performance during the construction phase and can adapt to changes in the project schedule. To validate this system, a case study was conducted to derive the current status and characteristics of sensor-based lifting performance.

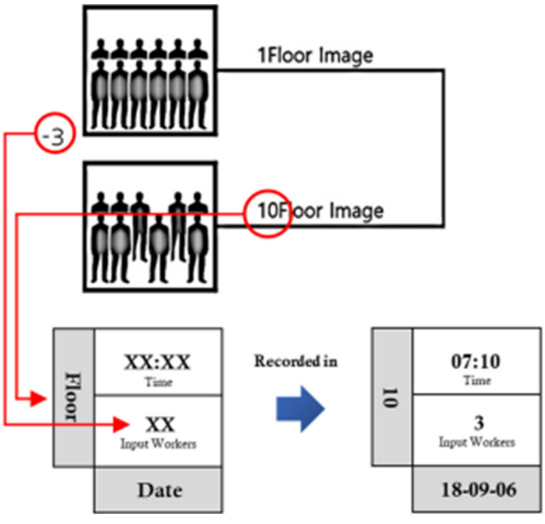


Figure 6. Detecting and recording changes in the number of lift users. (Taekyu Ko et al, 2022)

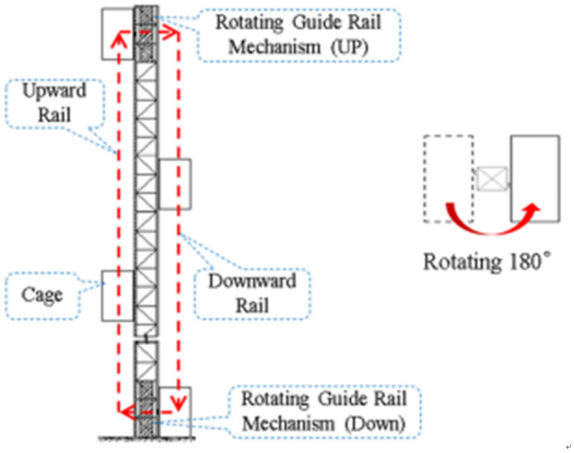


Figure 7. Rotary Elevator Operation Principle. (Kun Zhang et al, 2022)

The significance of this paper lies in its ability to utilize sensing technology to measure and monitor work frequency and load in real-time, providing the foundation for an efficient and automated lift operation management system.

3.6. Research of Circuit Working Construction Elevator with Single-guide Rail and Multi-cages by Kun Zhang et al. (2022)

This paper presents a study on the automation of crucial vertical transportation equipment in the construction of super high-rise buildings. One such equipment, the construction elevator, directly impacts project duration, costs, and efficiency. The paper proposes a novel construction elevator with a single guide rail and multiple cages. This system addresses challenges including insufficient capacity of a single construction elevator, reduced efficiency with height, occupation of plan and elevation positions by multiple construction elevators, and elongation of total construction duration through cycling operation of multiple cages on a single guide rail.

The paper focuses on the design and research of key components of the equipment, such as the rotating guide rail mechanism, vertical bearing mast tie system, segmented power supply system, group control scheduling system, and safety anti-collision system(Figure 7).

Recently, the rotating elevator has been applied to projects like the Wuhan Center Project and Wuhan Greenland Center Project, where its performance is being evaluated. This is expected to contribute to the optimization of automation systems in the future.

4. Conclusions

The automation and robotization of construction are becoming essential elements, not just options, in the

innovation of near future construction technologies. Rapid technological advancements are anticipated through the integration with core technologies of the Fourth Industrial Revolution, such as AI, robots, sensing, VR/AR, drones, 3D printing and so on. Recent research and development cases presented in this paper also confirm this expecting trends. The activation of construction automation and robots will not only promote improvements in construction productivity, consistent quality assurance, and efficient safety management but also play a significant role in enhancing the industry's image.

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