Opening the digital era of the construction industry through the development and practical application of smart construction technology

The construction industry has established itself as a key industry that greatly contributes to economic and social development in individual countries and globally through job creation and the expansion of infrastructure facilities that form the foundation of human civilization, such as housing, and social overhead capital (SOC), including roads, railways, and cities.

The construction industry’s production inducement, employment inducement, and value-added inducement coefficients exceed the overall industry average. The construction industry also significantly improves Korea’s current account balance due to overseas orders. The size of the global construction market was estimated at USD 11.5 trillion last year (about KRW 13,000 trillion) and is predicted to increase 7% on average annually, reaching USD 16.6 trillion (about KRW 19,000 trillion) by 2025.

However, the construction industry also has negative aspects, such as frequent accidents and lower productivity (measured by the value added per working hour) and digitalization levels than other industries such as manufacturing. To increase the sustainability of the construction industry and to make it a new driving force for national development, advanced economies are boldly promoting innovation in construction technology through convergence with various digital technologies.

Construction companies also acknowledge digital technology as an essential tool for survival and are equipped with dedicated departments and personnel. Moreover, innovative small and medium enterprises, venture companies, and startups are spurring commercialization of smart construction, through the development of various innovative technologies.

The trend toward digital transformation based on cyber-physical systems (CPS) is also taking place in the construction industry. Moreover, COVID-19, which shook the world after its sudden emergence in 2020, is becoming a game changer by accelerating the digitalization of industries and our lives.

“Smart construction” can be defined as a construction method that dramatically improves construction productivity and safety by combining traditional construction methods with innovative digital technologies, such as Building Information Modeling, Internet of Things, digital twin technology, artificial intelligence, and robotics, and by implementing data-based engineering, virtual construction, automated construction, and safety control throughout all stages of construction to maintenance.

Following the establishment of the “Smart Construction Technology Roadmap” in 2018, last year, the Korean government launched a large-scale national R&D project for technology development and commercialization. The Korea Expressway Corporation (KEC), the governing body of the smart construction technology development project, will promote the digital transformation of the construction industry by focusing on the commercialization and field application of the developed technologies, based on our capabilities accumulated over 60 years in the construction and management of highways, which are the representatives of Korea’s SOC. KEC will also help Korean construction companies enter the global market based on their accumulated digital capabilities.

By 2025, the global smart construction market is expected to reach USD 1.6 trillion (about KRW 1,700 trillion) in value, accounting for about 10% of the total construction market.

To this end, we have published the digital magazine “Smart Construction Global Insight” as a way to introduce and explore the latest trends and research on smart construction technologies. For the first issue, we chose a theme of “construction automation and robotics.”

We look forward to ongoing interest and support from our readers.

August, 2021

Head of the Center for Smart Construction Technology, Korea Expressway Corporation

Sung-min CHO
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Secretariat Office, Center for Smart Construction Technology
1. Overview

1.1. Shortage of Construction Workers

For a long time, there has been a perceived shortage of construction workers in Korea. As early as 1998, a research report by the Construction & Economy Research Institute of Korea titled "Survey on the Supply and Demand of Skilled Personnel at Large Public Construction Sites," analyzed the basic data and the causes of personnel shortage at construction sites, citing changes in the population structure along with a negative perception of the construction industry. In addition, the February 2021 census conducted by Statistics Korea predicted that Korea’s personnel shortage will gradually intensify following the decline in the country’s natural population (decline of 33,000 people in 2020) for the first time since Korea began compiling population statistics.

Considering these demographic realities, I am very concerned that the quantitative growth of Korea’s construction industry through the utilization of our construction workforce, which we have enjoyed until now, is no longer possible using current methods. At a time when many skilled construction personnel in their 60s and older are about to retire, the small number of new construction workers in their 20s and 30s will not be able to fill the labor gap. Most construction sites are already filling this gap with foreign workers.

The shortage of construction workers is not unique to Korea. According to a 2020 report by the Associated General Contractors (AGC) in the U.S., 81% of construction companies are having difficulty filling both full-time and temporary positions, and 72% expect this trend to continue next year. The construction companies affected by this problem acknowledge that the labor supply and demand issue are important because they can result in project delays and increased construction costs. Moreover, a 2021 paper on the shortage of construction workers in EU countries shows that most EU member states are suffering from labor shortages in the construction sector. However, due to the recent surge in immigration, there is a perception that the labor shortage could be alleviated if the government allowed immigrants to fill the gap, but there is also a perception that this could have a negative effect on the implementation of "Construction 4.0" in Europe by increasing the proportion of workers.

1.2. Emergence of the need for construction automation and robotics technologies

There are three main approaches to solving the construction worker shortage issue. The first approach is to train new construction workers. However, the ineffectiveness and limitations of this approach seem clear given the outcomes over the past 20 years and the expected changes to the population structure in the future. The second approach is to make existing labor multi-functional, and the third is to utilize construction equipment automation and robotics technologies.

In a survey of U.S. construction companies, 32% of the respondents said they have utilized labor-reducing equipment (e.g., drones, robots, 3D printers, laser scanners, or GPS-guided equipment). This figure is only slightly higher than the 28% of respondents who said they have used productivity-enhancing methods (e.g., lean construction, virtual construction, building information modeling (BIM), off-site construction (OSCI)). Changes in construction paradigms, such as with Japan’s i-Construction, Europe’s Construction 4.0, and Korea’s Smart Construction, are gradually becoming reality, and public demand for the development of the construction industry is increasing. In other words, it can be said that there is a social consensus on the need to automate Korea’s construction industry.

This article will look at the current construction industry in Korea, particularly at the cases where various innovative construction equipment automation technologies have been applied, and based on that, will examine the future of construction automation and construction technology development in Korea. The article will also cover the development of earthwork construction equipment control and automation technologies, the first of four focus areas of the Smart Construction Technology Development Project launched by the Ministry of Land, Infrastructure, and Transport and implemented by the Korea Agency for Infrastructure Technology Advancement in 2020. Already widely known machine guidance and control technologies have been excluded, and the survey was conducted focusing on foreign technologies rather than domestic technologies to establish a benchmark strategy.
To investigate trends in overseas construction equipment automation technology, we reviewed the latest developments in automation technologies from overseas construction equipment manufacturers (e.g., Caterpillar, Komatsu, Volvo, and Hyundai Construction Equipment). Additionally, we reviewed related products and services from various construction startups, so-called “ConTech” companies, and the values and valuation methods of these companies. Startup companies are usually evaluated as either Unicorn companies (valued at USD 1 billion), Soonicorn companies (companies that are likely to become Unicorn companies), or Minicorn companies (companies receiving Series A+ funding4). Most ConTech companies are rated as Soonicorn or lower, so the survey focused on Soonicorn and Minicorn companies. Moreover, while construction equipment can be used not only for construction work, but also for mining, landfill, forestry, demolition, landscaping, snow removal, and quarrying and aggregates, this article mainly examines the technologies used in construction.

2. Heavy Construction Equipment Automation Technology

2.1. Caterpillar

One example of recently commercialized construction equipment automation technology is the Cat® Command series. It is a system that supports two remote control modes: a 400-meter short-range remote control (console) mode and a long-range remote control (station) mode, both of which are currently available on the market. They were developed for the efficient supervision of construction personnel on site. The characteristics and advantages of these technologies are shown in Table 1. These technologies are being used to develop remote construction equipment control systems for focus areas 1 and 3 of the Smart Construction Technology Development Project.

While both of these technologies are remote control technologies, their applications differ. The Command Station allows the user to work very far from the project site by using screens transmitting footage from the site (one overview screen and one surround-view monitor installed in the cab) and the MG navigation screen. Whereas, with the Command Console, the operator uses a mini (pendant-type) controller and can see the vehicle driving outside the cab at a relatively short distance without using a video screen.

In the first study, 5G and ultra-low latency video transmission technologies will be used to build a remote-controlled environment that surpasses the Command Station technology. In the third study, the remote technology will also incorporate a user-friendly and attachable module to improve application and profitability. The short-distance remote technology is expected to be useful in reducing human casualties during disasters by supporting search and rescue activities.

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4) Series A, B, and C funding is a process that allows startup companies to raise investments from venture capital (VC). The process includes the development stage, in which VC investments are attracted (Series A); the expansion stage, in which business growth potential is increased (Series B); and the final funding stage, the corporate acquisition, or IPO (Series C) which mainly includes large-scale investors such as private equity funds (PEFs), hedge funds, and banks.

### < Table 1 > Caterpillar’s Heavy Construction Equipment Automation (Remote) Technology

<table>
<thead>
<tr>
<th>Cat® Command station</th>
<th>Cat® Command console</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available for Caterpillar dozers, excavators, and wheel loaders that support the system</td>
<td>Available for Caterpillar dozers, excavators, and wheel loaders that support the system</td>
</tr>
<tr>
<td>Allows the operator to work remotely in a comfortable “virtual cab” with familiar controls and machine displays</td>
<td>Enables equipment operators to work safely and comfortably outside the machine, while maintaining direct visual contact</td>
</tr>
<tr>
<td>Can be located in a command center on-site or several miles away</td>
<td>Enables line-of-sight operation from up to 400 meters (437 yds.) away</td>
</tr>
<tr>
<td>Reduces operator fatigue with a comfortable indoor working environment</td>
<td>Operator inputs are sent directly to the machine electronics via a dedicated radio transmitter/receiver, resulting in real-time implement control</td>
</tr>
<tr>
<td>Operator inputs are sent directly to the machine electronics via a dedicated radio transmitter/receiver, resulting in real-time implement control</td>
<td>Does not require on-site communications infrastructure, as it uses 900MHz or 2.4GHz frequency communication protocols</td>
</tr>
<tr>
<td>Controls deliver the same response time as in the cab, maintaining precise control of all excavator applications, and high-quality video delivers a clear view of the work area</td>
<td>Machine shuts down if the controller is tilted more than 45 degrees, indicating that the operator has fallen</td>
</tr>
<tr>
<td>Enables the operator to easily switch between systems or change job sites without downtime</td>
<td>Allows instructors to stand next to the operator and provide guidance without noise or movement</td>
</tr>
</tbody>
</table>

Additional functions to help the excavator work safely, as shown in the following table, are the E-Fence function (a)-(d) in Figure 1 and the real-time load information (safety-caution-danger section display) function (e) in Figure 1.
2.3. SafeAI and Obayashi Construction

On October 22, 2020, SafeAI, a startup that hosts an autonomous heavy equipment platform, and Obayashi, a Japanese global construction leader, announced a partnership to create an autonomous construction site, starting with a pilot program at a U.S. test site. From November 2020, SafeAI will demonstrate the loading-hauling-dumping (LHD) cycle at the site using the Caterpillar 725 articulated dump truck (ADT). SafeAI is a startup that automates Doosan Bobcat’s skid loader (Figure 3), enabling autonomous loading-hauling-dumping. The announcement can be seen as an attempt to extend automation technology to other construction equipment.

[Figure 3] SafeAI’s Autonomous Skid Loader

(Source: https://safeai.ai/)

3. Construction Equipment Control Technologies

Before discussing control technology, it is necessary to introduce the concept of XaaS (Everything as a Service). XaaS provides an endpoint for customers, meaning it provides a system that users can interact with through API and control through a web console in their web browser. PaaS (Platform as a Service) allows customers to rent systems that they want to use. PaaS does not require users to purchase or deploy traditional systems, such as operating systems, servers, databases, middleware, networks, and storage. Construction site managers play the role of DevOp and will find it very easy to run applications and gather data.

Because every construction project varies by location and content, construction equipment control technology that utilizes PaaS is expected to be incredibly useful in terms of equipment history, productivity, and asset management. In fact, companies such as Trimble and Topcon are commercializing enterprise-level cloud-based PaaS for use in large-scale earthworks or mines. This article will examine Trimble and Topcon’s construction equipment control technologies.
3.1. Trimble Platform as a Service (TPaaS) - WorksOS

Trimble Inc. is not just a manufacturer of GNSS surveying equipment. It has also secured BIM technology by acquiring SketchUp in 2012 and Tekla and Vico Office in 2014 through an M&A, and has developed and supplied construction equipment automation and control technologies in cooperation with leading construction machinery manufacturers, such as Komatsu and Caterpillar. Based on these partnerships, it is now creating added value not only in surveying, but also in almost all industries, including construction, agriculture, transportation, communication, asset management, mapping, railway, and utilities. This article will examine Trimble Inc.’s WorksOS, a construction equipment control technology.

WorksOS is an on-site monitoring solution with a feature that allows site managers to accurately monitor the site and simultaneously check real-time progress rates based on information obtained from construction equipment (Figure 4). The company’s core value is “connecting field to office,” enabling the acquisition of real-time precision work data (location and level) from construction equipment for the immediate creation of as-built models while providing an intuitive dashboard that allows users to identify the project’s progress and remaining work. The company also provides data prep software for 3D volume calculation and machine guidance through the Trimble Business Center (TBC).

3.2. Topcon – Sitelink3D

Topcon is a Japanese manufacturer of optical equipment for surveying and medical devices. In construction, it is widely known as a surveying equipment company along with its subsidiary, Sokkia. Topcon has been offering the construction equipment control technology Sitelink3D since 2014 (see Figure 5). While the basic features of Sitelink3D are the same as those of Trimble, Sitelink3D also provides a “Sitelink3D Enterprise” system that emphasizes process management functions and linkages, so that it can be used not only in the field but also in the enterprise stage.

4. ConTech Companies Related to Construction Equipment Automation

Many construction startups have been founded, and they have introduced various technologies. This article looks at eight ConTech companies either directly or indirectly related to construction equipment automation that were identified through a Crunchbase search (Table 2). These companies include hard robotics ConTechs that are working to automate the operation of earthwork equipment, such as Built Robotics and SafeAI; construction information management applications and platform companies, such as Rhumbix and Fieldwire; and platform companies that supply and share construction equipment between companies and with SMEs. The average funding for these companies is USD 38 million, or KRW 42.5 billion. Considering that Viva Republica, which developed and is servicing Toss, a well-known financial service application in Korea, has received Series B funding amounting to KRW 12 billion, it is clear that construction equipment ConTechs are highly valued. Among these ConTech companies, this article will focus on Built Robotics and SafeAI, which possess heavy construction equipment automation technology.
4.2. SafeAI

Similar to Built Robotics, SafeAI is a ConTech company that started out by automating LHD work of skid loaders. The company has also developed a web-based planning management system that can create and adjust autonomous operation paths (Figure 8). Lately, SafeAI has been expanding the scope of its web-based planning management system to the autonomous operation of ADTs and on-site trucks.

4.1. Built Robotics

Built Robotics is a company that offers automation technology for earthwork equipment. The company’s products enable non-automated excavators to be retrofitted to perform earthwork tasks, such as leveling, excavating and loading, and trench excavation, autonomously (Figure 6). Once the all-in-one device, which includes a control, box, sensors, and lights, is installed on the cab, the device implements autonomous driving using LiDAR (Figure 7), GPS, and Wi-Fi.

<table>
<thead>
<tr>
<th>Name</th>
<th>Area</th>
<th>Total Funding ($M)</th>
<th>Series Stage</th>
<th>Previous Funding ($M)</th>
<th>Previous Funding Period</th>
<th>Founded</th>
<th>Website</th>
</tr>
</thead>
<tbody>
<tr>
<td>SafeAI</td>
<td>Construction Earthwork Automation Robots</td>
<td>5</td>
<td>A</td>
<td>5</td>
<td>2019</td>
<td>2017</td>
<td><a href="https://safeai.ai">https://safeai.ai</a></td>
</tr>
<tr>
<td>Fieldwire</td>
<td>Construction Management Application</td>
<td>40</td>
<td>C</td>
<td>34</td>
<td>2019</td>
<td>2013</td>
<td><a href="https://www.fieldwire.com/">https://www.fieldwire.com/</a></td>
</tr>
</tbody>
</table>
4.3. Automation Technologies Other Than Earthwork Heavy Machinery

Other promising robotics technologies include a concrete finisher robot from True Autonomy; a UGV-based scanner, a robot that gathers 3D spatial information from construction sites, from Scaled Robotics in Barcelona, Spain; and an AI crane load and lifting management system from Versatile (Figure 9).

[Figure 9] Products from Promising ConTech Companies Other Than Earthwork Heavy Equipment

(a) True Autonomy’s Autonomous Concrete Finisher Robot
(b) Scaled Robotics’ UGV-based Scanner
(c) Versatile’s AI Crane Load and Lifting Management System

5. Closing

As of now, overseas construction equipment automation technologies have been proposed in various construction fields, but the development of these technologies is largely centered on earthwork equipment. This is because earthworks are seen to benefit the most from increased productivity and because technology in this sector is highly practical. Considering that earthworks account for a large portion of the total construction industry, it is clear that earthwork equipment automation technologies are an important aspect of smart construction technologies. The utility of construction equipment automation technologies has been confirmed, and these technologies have been widely used abroad. Currently, the market share of these technologies is gradually expanding in Korea as their suitability and practicality have been verified in the local construction industry. In order to do so, we need ongoing collaboration and effort from industry, government, academia, and researchers based on the Smart Construction Technology Development Project launched in 2020. Through these efforts, we hope that the popularization of construction equipment automation technologies will accelerate, rapidly increasing the competitiveness of Korea’s construction industry.

http://smartconstruction.kr
Artificial intelligence (AI): Identifying dangerous situations and process errors at construction sites

Netflix, with its 65 million subscribers in 50 countries around the world watching its movies and TV shows for over 100 million hours a day, analyzes its customers’ viewing habits and recommends what they should watch next. Google predicts which ads may be of interest to users based on web browsing habits. How many accidents can be prevented if we can predict dangerous situations in advance at construction sites?

Israel’s Buildots provides an AI-based project management platform. When a construction site manager walks around the site wearing a helmet equipped with a 360° camera, AI processes the images to identify discrepancies between the original design information (BIM) and the current design. This technology is already being used in several large construction projects throughout Europe.

Smartvid.io developed Vinnie, an AI engine trained with deep learning technology using photos of numerous construction sites. Vinnie monitors safety violations, such as workers not wearing protective equipment at construction sites, and analyzes high-risk tasks to predict where attention is required and provides guidelines to prevent an accident.

Robotics: Performing monotonous and dangerous tasks safely and quickly

The productivity of the construction industry has lagged behind that of other industries for the past several years, but there is a lot of room for improvement with the use of robots and automation technology. McKinsey predicted that the construction industry would undergo significant changes over the next decade due to its recent adoption of new technologies and methodologies used in the manufacturing industry. In fact, global construction equipment manufacturers have been making tremendous efforts to utilize automation, AI, and robotics in their products.

Canvas has developed, and is currently using, a robot that can complete the process of hanging indoor drywall faster than a person can. A worker walks around an unfinished building with a laser scanner and robotic arm mounted on a vertical platform. When the worker places the equipment in front of a wall, the robot uses LiDAR to scan the unfinished wall, smooths the surface almost completely, and applies the drywall compound.

Fast Brick Robotics in Australia has developed the world’s first fully autonomous brick-laying robot. The company has been working hard to introduce the robot to the field in partnership with Caterpillar, a global construction and mining equipment manufacturer.

A robot developed by Doxel in California, USA, is equipped with LiDAR to help track construction projects and find mistakes that occur during the construction process. Moreover, companies such as vHive, Propeller, ABJ Drone, and DJI are supplying drones for the inspection of construction sites.
Modular: Strategic technologies to increase productivity in the construction industry

The global construction industry is currently facing unprecedented crises, such as labor shortages and rising material costs. Thus, the U.S., the UK, and Singapore are promoting policies to encourage the use of the modular construction methods and prefab technologies in the hopes of transforming the construction industry to make it more like the manufacturing industry. Unlike traditional construction projects, which are completed from start to finish on-site, modular construction projects are mostly completed in a factory, transported to the site, and then assembled. This can significantly reducing a project’s timeline as well as minimize environmental and safety issues.

The global prefab market is growing at an average annual rate of more than 5%, and Global Market Insights estimates the global market value of modular and prefab construction at USD 174.37 billion by 2026.

Recently, China’s Broad Group gained a lot of attention after building a ten-story apartment building in about a day using modular construction. The company prefabricated 20 standard-sized containers in the factory, and then assembled the building by stacking them up like Legos while bolting the containers together.

Digital Twin: Supporting better decision-making for asset management

Digital twinning is a technology that represents a real physical space in a virtual space using software. In other words, it creates a digital twin identical to the real physical world. This allows the user to test and validate a variety of real-world problems in the virtual world.

With a digital twin, you can predict outcomes quickly without needing physical equipment.

According to McKinsey, a consulting firm, digital twins are expected to generate an economic value of USD 3.9 trillion (about KRW 4,397 trillion) by 2025.

Autodesk has unveiled Tandem, a BIM-based digital twin platform that supports data virtualization for construction projects. Construction projects generate a tremendous amount of data from design to construction, and considering that 80% of the life of a facility occurs after construction is completed, construction information must be delivered to the client at the end of the project. Therefore, Tandem integrates all the project data in a variety of formats to build a digital twin.

(Source: https://intandem.autodesk.com)
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1. Opening

Even though the construction industry contributes significantly to Korea’s national economic development, accounting for 14.5% of total GDP (based on 2019 construction investment data), it is still recognized as a 4D (difficult, dirty, dangerous, and despised) industry. To improve the quality of the industry and promote sustainable growth, the Ministry of Land, Infrastructure and Transport announced the Construction Industry Innovation Plan. As part of the plan, the Ministry is promoting the Smart Construction Technology Development Project, in which it will invest a total of KRW 197 billion over a period of 5 years and 9 months starting from 2020. The goal of the project is to develop smart construction technologies related to design, construction, and safety management across four key areas, and to build a smart construction platform where the digital information generated in each key area can be shared and utilized throughout the entire construction process. In two of the key areas, technology will be developed to improve the productivity and safety of the design-construction process by focusing on prefabrication technology related to the assembly of structures.

2. Status and Problems

The Korean construction industry is facing serious issues, such as decreasing construction productivity and an increasing rate of accidents, as a result of the decrease in the country’s working-age population due to low birth rates and an aging population, and the decrease in skilled workers due to a reduction in the flow of young people into the industry because of its reputation as a 4D industry. Employment stability in the construction industry is declining, with day and temporary laborers accounting for 60.6% of workers in the industry (as of 2017). Moreover, because young people are avoiding working in the industry, 81% of workers are in their 40s or older (as of 2018) compared to only 65% of workers in all industries. This shortage of skilled personnel, which is being addressed by the illegal employment of foreign workers, is causing concern that the industry may collapse.

The construction industry has the highest number of accidents among all industries. Moreover, while the accident rate in all other industries is decreasing, the construction industry’s accident rate is increasing. Falls account for the highest number of deaths in the industry. It has been confirmed that one-third of the construction sites where accidental fatalities occurred did not follow basic safety measures, such as the use of scaffolding, railings, and fall prevention nets.
The decrease in the number of skilled workers coupled with the increase in the industrial accident rate in the construction industry have resulted in a loss of construction productivity, which must be resolved quickly. These issues are the main reason for the increasing need to use robots at construction sites. The introduction of robots at construction sites can help solve the issues of insufficient labor supply and improve the working environment by reducing the risk of accidents.

3. Robot-based Remote Bridge Pier Construction Technology

During the development of remote and unmanned road structure construction technologies, bridge piers (excluding coping) were selected as the target of robot-based remote pier construction technology. Piers require high-altitude/high-risk work, which puts workers at a high risk of accidents, and encompasses various specialized tasks, such as connecting rebar and laying concrete. In response to these irregular working conditions, rather than automated robots that repeat the same task, remote-controlled robots are being introduced. These remote-controlled robots can replace workers at construction sites because operators can use the robots to scan the working environment and use that information to perform the work remotely.

The remote pier construction technology consists of a manipulation system and a formwork/workbench system. The manipulation system uses a remote-controlled robot instead of workers to carry out work tasks, and it includes a robot arm manipulator, a moving base that moves the manipulator, attachments for specific tasks, and a tool station where the attachments are stored. The formwork/workbench system includes a workbench for the installation/operation of the manipulation system, and a formwork capable of automatic ascent and descent.

Analysis of the construction process for existing cast-in-place bridge piers found that it is difficult to work with robots using existing construction methods. For example, robots cannot efficiently collaborate the way people do, and if there is a significant error between design information, which is used to control the robots, and construction information, it is impossible to carry out the tasks. To solve this problem, the work process was modified by using a prefabricated high-precision rebar cage and a rebar coupler joint, which is relatively simple to operate and can be done with a single robot.

Three types of attachments are being developed according to the modified work process. The first is a gripper that is required to move the rebar cage to a fixed position; the second is a coupler connector that connects the rebar; and the third is a vibrator for laying concrete. The manipulator performs the necessary tasks by selecting the appropriate attachment from the tool station.

The remote pier construction technology requires a highly-skilled operator to receive commands while looking at a monitor and precisely control the device. The time delay between the command and the operation determines the precision of the remote control. The smaller the time delay, the more realistic it feels, and the more precise the adjustment. In reference to previous studies, the development of the technology is aimed at reducing the time delay to 0.3 seconds, which takes into account the physical time required by the system and still allows operators to easily perform detailed tasks using remote controls.

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4. Closing

This article introduced the robot-based remote bridge pier construction technology that is being developed as one of the five Smart Construction Technology Development Projects. This technology is very inspiring because it directly applies robots to construction sites, examples of which are difficult to find anywhere in the world. The robot-based remote bridge pier construction technology provides a technological solution to the labor and safety issues mentioned earlier, which necessitate the introduction of robots. We hope to successfully develop this technology and to use it both promote and serve as a reference for the application of robots at construction sites.
2. The Five Stages of Bridge Construction Technology Development

Prefabricated modular bridge construction technologies are expected to be developed in the following five stages.

<table>
<thead>
<tr>
<th>Generation</th>
<th>Definition</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st Gen</td>
<td>Reinforced concrete bridges cured on-site by pouring concrete into partial module bridge forms</td>
<td>Requires a large workforce and a long time, and the quality of the structure varies depending on the conditions of the site</td>
</tr>
<tr>
<td>2nd Gen</td>
<td>Construction method that combines precast concrete girders and prefabricated steel girders with on-site concrete pouring using partial deck forms</td>
<td>Bridge girder manufacturing technology has rapidly advanced, and the deck form installation process has been shortened.</td>
</tr>
<tr>
<td>3rd Gen</td>
<td>An attempt to modularize bridge structures using full-depth precast decks, segmental girders, and modular bridges</td>
<td>At the current level of modular technology, individual structures are produced in plants using confirmed designs, then transported and installed</td>
</tr>
<tr>
<td>4th Gen</td>
<td>An attempt to modularize bridge structures using full-depth precast decks, segmental girders, and modular bridges</td>
<td>Research is in progress to develop from the design then produce phases to the pre-build then design phases</td>
</tr>
<tr>
<td>5th Gen</td>
<td>Platform-based road construction that simultaneously carries out DfMA-based 3D model design and planning, material supply, process management, quality management, and maintenance processes for road construction using standard modules</td>
<td></td>
</tr>
</tbody>
</table>

3. Complete Prefab Bridge Construction and Smart Quality Management Technologies

Bricon has finalized prefabrication technology for each element of steel and concrete bridges, including piers, girders, and decks, and has experience in all elements of prefabricated bridge construction. Currently, Bricon is conducting research on the mechanical assembly of joints and the prefabrication of median strips, guardrails, retaining walls, and earth anchors. The Buhang Bridge at the Yangpyeong-Icheon Expressway construction site, which the Center for Smart Construction Technology selected as a demonstration site, will be the first bridge in Korea constructed entirely from prefabricated parts.

Research is underway at the Center for Smart Construction Technology to establish a prefab quality control platform that will increase the safety of prefab structures by ensuring their quality throughout the design-production-assembly-maintenance process and by linking the data obtained from each step of the process. When the research is completed, the prefab quality management platform will be a groundbreaking technology that will improve the productivity, safety, and economic viability of construction sites based on BIM systems designed for prefabrication and intuitive quality information.
Bricon is working on a 3D printer that can instantly produce various bridge components and road structures required at the project site. Through further development of the current printing technology that produces limited non-structural elements by layering non-reinforced mortar, the aim is to develop a mobile factory equipped with smart adjustable formwork and an automatic curing device that can produce various atypical structural elements, and a robotic transporter that supports prefab production and installation. After installing the smart mobile factory at the desired location, it will become an innovative facility that quickly analyzes on-site conditions and produces prefab structures.

4. Digital Terraforming of Construction Technologies

Terraforming is the process of modifying the environment of other planets and satellites to have an ecosystem with a similar atmosphere and temperature as Earth to make them habitable by humans. Creating a smart construction industry does not require sequential innovation through the consensus of various stakeholders. Rather, terraforming of the construction industry ecosystem, which can be compared to an alien planet, is needed in the industry’s digitalization sector.

The completion of the prefabrication technology for each structural element is bringing the technology closer to active commercial use. The next step is standardizing the structures for digitalization. The robotization of smart factories can only be achieved after the configuration of standard digital models. Platformation will make it possible to collect and manage data from the entire process, from design and production to construction and maintenance, and producers of fundamental technologies must be upgraded from original equipment manufacturers (OEM) to original development manufacturers (ODM).

The Smart Construction Technology Development Project supervised by the Korea Expressway Corporation will serve as the motivation for the complete prefabrication of road structures and the digital terraforming of the construction industry ecosystem.

If the digitalization of the construction industry enables C2E (Construction to Everything), or the integration of digital information into the planning, construction, and operation of social infrastructure, the construction industry will be able to contribute to the preservation of the global environment by taking the lead in providing safety and convenience for society and by reducing the industry’s carbon emissions, which account for 10% of the 51 billion tons of greenhouse gases that humans emit each year.
1. Opening

For years, researchers have been trying to integrate geographic information systems (GIS) and building information model (BIM) systems for various purposes. An important aspect of BIM application in construction is asset management, and the integration of BIM and GIS can provide a highly detailed and comprehensive picture of the project. Information gathered from GIS in relation to BIM can increase the success of asset management, and in earthworks/paving, it can be used for asset management, including controlling construction equipment and calculating work volume.

2. Current Status and Problems

BIM is widely accepted as one of the major technological advances that has had an increasing impact on the construction industry over the years, as it enables stakeholders to collect and exchange information throughout the life cycle of building construction projects. It is used in the industry to bridge the interoperability gap, making it popular among both customers and stakeholders, and is regarded as a technology that facilitates integration, interoperability, collaboration, and process automation.

GIS allows users to access detailed spatial information about a specific location using coordinates. Recently, there has been a push in the industry to integrate GIS data with BIM data for various purposes. The focus, however, is currently on building-related information. Thus, it is necessary to also develop and consider technologies that can be used in earthworks/paving.

3. Construction Equipment Control Technologies Using BIM-GIS

BIM/GIS is expected to improve the productivity of earthwork/paving projects through the development of smart technologies, such as cloud e-BIM, big data navigation, AI, IoT sensor networks, edge computing, smart networks optimized for construction sites, high-precision hybrid positioning, and unmanned remote environments that support the intelligent, autonomous, and advanced control of earthwork/paving construction equipment (bulldozers, rollers, graders, pavers, and dump trucks).
BIM technology is currently focused on modeling building information, but the goal of BIM is information interoperability throughout the construction process. Therefore, to manage BIM from the perspective of the entire project life-cycle and to select alternatives and applications, existing BIM technology must be integrated with GIS, which models the surrounding environment.

Therefore, this technology was designed to integrate BIM and GIS by developing an interface and information model that improves information interoperability between systems. The interface was developed considering information query and mapping rules for exchanging information between heterogeneous sources and metadata for linking information managed by heterogeneous systems. Moreover, based on the developed technology, there are plans to acquire big data for earthwork/paving construction equipment at various sites, and establish an earthwork/paving construction equipment control environment using more advanced control service platforms (equipment control technology using BIM-GIS).

As shown by the rapid dissemination of BIM-GIS technology and systems, which are revolutionizing productivity and quality of construction projects, the construction industry is facing increasing demands for change in line with shifts in the global paradigm. In Korea, research institutes, associations, and academic societies have been conducting related R&D. However, the focus has been on developing information technology or guidelines, leaving application methods for technology systems for contractors; related industrial environments; and systems, policies, and clear roadmaps for ecosystem development insufficient. Moreover, the Korean construction industry is organized like a closed system, where each field is separated from the others, which hinders the dissemination of these technologies.
Doosan Infracore Technology Convergence Technology Center

Doosan Infracore has positioned itself as a global leader in various business areas, including construction machinery represented by excavators and loaders, diesel and gas engines, and attachments. Doosan Infracore is expanding its provision of smart equipment linked to ICT technologies and solutions, strengthening its customer service programs, and leapfrogging forward as a total solutions provider that offers better value and convenience to customers.

Concept-X is a comprehensive unmanned control solution that surveys the topography of a job site with 3D scanning technologies using drones to automatically analyze the surveyed topographic data and establish a work plan for unmanned construction equipment. The manager monitors the work process of the site at the control center. Doosan plans to commercialize comprehensive control solutions for construction sites by 2025.

Daewoo Institute of Construction Technology (Research Group for Project No. 3 & No. 4)

In 1983, Daewoo Engineering & Construction (E&C) opened the Korea construction industry’s first technology institute and has been lauded as the top performer in the industry with 706 patent applications and 643 registrations.

Daewoo E&C has since developed new technologies for construction, the environment, and disaster prevention, and has been promoting shared growth by transferring 65 new technologies and 42 patented technologies to 97 SMEs. Daewoo E&C is acting as a technology hub to discover new growth engines to leapfrog forward as a total solutions provider that offers better value and convenience to customers.

The next technology is COCO, a photo-based on-site collaboration app, developed for quick and accurate communication at construction sites. It takes pictures of issues or risk factors on-site, selects the user and work type tag, asks the personnel in charge to take action in real time, and provides real-time tracking and management.

Hanyang University Intelligent Construction Technology Laboratory

Professor Suh Jongwon’s Intelligent Construction Technology Laboratory at the Department of Civil and Environmental Engineering at Hanyang University has been conducting empirical research to develop smart construction technology.

The "DW Drone Control System (DW-CDS)," which was pioneered in the domestic construction industry, enables periodic and stable automatic drone flights without a drone expert on-site by using a central control system. It is now being used at 25 domestic and overseas construction sites, and from 2021, with the help of Naver Cloud, it will be used in other industries, such as firefighting, search and rescue, and coastal reconnaissance.

Korea Institute of Machinery and Materials Smart Industrial Machinery Laboratory (Research Group for Project No. 5)

This government-funded research institute was established to contribute to Korea’s national and industrial development through R&D, performance diffusion, and reliability evaluation in the mechanical sector. It has been leading the development of original technologies and demonstrating large-scale research results in the field.

It has also been conducting unmanned and autonomous studies on off-road industrial machineries, such as construction machinery, agricultural machinery, and unmanned vehicles, for defense and disaster response.

Aiming to develop a system that autonomously performs heavy duty work in an atypical environment, it has been developing technologies for the smartification of industrial machinery, from traditional H/W technologies, such as high-efficiency power transmission systems, structural optimization and test evaluation technology, to S/W technologies, such as off-road autonomous operation and autonomous work technology, and even virtual test evaluation technology.

Korea University

The Korea University Foundation has been conducting research in various fields related to TBMs, such as TBM tunnel face forward prediction, TBM tunnel risk analysis, artificial freezing, and surface subsidence prediction during TBM excavation, and aims to develop smart construction technology for TBM tunnels based on this research.

It has also been conducting a quantitative risk analysis/evaluation model (STM) applicable to TBM tunnels through a research project sponsored by the Ministry of Land, Infrastructure, and Transport titled “Development of the Key Element Technology for the Technological Independence of High-pressure and Ultra-long Submarine Tunnels.”

There are also plans to develop a machine learning-based TBM risk analysis and management system through the development of tunnel face forward prediction technology and the application of machine learning techniques. The machine learning-based TBM risk analysis and management system will predict possible risks through real-time analysis of geotechnical information and TBM excavation data during tunnel excavation, and it will propose measures to minimize damage to people and materials. It can also contribute to TBM smart operation.
Preparing for digital transition (DX) with industry, academia, and related organizations

Launch of the Smart Construction Roundtable (ScRT) and Technology Seminar

The Smart Construction Roundtable (ScRT) is a consultative body composed of experts who possess or have implemented smart construction technology. The ScRT meeting was created with the aim of exploring the Korean construction industry’s digital transition through informal and open discussion and information sharing.

This event was held in conjunction with the Korea Build (March 18-21) Exhibition and Digital New Deal Conference. Some 500 experts in the smart construction field from construction companies, design companies, universities, research institutes and startups attended the conference, which was sponsored by the Ministry of Land, Infrastructure and Transport.

MOUs with Related Organizations for the Practical Application of Technology

(June 8) Korea Expressway Corporation and KEPCO E&C signed a Memorandum Of Understanding (MOU) for research cooperation on smart construction and digital engineering technologies, promising to cooperate on process and project management based on BIM, building a cloud-based digital platform, and high-tech facility management using drones and IoT.

Current completed MOUs
- Multilateral agreements with 7 organizations including Seoul Metropolitan Government (May 2020)
- Bilateral agreement with the Korea Institute of Construction Technology (July 2020)
- Bilateral agreement with KSARC (December 2020)
- Bilateral agreement with Hyundai E&C (March 2021)
- Bilateral agreement with KEPCO E&C (June 2021)

Smart Construction Pioneer (SCP) Seminar

Since May 2021, the Center for Smart Construction Technology has been hosting the SCP Seminar, inviting companies and experts from the construction and IT sectors to give presentations on and discuss smart construction. Recently, IntelliVIX was invited to hold its 38th seminar with the theme, “Intelligent video analysis and safety monitoring technology using AI.”

MOU with Hyundai E&C (Mar. 9, 2020)
MOU with KEPCO E&C (Jun. 8, 2020)

Strategic Partnership with KSARC

* Inaugural assembly on June 1, 2021, with first president, Hanyang University’s Professor Jong-won SEO (Head of Project NO.1)

We plan to promote the development and realization of construction automation and robots technologies, and to implement cooperation among relevant stakeholders, including construction equipment manufacturers, construction companies, and academia.

Implementation of Pilot Projects for the Application of Smart Construction Technologies for the Entire Construction Process

We are promoting pilot projects for the application of smart construction technologies at actual construction sites* in order to establish a smart construction technology operation process for the entire construction process.

Current completed MOUs
- MOU with KEPCO E&C (June 2021)
- MOU with Hyundai E&C (March 2021)
- MOU with KEPCO E&C (June 2021)

Before Year 1 (2021)
1. Status modeling (topography, etc.)
2. BIM-converted design (2D → 3D)
3. BIM-based project management
4. Technology development

Years 1-3 (2021–23)
1. BIM-based project management
2. Detailed construction preparation
3. Equipment automation
4. Quality and safety control

Completion, Transfer Year 3 (2023.12)
1. 3D as-built blueprint transfer
2. Outcome report preparation

Opening of the Digital Collaboration Room (BIM Room)

We opened a digital collaboration room (BIM Room) and a digital engineering collaboration space at our R&D HQ in Dongtan, and we have been operating digital information operation solutions software, such as BIM, 3D topographic information, and Point Cloud, to improve the usability of digital models including BIM at construction sites.

* MOUs with Related Organizations (2020-2023)

- WG1 : data for interoperability
- WG2 : digital modelling (BIM)
- WG3 : test-bed operation

We are running practical working groups (WG)

- WG1 : data for interoperability
- WG2 : digital modelling (BIM)
- WG3 : test-bed operation