Front. Eng. Manag. 2019, 6(4): 503–516
https://doi.org/10.1007/s42524-019-0073-9

RESEARCH ARTICLE

**Chunfang LU, Junfei LIU, Yanhong LIU, Yuming LIU**

# Intelligent construction technology of railway engineering in China



**Abstract** Intelligent construction technology has been widely used in the field of railway engineering. This work first analyzes the connotation, function, and characteristics of intelligent construction of railway engineering (ICRE) and establishes its system structure from three dimensions, namely, life cycle, layers of management, and intelligent function, to deeply understand the development situation of intelligent railway construction in China. Second, seven key technical support systems of ICRE, which include building information modeling (BIM) standard system for China's railway sector, technology management platform and life cycle management based on BIM + GIS (geography information system), ubiquitous intelligent perception system, intelligent Internet-of-Things (IoT) communication system based on mobile interconnection, construction management platform based on cloud computing and big data, unmanned operation system based on artificial intelligence, intelligent machinery and robot, and intelligent operation and maintenance system based on BIM and PHM (prediction and health management), are established. Third, ICRE is divided into three development stages: primary (perception), intermediate (substitution), and advanced (intelligence). The evaluation index system of each stage is provided from the aspects of technology and function. Finally, this work summarizes and analyzes the application situation of ICRE in the entire railway sector of China, represented by Beijing–Zhangjiakou and Beijing–Xiong'an high-speed railways. Result shows that the technical support systems of the ICRE have emerged in China and are still in the process of deepening basic technology research and preliminary application. In the future, the ICRE of China's railway sector will develop toward a higher stage.

**Keywords** China railway sector, intelligent construction, railway engineering, informatization, development stage

Received May 20, 2019; accepted September 30, 2019

Chunfang LU
China Railway Society, Beijing 100844, China

Junfei LIU, Yanhong LIU
Engineering Management Center, China Railway Corporation, Beijing 100844, China

Yuming LIU (✉)
School of Economics and Management, Beijing Jiaotong University, Beijing 100044, China
E-mail: ymliu@bjtu.edu.cn

## 1 Introduction

The collection, utilization, control, and sharing of information have become considerably fast and convenient with the advancement of information and communication technologies, such as mobile Internet, cloud computing, big data, and Internet of Things (IoT). Integrated intelligent innovation arises because of information technology's exponential growth and digitization, and the extensive application of networking. Currently, exponential growth of information technology, popularization and application of digitization and networking, and integrated intelligent innovation are the three driving forces for the new scientific, technological, and industrial revolution (Zhou et al., 2018; Zhou et al., 2019). The Chinese government keenly grasps the general trend of global economic development and stands at the forefront of the current era's development. For example, the Chinese government takes informatization and intelligent technology as the initiative to promote the structural reform, accelerate the transformation and upgrade of traditional industries, and drive innovation in the supply side. The 2019 Government Work Report mentioned that creating industrial Internet platforms and expanding "Internet +" are crucial in facilitating the transformation and upgrade in manufacturing (Li, 2019). Thus, the Chinese government takes active supporting attitude and policy toward the promotion of a new generation of information and communication technologies. Therefore, the construction sector should grasp the development trend of the new era and leverage scientific and technological advancement to comprehensively improve the level of technology and management. Ultimately, the construction sector can realize the factor-driven transformation, that is, from investment-driven to innovation-driven and from scale-oriented model to quality-oriented model.

In recent years, China’s railway construction and management has been greatly improved with the rapid development of engineering construction and information technologies. A set of advanced, practical, and universal standardized management systems for railway construction projects (SMSRCP) have been established and successfully implemented in high-speed railway project construction (Fig. 1) (Lu, 2016; Lu and Zhang, 2018). The SMSRCP emphasize the supporting role of mechanization, professionalization, industrialization, and informatization. Applying information technology in railway engineering construction, which strongly promotes the development of railway engineering construction toward “Intelligent Construction (IC)”, is becoming extensive and in-depth. Hence, systematically exploring the connotation, extension, development stages, and key technologies of intelligent construction of railway engineering (ICRE) has great theoretical and practical significance in guiding the development of China’s railway sector in the direction of IC.

## 2 Literature review

The construction sector currently faces transformation driven by a shift toward the IoT system enabled by using sensors and controls, cognitive and high-performance computing, additive manufacturing, advanced materials, autonomous robots, digital design and simulation systems, and other technologies (Craveiro et al., 2019). This transformation will improve project productivity and quality, reduce project delays and cost overruns, manage project complexity, and strengthen worksite safety (Ghaffar et al., 2018; Woodhead et al., 2018).

Information and communication technologies are the core tools for IC. Aziz et al. (2006) predicted the function of intelligent wireless web support for mobile construction workers by examining convergence and synergy among high-speed wireless network technologies. Building information technology (BIM) is another main tool that is applied to achieve information-based integrated construction management, such as schedule, resource, cost, and conflict analysis, as well as dynamic collision detection (Hu and Zhang, 2011). Wang et al. (2012) proposed a development strategy for IC based on the analysis of its concept and the relationship between BIM and intellectualization. Han et al. (2018) proved that BIM could compensate for the shortcomings of the traditional method of railway engineering construction and operation. Project stakeholders can cooperate from different locations in real time by integrating cloud computing technology with BIM (Birje et al., 2017). This method can effectively integrate large and complex project information and data, and hence improve the decision-making process (Yao et al., 2015). Geography information system (GIS) is a spatial information system for collecting, analyzing, and displaying geographic data, which are greatly important for railway construction, and in which a complex geographic environ-

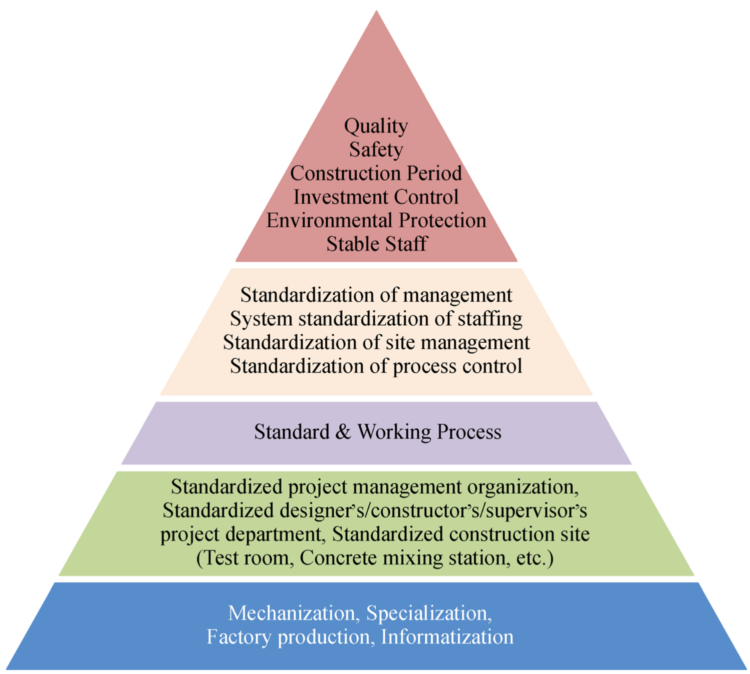



**Fig. 1** The basic framework of standardized management system for railway construction project.

ment must be encountered (Liu et al., 2018). The integration of GIS with BIM has great potential benefits (Zhu et al., 2018). BIM focuses on the micro-level representation of the building itself, whereas GIS provides a macro-level representation of the building's external environment. The integration of BIM and GIS creates a comprehensive view of construction (Wang et al., 2019). IoT can maximize user comfort, security, and energy saving by diverse intelligent solutions to reduce equipment maintenance cost (Khan and Salah, 2018). Several literatures researched the function of IoT in the operation and the maintenance stages of railway engineering rather than in the construction stage (Liu et al., 2013).

In recent years, these technologies have been widely used in the engineering construction stage, but the level of IC in the construction sector is still in the primary stage compared with other industries (Kehoe et al., 2015). ICRE remains to be a broad concept that must be studied systematically. Existing studies on ICRE focus on the application of specific technologies and have not yet completely formed an integrated intelligent construction system. Therefore, in this work, a systematic research on ICRE will be conducted from the holistic perspective, which includes connotation, function, system structure, key supporting technologies, and development stages of ICRE, and the application and current practices of ICRE in railway construction projects will be analyzed on this basis.

## 3 Connotation, function, and system structure of ICRE

### 3.1 Connotation, function, and implementation effects

#### 3.1.1 Connotation of intelligence

The core element of the IC is "intelligence", and the concept of intelligence has been defined in many ways, including the capacity for logic, understanding, self-awareness, learning, emotional knowledge, reasoning, planning, creativity, critical thinking, and problem solving. It can be described as the ability to perceive or infer information and to retain it as knowledge to be applied toward adaptive behavior within an environment or context. In the context of intelligent manufacturing (Lu, 2010a; 2010b; 2010c), the core of intelligence is the deep processing and utilization of data (including digital, text, sound, and image). Intelligence can be realized by deeply integrating information with human needs.

*a*. Data collection. New sensor technology, new detection technology, and remote-sensing technology can collect the data rapidly and efficiently.

*b*. Data transmission. Internet, mobile network, cloud storage, and other technologies can achieve high-speed transmission of information between application levels.

*c*. Data analysis and mining. Deep learning in artificial intelligence (AI), big data, cloud computing, and other technologies can perform calculation, analysis, and deep mining of a large variety of data, thereby forming information and knowledge.

*d*. Information utilization. Supported by advanced data collection, transmission, and analysis technology, useful knowledge is formed for human production and life, thereby guiding human production and life practice, which are also the fundamental purpose of intelligence.

The intelligent technological system is illustrated in Fig. 2.


**Fig. 2** The intelligent technology system.

#### 3.1.2 Connotation of ICRE

Railway engineering construction has major characteristics, such as large scale, enormous investment, fast technological advancement, long supply chain, and involvement of wide range of stakeholders and communities. Correspondingly, railway engineering has four attributes, namely, strategic significance, steering direction, fundamental support, and service nature. These characteristics and attributes determine that the construction management system of railway engineering is large and complex, and requires considerable inputs. A large amount and great variety of data are produced and used during construction. Therefore, exploring ICRE by integrating new generation information and communication technologies with advanced railway construction technologies has strong necessity and feasibility.

ICRE can be defined as a new construction mode that deeply integrates new-generation information and communication technologies with advanced design and construction technologies of railway engineering based on the aforementioned analysis and related references (Wang, 2019a; Li, 2018). ICRE can be applied in all aspects of engineering activities, such as survey, design, construction, and hand-over of railway engineering construction. Consequently, this mode can realize the functions of self-perception, self-learning, self-decision making, and self-adaptation.

Figure 1 shows the four supporting measures of the SMSRCP for high-speed railway construction proposed by the former Ministry of Railways of People's Republic of China, namely, mechanization, specialization, industrialization, and informatization. ICRE is the deep integration and further development of the four supporting measures. These measures are mutually reinforcing and supportive, where informatization, as the key measure, is running through mechanized operation, industrialization, and specialized management and control during the entire life cycle.

#### 3.1.3 Main functions of ICRE

ICRE has the following functions based on the understanding of its connotation.

*a*. Comprehensive perception. The key elements of railway construction, such as human, machine, material, and environment, are perceived comprehensively and thoroughly.

*b*. Intelligent diagnostic. The perception of massive volume of data and information is stored and analyzed to evaluate the quality, safety, progress, and efficiency of railway construction.

*c*. Collaborative interaction. Comprehensive sharing of information and resources can be achieved through better quality and more active interaction, as well as in-depth, secure, and reliable connectivity.

*d*. Self-learning. A large amount of data and knowledge can be accumulated and constantly iterated to meet the needs of railway construction and development.

*e*. Intelligent decision-making. Decision-making information can be extracted from massive data to assist construction management and construction decision-making based on data-, model-, and knowledge-driven approaches.

#### 3.1.4 Implementation effects of ICRE

The following functions can be realized with the implementation of ICRE based on the aforementioned analysis and related reference (Lin et al., 2018).

*a*. The management and control of railway project construction, which can improve the quality of railway projects, can be precise and efficient.

*b*. System integration, communication, and coordination of the entire process can be enhanced to improve work efficiency.

*c*. The working environment of employees in railway construction can be enhanced to improve occupational health and safety.

*d*. Resource and energy consumption can be effectively reduced to eventually realize green railway construction.

### 3.2 System structure of ICRE

The ultimate goal of railway engineering construction is to serve railway operation. In 2017, China Railway Corporation issued the Master Plan for Railway Informatization, which proposed the establishment of China Standard Intelligent Railway Information System (CRIS) (Fig. 3). The CRIS incorporates six application business systems to build an integrated information platform, which includes intelligent perception layer, intelligent transport layer, data resource layer, intelligent decision layer, and intelligent application layer. The six major application business systems include strategic decision system, transportation production system, business development system, resource management system, construction supervising system, and comprehensive coordination system. Figure 3 shows that the ICRE has become an integral part of "intelligent railway" in this platform.

The system structure of ICRE can be described from three dimensions, namely, life cycle, layers of management, and intelligent function (Fig. 4).

*a*. For life cycle, ICRE includes design, construction, hand-over, and other stages; it can extend to the operation stage and finally serve railway operation.

*b*. For layers of management, ICRE includes five levels: team, work area, bid section, project, and entire railway networks.

*c*. For intelligent function, ICRE begins with intelligent model or equipment, gradually achieves the interconnection of intelligent information, and then realizes the intellectualization of comprehensive construction organization and management.

## 4 Key technological support systems for ICRE

The China Railway Corporation has introduced BIM in the construction process management since 2013, such as railway engineering design, construction, and hand-over, to build an intelligent system of railway engineering that covers the entire life cycle throughout the entire management levels and has systemic advantage. BIM is an important technology for addressing the data standardization, application standardization, and supporting management standardization of railway engineering construction information. In addition, the China Railway Corporation

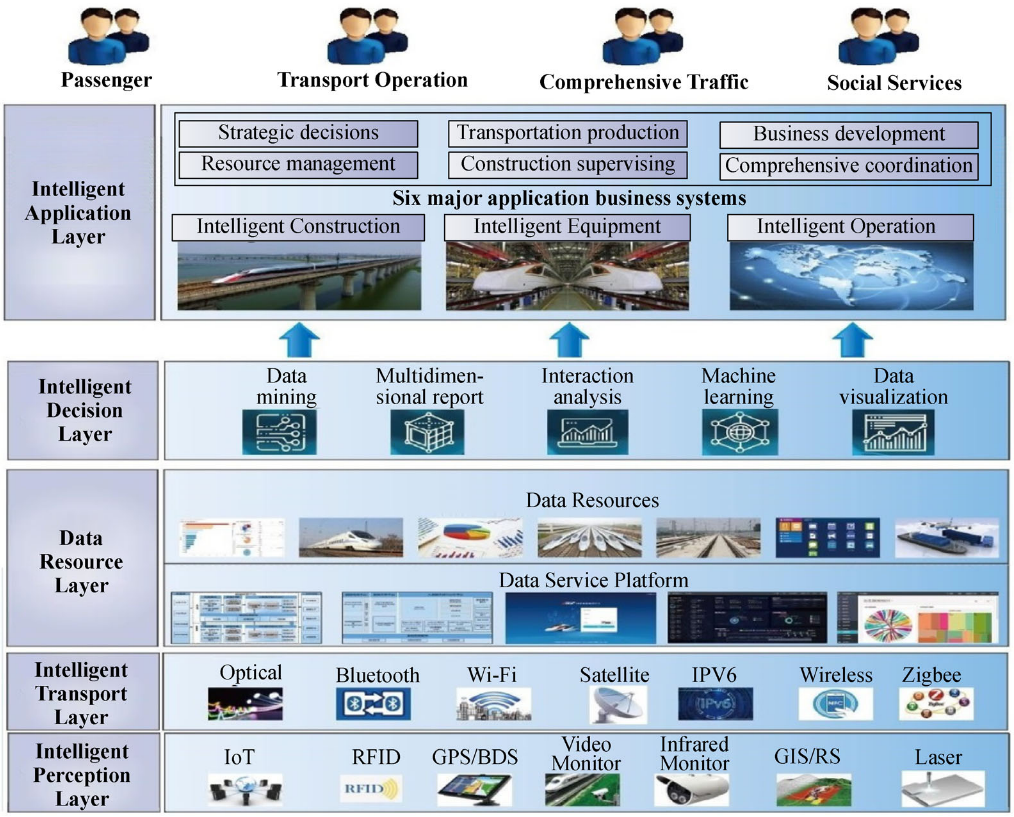



**Fig. 3** The basic framework of intelligent railway information system.

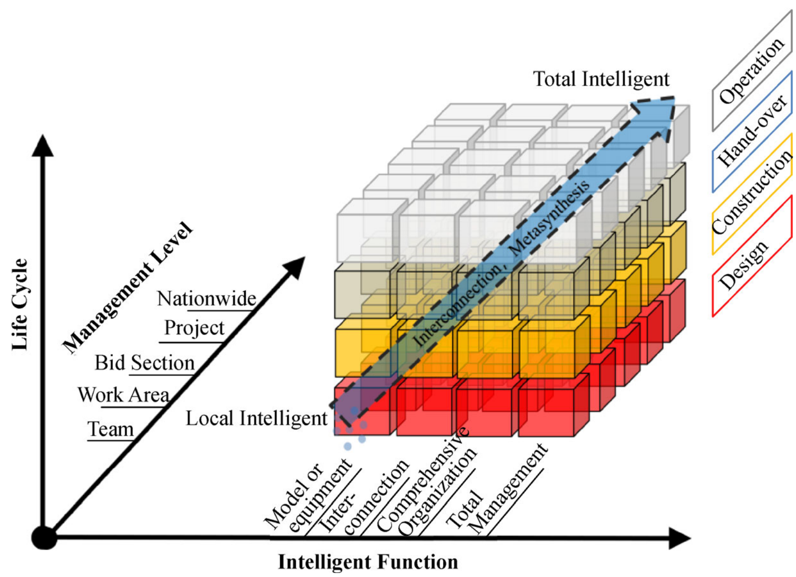
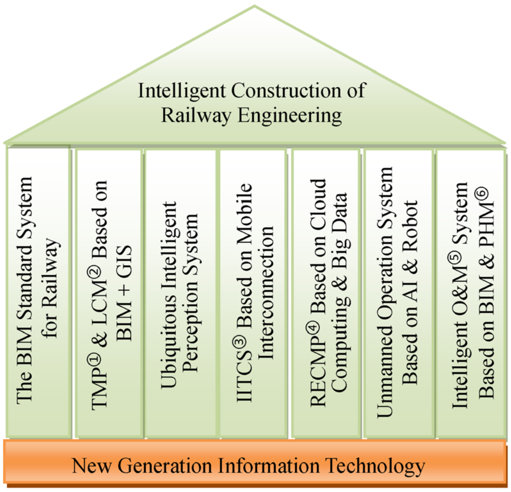



**Fig. 4** The system structure of the ICRE.

has implemented collaborative design, information management and control, virtual construction, intelligent construction site, precast production line, intelligent assembly, and digital delivery. The exploration and practice of life cycle management based on BIM technology has gradually formed the seven supporting technological systems for ICRE (Fig. 5) (Li, 2018; Fan et al., 2019; Wang, 2019b).




Note: ① TMP—Technology Management Platform;
② LCM—Life Cycle Management;
③ IITCS—Intelligent Internet-of-Things Communication System;
④ RECMP—Railway Engineering Construction Management Platform;
⑤ O&M—Operation & Maintenance;
⑥ PHM—Prediction and Health Management.

**Fig. 5** Seven-supporting technological systems for the ICRE.

### 4.1 BIM standardized management model

The BIM standardized management model constructed in China includes technical and implementation standards. Technical standards include data storage, information interpretation, and information transmission standards. Implementation standards include resources, behavior, delivery, and collaboration standards. Since 2015, the China Railway Corporation has been actively promoting the internationalization of BIM standards for Chinese railways. It is currently working with building-SMART, German, French, Swiss, and Italian railway companies, together with Finland and Swedish Transport Department to compile Industry Foundation Classes (IFC) standards for international railways.

### 4.2 Technology management platform based on BIM + GIS and its life cycle management

The overall framework of BIM application currently targets the entire life cycle of engineering construction, which can provide a technical management platform for the construction mode of design, factory prefabrication, and on-site assembly (Wang, 2015). On this basis, a technical system of “investor-leading, participant-sharing” has been formed to realize information sharing and transmission in the life cycle of survey, design, construction, and operation.

### 4.3 Ubiquitous intelligent perception system

The spatiotemporal self-perception system of railway construction is established to achieve a comprehensive perception capture of engineering factors, such as nature, human, engineering entities, equipment, and materials by applying intelligent perception technology (Fig. 6). For example, a three-level perception network of people and people, people and objects, and people and nature can be constructed through real-time perception and collection of various data about natural environment, such as terrain, geology, and hydrology along the line; construction sites, such as bridges, tunnels, roadbed, and station buildings; large-scale temporary projects, such as mixing stations, beam yards, and slab yards; and experimental equipment, such as laboratory presses and test machines. This three-level perception network can achieve the barrier-free acquisition and transmission of information.

### 4.4 Intelligent IoT communication system based on mobile interconnection

The barrier-free information transmission between railway engineering construction site and participants involved has been realized through a series of communication technologies, such as near-field communication based on short-

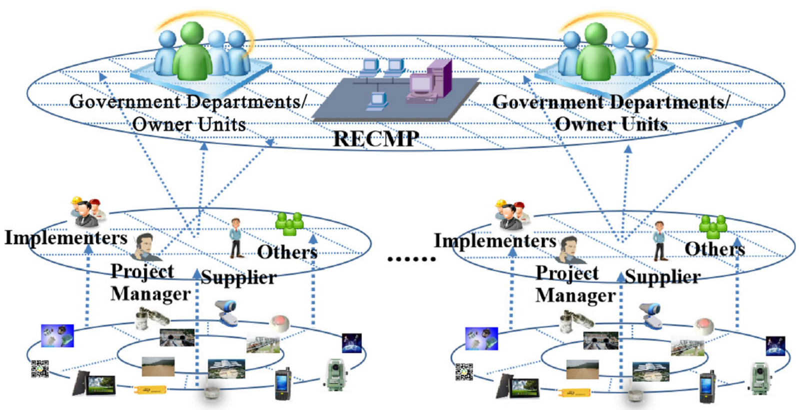



**Fig. 6** Ubiquitous intelligent perception system.

range wireless communication and radio frequency identification, short-distance and large-capacity communication based on Wi-Fi and Bluetooth, low-power long-distance communication based on narrowband IoT, and long-distance communication based on 4G and satellite.

### 4.5 Railway engineering construction management platform based on cloud computing and big data

The China Railway Corporation has set up a private cloud computing center in the railway sector, which has multi-level engineering construction applications, such as schedule, quality, safety, investment, environment, and acceptance. As a railway engineering construction management platform, the railway sector can address the technical bottlenecks of fast calculation, optimization processing, cloud storage, and information sharing during construction, and provide data resources, professional management, and technical application services for the participants. This platform can now provide services that cover infrastructure, platforms, and their applications.

This platform can realize project digitized construction with intelligent information collection, efficient management collaboration, scientific data analysis, and smart process prediction, and finally form the new mode of ICRE by integrating BIM, big data, cloud computing, IoT, mobile interconnection, artificial intelligence, and other information technologies (Fig. 7) and encompassing key factors, such as personnel, machinery, materials, methods, and environment.

### 4.6 Unmanned operation system based on AI, intelligent machinery, and robot

Unmanned operation, the core content of realizing intellectualization of on-site work team in construction stage, is the source of multivariate data. For example, through the application of new tools and technologies, such as the intelligent fine-tuning trolley of the track plate and tilt photography of unmanned aerial vehicle, automatic and self-help collection of actual construction data can be achieved. Combined with BIM technology, multi-calculation comparison can be carried out to realize comprehensive supervision and timely feedback on the construction process. Furthermore, BIM technology can be applied to plan topography, geology, site, and entity model as a whole to guide shield machine, girder erector, paver, excavator, and other equipment to automatically achieve data acquisition, precise construction, and intelligent evaluation, thereby further improving engineering efficiency and quality.

### 4.7 Intelligent operation & maintenance system based on BIM and PHM

The relevant information of railway engineering project generated during the design and construction stage can be transferred to the operation & maintenance (O&M) stage, integrated with the inspection, monitoring, and maintenance information generated during the O&M stage, and combined with fault prediction and health management (PHM) systems by applying the BIM system. Thus, the railway intelligent O&M system based on BIM and PHM can be established. The railway intelligent O&M system can realize automatic monitoring and detection of railway equipment and automatic analysis of monitoring and detection information. It has the function of automatic diagnosis and can automatically propose maintenance plan based on intelligent fault trend analysis model. Finally, it can realize unmanned maintenance.

## 5 Three-stage development of ICRE

Applying the new information technologies represented by BIM, IoT, mobile communications, big data, cloud

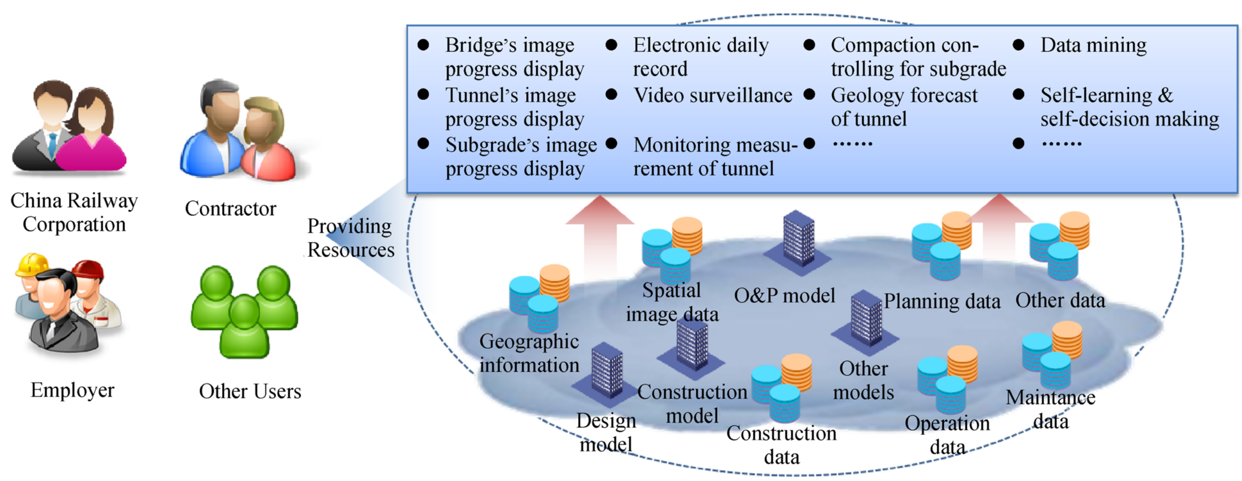



**Fig. 7** The railway engineering construction management platform.

computing, artificial intelligence technology, and robots with deep integrated applications, the mode of ICRE can be realized under the framework of railway engineering intelligent construction system (Wang, 2019a). According to the development status of information and AI technology, and the development law of intelligent technology itself, the development of ICRE can be divided into three stages (Mao, 2017) , as shown in Fig. 8. The first stage (perception stage) aims to achieve the perception capability with technology core; the intermediate stage (substitution stage) aims to achieve partial substitution ability of labor; the advanced stage (intelligence stage) aims to achieve high-level substitution ability of human with intelligence.

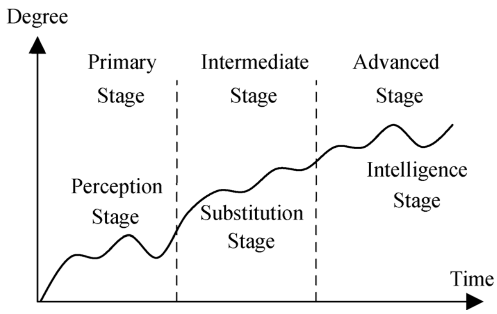



**Fig. 8** Three-stage development of the ICRE.

### 5.1 Primary stage—perception stage

In the first stage of ICRE, with the help of modern information technology, people can enlarge their vision, expand their perception ability, and enhance several skills. For example, the IoT sensor can be applied to sense the running conditions of the device and the safety behavior of construction personnel; intelligent machines can be applied to enhance the skills of construction personnel.

At this stage, railway construction enterprises must actively explore the integrated application of modern information technology and related equipment represented by BIM, IoT, mobile communication, cloud computing, artificial intelligence technology, and robots. Moreover, they should start to collect big data of railway sector, related companies, and projects. However, project management based on big data are not yet available at this stage.

From the technical point of view, the first stage can be evaluated from the following aspects: a. At the design stage of construction project, BIM technology is applied in certain sections of railway construction projects and in all housing construction projects of railway. b. Taking BIM technology as the core, cloud computing and mobile Internet as supporting mechanisms, and ubiquitous perception as tool, the railway engineering information management platform is established and applied to realize electronic display of various forms and reports, supervision visas, and engineering logs. c. All materials and equipment at the construction site are managed by IoT. d. Intelligent construction can be partially achieved, which includes bridge factory prefabrication, intellectualization of core equipment, informatization of whole-process quality control of manufacture, and transportation and installation; site virtual pre-assembly and digital manufacturing of special bridge span; auxiliary decision-making informatization of excavation and lining construction in tunnel construction (via surrounding rock measurement and three-dimensional laser section scanning); informatization of continuous compaction and settlement monitoring in roadbed construction; track accuracy adjustment and stress automatic release of continuous welded rail based on BeiDou positioning, CPIII, and measuring robot; and the realization of visual and virtual construction in the railway station building.

From the function realization point of view, this stage can be evaluated by the following indicators: a. The work efficiency of design and construction can be improved by 10%. b. The level of safety and quality control is improved. c. The construction costs can be reduced by 5%. d. In terms of life cycle coverage, ICRE can only cover partial processes in survey, design, construction, and acceptance of railway construction project. e. In the coverage degree of management hierarchy, some of the information can realize the interconnection on different construction management levels of on-site work team layer, working area layer, contract section layer, project layer, and entire railway network layer. f. In terms of intelligent function, intelligent construction machinery, intelligent factory, intelligent construction organization, and other functions can be realized in several processes of railway project.

### 5.2 Intermediate stage—substitution stage

In the intermediate stage of ICRE, intelligent construction technologies can not only replace most of the repetitive manual work but also partially replace human mental work with the help of AI, which can help accomplish previous impossible or risky works. For example, intelligent bricklaying robots, intelligent welding robots, and tunnel drilling robots are now being studied and explored. As a result of their emergence and application, several construction scenarios may achieve full intelligent production and operation. This kind of substitution is based on the given application scenario, and intelligence is realized with assumed implementation conditions and paths. The boundary conditions of intelligent substitution are strictly defined within a certain range.

In the intermediate stage, modern advanced technologies represented by BIM, IoT, mobile communication, cloud computing, artificial intelligence technology, and robots will be widely used, and rich experiences will be accumulated by many railway construction enterprises and projects. The accumulation of big data in railway sector, related enterprises, and projects will reach a certain scale, and project management based on big data will be carried out in railway engineering practice.

From the technical point of view, the intermediate stage can be evaluated from the following aspects: a. From the aspect of design, intelligent analysis software and intelligent algorithms are developed based on BIM + GIS and further integration with BIM + GIS system, generally achieving overall intelligent design. b. The railway engineering information management platform will have functions such as information transmission, on-site construction monitoring, over-limit alarm about safety, quality, and schedule, commanding by video, data analysis, and decision support. c. All main materials, auxiliary materials, local materials, equipment, tools, instruments, and other production materials are managed by IoT. d. ICRE, which includes railway roadbed engineering, railway bridge engineering, railway tunnel engineering, railway passenger station engineering, railway communication engineering, railway signal engineering, railway power engineering, railway electrification engineering, and all auxiliary construction, can be achieved. e. Railway intelligent O&M, an extension of digital construction based on BIM to intelligent operation and maintenance, can be achieved.

From the function realization point of view, the intermediate stage can be evaluated by the following indicators: a. The work efficiency of design and construction can be improved by 15%. b. The level of safety and quality control has been evidently improved. c. The construction costs can be reduced by 10%. d. In terms of life cycle coverage, ICRE can cover most processes in survey, design, construction, and hand-over of railway construction project. e. In the coverage degree of management hierarchy, the interconnection of information can be widely realized among different construction management levels of on-site work team layer, working area layer, contract section layer, project layer, and whole railway network layer. f. In terms of intelligent function, intelligent construction machinery, intelligent factory, intelligent construction organization, and other functions can be realized in most processes of railway project, and the "intelligence" capability of process optimization and management optimization can be increasingly improved.

### 5.3 Advanced stage—intelligence stage

In the advanced stage of ICRE, with the increasingly development of AI technologies and the help of its "human-like" thinking capability, AI technologies will replace most of the human involvements in construction production and management. A "construction brain" will command and manage the intelligent machines and equipment to complete the entire construction process. This "construction brain" will have strong capability of "knowledge based" management and self-learning, that is, it can "self-evolve". The human will take the supervisor role of the "construction brain".

In the advanced stage, the integrated application of modern advanced technologies represented by BIM, IoT, mobile communication, big data, cloud computing, artificial intelligence technology, and robots will be widely popularized. In terms of management, supporting tools such as highly integrated information management system and deep learning system based on big data can be applied to comprehensively realize the "knowing" of the past, the "grasping" of the current situation, and the "predicting" of the future of the project. Furthermore, ICRE can provide scientific decision making and coping plan for all kinds of problems that have happened or may happen.

From the technical point of view, the advanced stage can be evaluated from the following aspects: a. From the aspect of design, AI will be extensively applied to survey and design, and new intelligent algorithms will be developed. b. The railway engineering information management platform will cover the entire life cycle of survey, design, construction, hand-over, and operation and will have the functions of self-learning and self-decision making. c. ICRE can be achieved, which means that on-site construction will be unmanned; the construction mode of factory prefabrication and on-site assembly will be realized. d. Railway intelligent O&M can be achieved, which means that the intellectualization of inspection, analysis, maintenance programs, and unmanned maintenance will be realized.

From the function realization point of view, the advanced stage can be evaluated by the following indicators: a. The work efficiency of design and construction can be improved by 25%. b. The quality of railway engineering can reach excellent level, and safety management can realize zero death rate. c. The construction costs can be reduced by 20%. d. In terms of life cycle coverage, ICRE can cover entire processes in survey, design, construction, and hand-over of railway construction project; the construction information can be extended to the O&M stage. e. In the coverage degree of management hierarchy, the interconnection of information can be comprehensively realized among different construction management levels of on-site work team layer, working area layer, contract section layer, project layer, and whole railway network layer. f. In terms of intelligent function, intelligent construction machinery, intelligent factory, intelligent construction organization, and other functions can be widely realized in the processes of railway project.

The three stages of ICRE are continuously and gradually developing processes with the research and application of new generation information and communication technologies including AI, which cannot be realized in one step. Thus, top-level design must be conducted at the "perception stage", and research and development and application of related technologies must be carried out under the guidance of the overall design ideas. During the development of ICRE, special attention should be paid to the integration and application of software and hardware information technologies such as BIM, IoT, cloud computing, big data, mobile communication, and intelligent equipment. Only in this manner can ICRE follow the right direction and realize the development purpose from the primary stage to the advanced stage step by step.

## 6 Application and current practices of ICRE

China is now actively exploring and practicing ICRE in railway construction projects. The exemplary projects are the Beijing–Zhangjiakou and Beijing–Xiong'an high-speed railways. The main practices and applications of intelligent technologies are as follows.

### 6.1 Space–sky–earth integration survey

By applying 3S technologies (remote sensing, geography information system, and global positioning system) and advanced sensor technology, spatial information is collected, processed, managed, analyzed, expressed, and transmitted in a multi-disciplinary and highly integrated manner. The information of terrain, geomorphology, surface deformation, covering, and geology can be rapidly acquired in a large area and finally integrated into a centralized BIM display platform. For example, several intelligent technologies such as satellite image, satellite interferometric synthetic aperture radar (InSAR), airborne lidar system, unmanned aerial vehicle image, and BeiDou satellite positioning technology can be applied to investigate and monitor geological disasters such as landslides and debris flow, which can rapidly carry out a large-area and preliminary identification of the geological disasters, determine the key landslides and debris flow bodies, individually survey and monitor them by using high-precision BeiDou, subsoil InSAR, and optical time domain reflectometry (OTDR), and incorporate them into BIM platform.

### 6.2 Three-dimensional collaborative design

3D collaborative design is a process of knowledge sharing and integration based on 3D digital technology and BIM design software. The design team is composed of different professionals who work together to achieve or complete a common design goal or project that can share data, information, and knowledge (Fig. 9). 3D collaborative design can realize multi-professional collaborative design and data sharing, thereby improving the overall work efficiency; its 3D scene is intuitive and vivid, which can break through the visual limitations of two-dimensional drawings. The integration of multi-professional design results can improve design system and quality. At present, many large-scale railway design institutes have introduced advanced BIM design platform, and carried out a cross-disciplinary, whole-process, and collaborative design technology research based on the same database, which includes establishment of hardware network environment to meet storage, management, and transmission needs of massive information data used by BIM, and a system to support the simultaneous implementation of BIM design across multiple disciplines. The railway IFC standard is embedded in the platform, and the model that contains the non-geometric information is specified in the BIM standard.

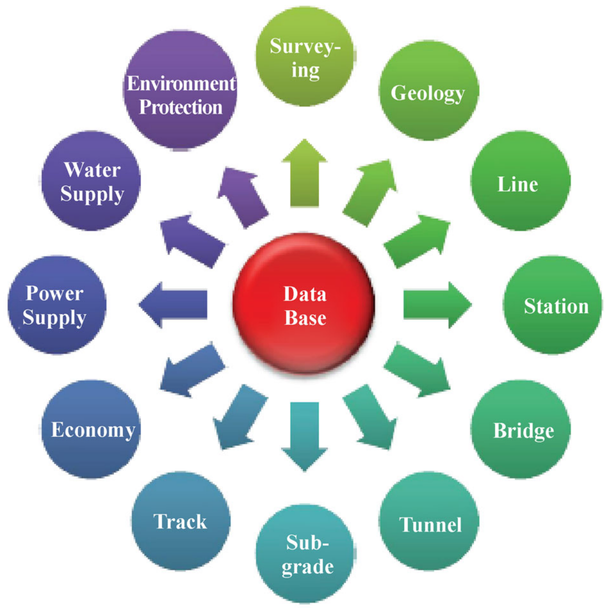



**Fig. 9** Three-dimension collaborative design based on the same database.

### 6.3 Design optimization and structural analysis

BIM technology is used to optimize the design scheme and conduct the structural analysis. For example, in the original design of ring prestressing scheme, the prestressing tendons collided seriously with ordinary steel reinforcement bars in the anchorage zone of bridge tower, and the constructability could not be guaranteed; through the BIM technology applied to a cable-stayed bridge, the original design scheme was optimized to the steel anchor box scheme (see Fig. 10). The optimized steel structure had high machining accuracy, and the hoisting of the whole section could accelerate the construction progress. In terms of structural analysis, the information of BIM model could be directly exported to the general finite element software for analysis, which shortens the design analysis duration. At present, BIM technology has been well applied in the calculation of large sections of steel beam and the anchorage zone of bridge tower.

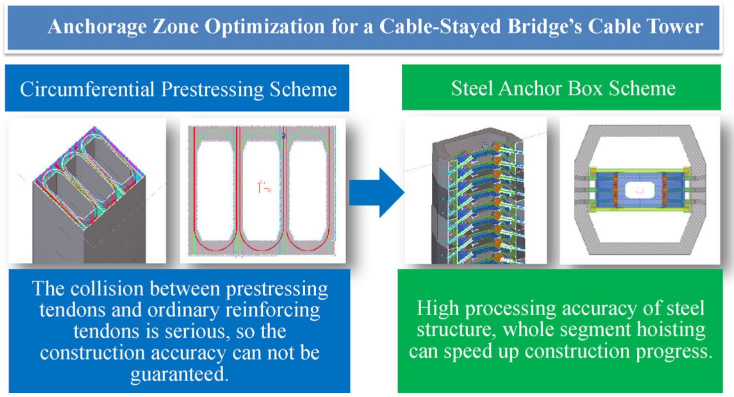



**Fig. 10** Optimum design with BIM in a cable-stayed bridge.

### 6.4 Construction site planning and construction simulation

In terms of construction site planning, BIM model can be used to guide construction site planning and reasonably allocate resources by GIS and large-scale temporary facility modeling (see Fig. 11). In terms of construction simulation, BIM model can be used to simulate the construction scheme, construction schedule, operation, and maintenance of the project, which enables the construction personnel to more clearly and thoroughly grasp the construction process, and improves the fluency and integrity of information communication and also the efficiency and quality of construction stage.

### 6.5 Three-dimensional visualization disclosure

In terms of the visualization construction disclosure, BIM model is applied for technical disclosure and construction simulation through the correlation of model drawings (see Fig. 12), which can achieve the effect of "one picture/three

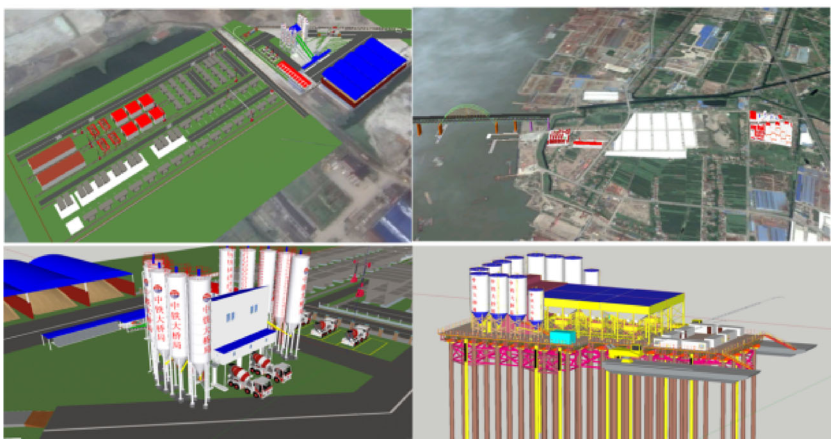


**Fig. 11** Construction site planning.

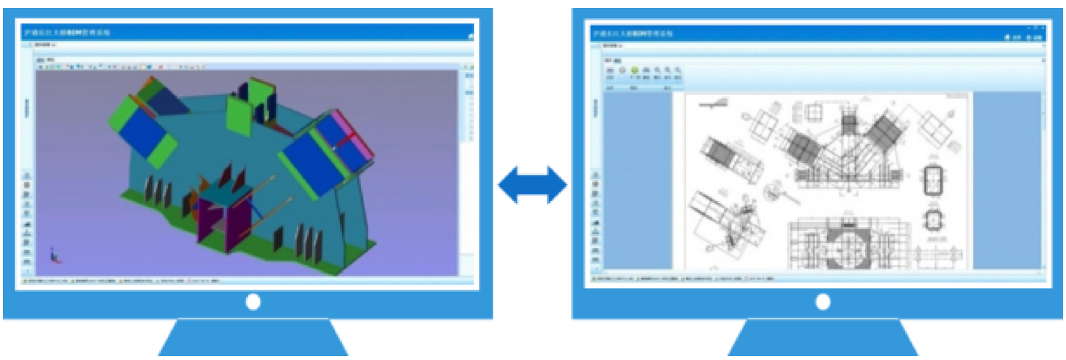


**Fig. 12** Three-dimension visualization technical disclosure.

dimensional wins a thousand words”. For example, BIM technology could provide direct service for front-line workers by setting up the mobile app to automatically send them daily tasks with model view, process description, and safety instructions.

### 6.6 Three-dimensional digital processing and pre-assembly

In the aspect of 3D digital processing, the direct docking of BIM model data with numerically controlled machine tools can be realized through the steel beam manufacturing integration technology based on BIM technology, which can reduce the workload of manual secondary conversion and improve the manufacturing accuracy. In the aspect of 3D digital pre-assembly, space measurement network can be established by high-precision digital acquisition equipment, and dynamic comparison with BIM mode can be conducted. All these can adjust the segment assembly interface size in real time. Through virtual assembly technology, the accuracy of steel truss beam manufacturing and installation is largely improved (see Fig. 13).

### 6.7 Digital construction

Site information resources can be effectively integrated to establish an open information environment based on digital geographic platform, geographic information system, remote sensing, site data collection system, on-site mechanical guidance and control system, and global positioning system. These resources could break through the limitations of time and space and make the construction project participants’ more effective in exchanging real-time information to realize digital construction by applying BIM. At present, digital construction has been applied in the continuous compaction of roadbed (Fig. 14) and tunnel intelligent rock drilling rig. Information management and intelligent production of key processes have been realized in the track board production plant, sleeper production plant, and prefabricated beam plant.

In addition, “BIM + VR” technology has been applied to technical training, simulation operation, scheme comparison, and emergency drills, which enables construction workers to have an immersive feel and establish more

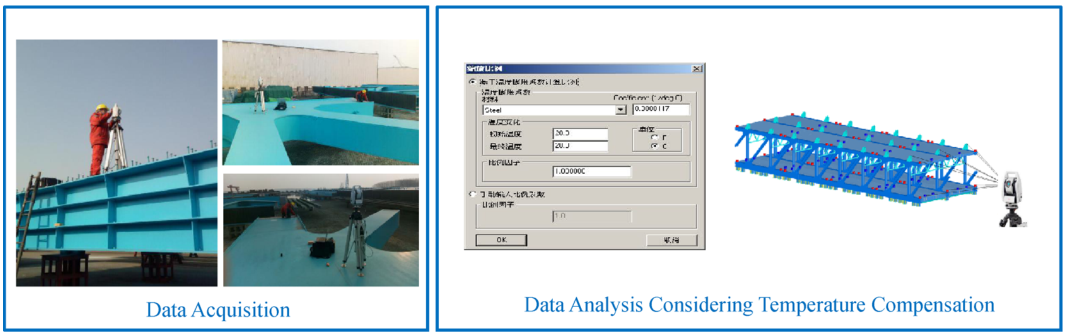



**Fig. 13** Three-dimension digital pre-assembly.

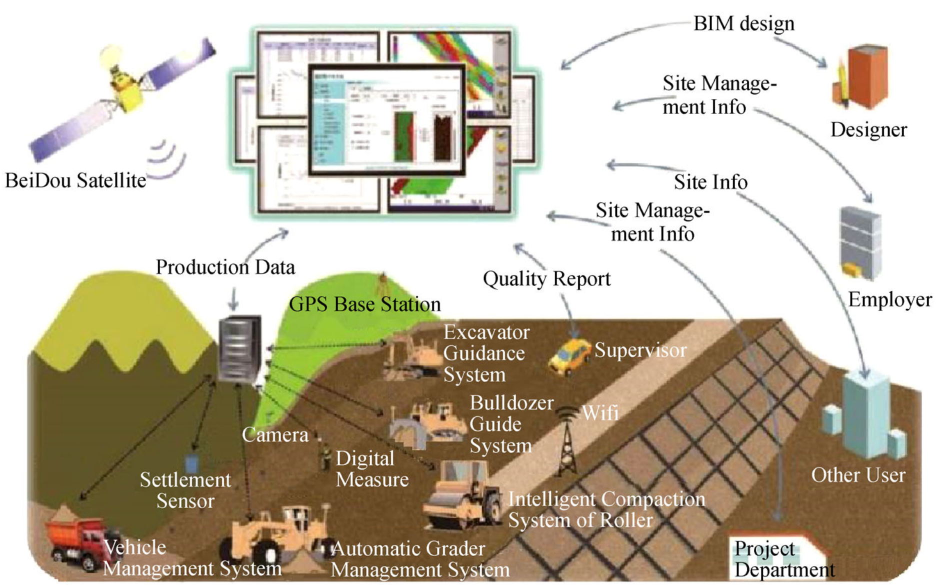



**Fig. 14** Digital construction based on BIM.

intuitive understanding. All these factors can improve the efficiency and safety of front-line construction. At present, the prefabricated segmental box girder constructed with BIM and fabricated construction technologies have been applied in several projects, such as Zhengzhou–Fuyang railway and Beijing–Xiong'an high-speed railway. Furthermore, "BIM + PHM" technology has been applied in the O&M system of large-scale railway bridges.

## 7 Conclusions

The seven technical support systems for the ICRE of China's railways have been in place and provide a solid foundation for basic technical research and pilot application based on the analysis of the aforementioned application situation. The application of project-level BIM in Beijing–Xiong'an high-speed railway project has been realized, and professional collaboration design, result delivery, and construction applications have been achieved. The BIM-based railway engineering information management platform can enable information interconnection in all railway networks of China. At present, the construction process information can be incorporated into this platform through the automation and intelligent equipment. Moreover, six application systems, namely, comprehensive, schedule, material, quality, safety, and investment management, can be achieved. However, the application of new-generation information, such as IoT, big data, and AI, is still at the trial stage. ICRE has great application potential in the field of railway construction and will certainly become a leading driving force for the development of railway construction technology. In the future, the railway sector will continue to promote the development of ICRE to a more advanced stage and facilitate prosperous development for railway construction.

## References


Aziz Z, Anumba C J, Ruikar D, Carrillo P, Bouchlaghem D (2006). Intelligent wireless web services for construction—A review of the enabling technologies. Automation in Construction, 15(2): 113–123

Birje M N, Challagidad P S, Goudar R H, Tapale M T (2017). Cloud computing review: Concepts, technology, challenges and security. International Journal of Cloud Computing, 6(1): 32–57

Craveiro F, Duarte J P, Bartolo H, Bartolo P J (2019). Additive manufacturing as an enabling technology for digital construction: A perspective on construction 4.0. Automation in Construction, 103: 251–267

Fan Q X, Yang Z L, Wang Z L, He W, Wu K (2019). Digital dynamic control over whole construction process of large hydropower projects. Journal of Hydroelectric Engineering, 38(1): 1–11 (in Chinese)

Ghaffar S H, Corker J, Fan M (2018). Additive manufacturing technology and its implementation in construction as an eco-innovative solution. Automation in Construction, 93: 1–11

Han X H, Yuan F, Hou L M, Liu W (2018). Analysis on the BIM application in the whole life cycle of railway engineering. In: ICRT 2017: Railway Development, Operations, and Maintenance. Reston, VA: American Society of Civil Engineers, 331–338

Hu Z Z, Zhang J P (2011). BIM- and 4D-based integrated solution of analysis and management for conflicts and structural safety problems during construction: 2. Development and site trials. Automation in Construction, 20(2): 167–180

Kehoe B, Patil S, Abbeel P, Goldberg K (2015). A survey of research on cloud robotics and automation. IEEE Transactions on Automation Science and Engineering, 12(2): 398–409

Khan M A, Salah K (2018). IoT security: Review, blockchain solutions, and open challenges. Future Generation Computer Systems, 82(5): 395–411

Li K Q (2019). 2019 Government work report. In: The 13th National People's Congress. The State Council of People's Republic of China (in Chinese)

Li Y J (2018). The application of intelligent building technology in railway construction management. China Railway, (5): 1–7 (in Chinese)

Lin M, Wang Q, Wang M J, Li J G (2018). Exploration and practice of intelligent construction in island tunnel project of Hong Kong–Zhuhai–Macao Bridge. Science & Technology Progress and Policy, 35(24): 81–85 (in Chinese)

Liu J P, Zhang J S, Wang H, Sun X L, Zhu L L (2018). Research on 3D GIS platform construction of expressway based on 3D data model. In: 2018 International Conference on Smart Grid and Electrical Automation (ICSGEA). Changsha: IEEE, 341–345

Liu X, Wang X F, Feng X (2013). Study and application of the IoT technology in railway. In: Advanced Materials Research. Trans Tech Publications, 694: 3329–3332

Lu C F (2016). Study and practice on integrated management model for high-speed railway construction projects in China. Journal of the China Railway Society, 38(11): 1–8 (in Chinese)

Lu C F, Zhang J (2018). Technological innovation and engineering construction management of high-speed railway. China Occupational Safety and Health, 13(4): 8–10 (in Chinese)

Lu Y X (2010a). Towards green and intelligent manufacturing (I)—The way of manufacturing development in China. Journal of Electrical Engineering, (4): 14–18 (in Chinese)

Lu Y X (2010b). Towards green and intelligent manufacturing (II)—The way of manufacturing development in China. Journal of Electrical Engineering, (5): 22–24 (in Chinese)

Lu Y X (2010c). Towards green and intelligent manufacturing (III)—The way of manufacturing development in China. Journal of Electrical Engineering, (6): 14–19 (in Chinese)

Mao Z B (2017). Promoting the construction of intelligent sites to advance sustainable and healthy development of construction industry. Journal of Engineering Management, 31(5): 80–84 (in Chinese)

Wang H, Pan Y S, Luo X C (2019). Integration of BIM and GIS in sustainable built environment: A review and bibliometric analysis. Automation in Construction, 103(3): 41–52

Wang L J, Huang X, Zheng R Y (2012). The application of BIM in intelligent construction. Applied Mechanics and Materials, 188(6): 236–241

Wang T J (2015). Construction and prospect of railway engineering management platform based on BIM. Railway Technical Innovation, (3): 8–13 (in Chinese)

Wang T J (2019a). Innovation and practice of railway engineering construction on management based on BIM technology. Journal of the China Railway Society, 41(1): 1–9 (in Chinese)

Wang T J (2019b). Study on the development strategy of China intelligent high speed railway. China Railway, (1): 9–14 (in Chinese)

Woodhead R, Stephenson P, Morrey D (2018). Digital construction: From point solutions to IoT ecosystem. Automation in Construction, 93: 35–46

Yao Y L, Lu H, Qu H N (2015). Lifecycle information management of cloud computing information park based on BIM. Journal of Engineering Management, 29(3): 45–49 (in Chinese)

Zhou J, Li P G, Zhou Y H, Wang B C, Zang J Y, Meng L (2018). Toward new-generation intelligent manufacturing. Engineering. 4(1): 11–20

Zhou J, Zhou Y H, Wang B C, Zang J Y (2019). Human–cyber–physical systems (HCPSs) in the context of new-generation intelligent manufacturing. Engineering. 5(4): 624–636

Zhu J X, Wright G, Wang J, Wang X Y (2018). A critical review of the integration of geographic information system and building information modeling at the data level. ISPRS International Journal of Geo-Information, 7(2): 66