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Guanghui Xu · Dongsheng Wang

Introduction to Intelligent Construction Technology of Transportation Infrastructure

Translated by George K. Chang, Hao Wang, Fei Wang, Shihui Shen, António Gomes Correia, Soheil Nazarian

Springer

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Foreword to the English Edition

This English edition is a translation of the Chinese version of "Introduction to Intelligent Construction for Transportation Infrastructure," with the Chinese Title "交通基础设施智能建设技术导论". Professor Guanghui Xu initiated the Chinese book series for Intelligent Construction Technologies (ICT), starting with this book. The Chinese edition was published by China Railway Publishing House (CRPH) Co., Ltd. in November 2020. In March 2021, CRPH and Springer Nature Switzerland AG signed a license agreement to publish this English version in the book series "Springer Tracts in Civil Engineering". The English edition aims to reach out to global readers with the ultimate goal of training and cultivating the current and next-generation intelligent construction technologies workforce.

In March 2021, the Executive Committee (EC) of the International Society for Intelligent Construction (ISIC) decided to assist CRPH in translating the Chinese ICT book series into English editions. The EC includes Dr. George K. Chang (Transtec Group, USA; President of ISIC), Prof. António Gomes Correia (University of Minho, Portugal; Vice President of ISIC), Prof. Guanghui Xu (Harbin Institute of Technology and Southwest Jiaotong University, China; Vice President of ISIC, also the primary author of the Chinese edition), and Prof. Soheil Nazarian (University of Texas at El Paso, USA; Vice President of ISIC).

The EC established the translation plan and invited several US scholars with English and Chinese language skills to accomplish the English translation work. The translators include Dr. George K. Chang, Prof. Hao Wang (Rutgers University, USA), Prof. Fei Wang (Tarleton State University, USA), and Prof. Shihui Shen (Pennsylvania State University—Altoona, USA).

The English translation work was divided into: Chapters 1 and 7 by Dr. George K. Chang; Chapters 2 and 6 by Prof. Hao Wang; Chapter 3 by Prof. Fei Wang; and Chaps. 4 and 5 by Prof. Shihui Shen. The reviewers for the English version include Prof. Antonio G. Correia and Prof. Soheil Nazarian.

The EC acknowledges the efforts of the above English translators and reviewers as well as the coordination efforts between CRPH and Springer to make this English edition possible. EC encourages any feedback from readers to be sent to GKChang@TheTranstecGroup.com.

International Society for Intelligent Construction (ISIC)

Preface to the First Chinese Edition

The intelligent construction of transportation infrastructure is a new field as the product of multidisciplinary cross-integration. It is the concrete manifestation of a new generation of information technology in engineering construction, which will change the technical system of the traditional construction industry. Since it is a new field, the basic concept, technical composition, and application of intelligent construction are still inconclusive. Because of this, how to build the technical architecture of intelligent construction is very critical, involving issues such as technical composition.

Based on years of practical experience in intelligent construction monitoring technology and the latest research results in related fields, the authors conclude that intelligent construction should have the essential characteristics of "perception, analysis, decision-making, and execution." Among them, the "perception" part involves electronic information technology, sensing technology, detection technology, and domain knowledge; "analysis and decision-making" involve artificial intelligence technology and domain knowledge; the "execution" involves control technology, domain knowledge, and engineering machinery. This book is the first volume of the "Frontiers of Transportation Infrastructure Intelligent Construction Technology" series. It focuses on the essential characteristics of intelligent construction, mainly expounds on the relevant technologies of intelligent construction of transportation infrastructure, and involves most of the content in the series. This book is an overview of intelligent construction technology.

Chapter 1 summarizes the technical characteristics and critical points of intelligent construction; firstly recognizes the essence of artificial intelligence and the method of realizing "intelligentization"; then establishes the basic structure of intelligent construction technology. Chapter 2 provides a set of systematic methods for mastering new technologies, gives the characteristics of five fundamental problems of the system, and introduces the technical characteristics of the road structure system, artificial intelligence system, intelligent construction system, and information platform. Chapter 3 analyzes intelligent algorithms or machine learning algorithms (such as neural networks, deep learning, and reinforced learning), restores a real artificial intelligence, and briefly describes the relationship between machine learning

and engineering construction. Chapters 4 and 5 reveal the nature of big data and the Internet of Things (IoT) foundation behind the information platform, introduce several perception technologies in engineering, and discuss data security issues. Chapter 6 expounds on the feasibility and technical solutions of the application of various intelligent technologies in design, construction, and maintenance; discusses the application of virtual reality technology in engineering construction; takes intelligent compaction as an example to demonstrate the realization of "perception, analysis, decision-making, execution" steps. Chapter 7 briefly explains that improving engineering quality is the short-term goal of intelligent construction and discusses the essential characteristics and implementation methods of information highways and railways, intelligent highways, and intelligent railways. According to the essential characteristics of intelligent construction, the final chapter combines intelligent construction talent training and sorts out the required professional knowledge and the theoretical basis behind it.

Part of the content of this book has been taught several times to the undergraduates of Harbin Institute of Technology (including those majoring in road, bridge, traffic engineering, and traffic information control). This book has been revised several times according to the feedback information. It took more than three years to complete the manuscript. Even so, since intelligent construction is a new field and is still in its infancy, how to grasp the technical composition of intelligent construction is still in the exploratory stage. This book draws the attention of more technical personnel in the field and jointly promotes intelligent construction technology's sound development.

The founders of the International Society for Intelligent Construction (ISIC), Dr. George K. Chang of the Transtec Group in the USA, Prof. Soheil Nazarian of the University of Texas in El Paso in the USA, and Prof. António Gomes Correia of the University of Minho in Portugal, participated in the overall planning of the series and this book. Dr. George K. Chang also provided some original content. They also participated in the reviews and edits of the English version.

Due to the limited knowledge of the authors, this book consists of their own thoughts, and some misses may be inevitable. Therefore, we urge readers to send critics and feedback to highx@163.com.

Guanghui Xu

Preface to the Second Chinese Edition

With the re-emergence of artificial intelligence (AI) technology, almost all fields are developing in the direction of intelligence, hoping to use AI technology to promote innovation in this field. This phenomenon can be collectively referred to as "AI+." Inspired by intelligent manufacturing, starting from 2016, we have been researching intelligent issues in the road and railway engineering field in Harbin, China. We have provided such materials to the undergraduate students in the School of Transportation Science and Engineering of Harbin Institute of Technology (including roads, bridges, traffic engineering, and traffic information control major). We have set up a course on intelligent construction to teach the application of multidisciplinary knowledge in the field of transportation infrastructure. We soon realized that the so-called AI+ is not a simple "AI+ field technology" but the integration of modern information technology and a specific field technology (professional technology), which is the technological upgrading of traditional industries. This requires us to break the traditional disciplinary boundaries and view and study related issues in this field from a broader perspective.

Since the first edition of this book was published in October 2020, it has sold out for almost a year, and some colleges and universities use it as a text book. To meet the needs of development, this revision rewrites and draws the structure and content of the book, deletes parts that are not closely related to intelligent construction, and adds new content to meet the needs of the rapid development of intelligent construction. This book can also be arranged in the order of "perception, analysis, decision-making, execution", the basic characteristics of intelligent construction (the teaching order can also be arranged in this way). It can also be taught by highlighting machine learning first and letting readers understand the essence of AI as soon as possible. This part of the content is placed in the front but does not affect the reading order. Because these four basic characteristics correspond to different disciplines, they exist independently.

Although there are various references to "AI+", the basic idea is the same—using machines to do work instead of humans. Since human beings do work along the basic sequence of perception→analysis→decision→execution, "perception, analysis, decision-making, and execution" have become the basic characteristics of

"AI+". "Perception technology" includes perception terminals based on microelectronics technology and perception methods based on physics. "Analytical technology" is based on data science, and machine learning is only a technical means of data analysis. "Decision-making technology" not only requires the intervention of AI technology, but it also needs more support from field technology. "Execution technology" mainly exists in various fields, but the common foundation is the control theory. Based on the above considerations, this book mainly introduces machine learning and data knowledge in "Analysis and Decision" and electronic terminal knowledge in "Perception". At the end of the book, it facilitates readers to grasp the technical system of "AI+" from a macro perspective. Starting from the basic characteristics of intelligent construction, it sorts out artificial intelligence, electronic technology, dynamics, big data, control technology, cloud computing, Internet of Things, the relationship between communication technology and domain (professional) technology, etc.

When this book is used as a university teaching material, the teaching can be arranged for a 32-hour curriculum. Don't hesitate to contact the publisher if you need electronic teaching material. At the same time, there will be more discussions and related materials for readers' reference on the International Society for Intelligent Construction (ISIC) expansion platform (www.isicshow.com in English, www.isicshow.cn in Chinese).

This revision has received extensive support from all walks of life in China and abroad. Many experts have put forward revision opinions from different angles, and we would like to express my heartfelt thanks. Limited by the author's knowledge, the book may still have some inaccuracies. Please send feedback to highx@163.com.

Guanghui Xu

ISIC's Endorsement

With modern science and technology development, the traditional transportation infrastructure construction industry is undergoing profound changes. The combination of modern information technology represented by artificial intelligence and the traditional construction industry has become an inevitable trend. In this context, intelligent construction is proposed to improve engineering construction quality and ultimately realize intelligent transportation infrastructure.

Transportation infrastructure construction belongs to the traditional civil engineering industry. Due to various reasons, many civil engineering technicians have limited knowledge of modern information technology, and even some terms are unclear. Therefore, we need to change the technical system of the traditional construction industry and update our knowledge. The cross-integration of different disciplines and majors has become inevitable. This is called "long-term integration." It is against this background that this series of books is proposed. The purpose is to break the boundaries of disciplines, integrate multidisciplinary knowledge, initially establish a technical system for intelligent construction, and promote the development of intelligent construction technology.

Currently, many "AI +," including intelligent construction, do not have a complete technical system. Different people and industries have different understandings of intelligent construction, which is an inevitable phenomenon in the development process. We have been researching this issue for many years. Based on practical experience, basic ideas for developing intelligent technology applications are summarized. One of the purposes of developing artificial intelligence is to allow computers to do work instead of human brains. It is necessary to analyze the fundamental processes and characteristics of people doing work. According to our practical experience in road and railway engineering intelligent construction monitoring technology, it is feasible to implement intelligent construction by following the technical route of "perception, analysis, decision-making, and execution." Therefore, the book series uses the transportation infrastructure (highways, railways, airport pavements, and urban roads) as the background to carry out the overall concept and implementation of intelligent construction around the four essential characteristics of "perception, analysis, decision-making, and execution." This book series, taking into account

theory and practice, would help engineers and technicians in related fields understand and master new technologies in engineering construction.

The book series uses engineering construction as the background, combined with the applications, and discusses the theory, technology, and engineering application involved in the aspects of "perception", "analysis", "decision-making", and "execution." The books include (1) Introduction to Intelligent Construction of Transportation Infrastructure; (2) Foundations of Perception Terminals: Information Technology in Engineering; (3) Foundations of Perception Methods: One-Dimensional Dynamics and Applications in Engineering; (4) Foundation of Machine Analysis and Decision-Making: Entering Machine Learning; (5) The Weapon of Engineering Quality: Perception and Data; (6) Assistant to Execution: Control Technology in Engineering; and (7) Pioneer of Intelligent Construction: Intelligent Compaction. Series (1) is a framework that is a general discussion of "perception, analysis, decision-making, and execution", covering the main content of intelligent construction technology. Series (2) takes the perception terminal as the background and introduces the related electronic information technology. Series (3) introduces the vital basis of perception methods—one-dimensional dynamics and application, which is the basis of various non-destructive testing techniques. Series (4) introduces how to use machines to replace human brains for data analysis and decision-making, which is machine learning as an upgrade of traditional data analysis techniques. Series (5) introduces perception technology and data analysis technology (data science) together. It is mainly because perception is the primary technical means of data acquisition, data is the result of perception, and data analysis is also the basis of decision-making and a tool for mining information and knowledge in data. Series (6) introduces the assistant of "execution"—control technology, which is one of the common foundations in various fields. Series (7) is the application case study in intelligent compaction, which describes how to "perceive, analyze, decide, and execute."

The intelligent construction of transportation infrastructure is one of the frontier issues in the construction industry. As for new areas, there are still many unknown to explore. A journey of thousands of miles begins with a single step, and laying a solid foundation is the key. Knowing and mastering the necessary multidisciplinary knowledge is a tool and a weapon in the path of exploration. China Railway Publishing House (CRPH), in conjunction with the International Society for Intelligent Construction (ISIC, www.is-ic.org), organized and compiled this frontier series of intelligent construction technology for transportation infrastructure for the first time in the world. This book series is indispensable and timely and can help construction engineers and technicians in related fields broaden their knowledge, inspire ideas, and support the popularization of new concepts and technologies in intelligent construction.

The series is published in Chinese edition (by CRPH) and English edition (by Springer Nature). The authors and translators are from China, the USA, and the European Union. They are all members of the International Society for Intelligent Construction. They have different professional backgrounds and rich practical experience. They understand the current situation of technical personnel in the engineering

construction industry, making the writing more targeted and readable. The series has the following characteristics.

(1) New fields. The intelligent construction of transportation infrastructure belongs to a new field and is the product of multidisciplinary intersection. The series of books is compiled for the first time in the world, which can help technical personnel in engineering construction to understand and master new knowledge and technologies in the information age.
(2) Innovation. Intelligent construction is an interdisciplinary subject, and its technical composition is still inconclusive. From the perspective of engineering construction, the series of books explores the establishment of the basic structure of intelligent construction technology, extracts relevant knowledge from multiple disciplines, and carries out systematic writing and integrated innovation.
(3) Practicality. The series of books is based on engineering construction and revolves around "perception, analysis, decision-making, and execution." The engineering cases involved are all derived from practical applications and have been validated in the fields.
(4) Readability. The authors avoid using obscure professional language but use popular language to explain professional issues, which is convenient for technical personnel in engineering construction to read.

Combining the characteristics of engineering construction, the series of books expound on the related technologies of intelligent construction from multiple technical perspectives. The book series provides a set of professional-level introductory materials for technical personnel in related fields such as highways, railways, airports, and urban roads to understand, learn and master new intelligent construction technologies. Readers with college knowledge can understand most of the content. At the same time, it will also play a role in broadening horizons and inspiring research ideas for undergraduates and postgraduates in related majors in colleges and universities. It can also be used as a textbook.

Although the series is based on engineering construction, its fundamental ideas, technical routes, and various technologies are applied to other fields as long as the application background is modified accordingly.

International Society for Intelligent Construction (ISIC)

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About the Authors and Translators

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Guanghui Xu Ph.D. (https://orcid.org/0000-0002-4004-2374) worked in railway design and research institutes in his early days in China. He later joined Harbin Institute of Technology and other Chinese universities to engage in scientific research and teaching. His research interests include road and railway engineering dynamics theory, testing and information analysis technology, and intelligent technology applications. Professor Xu is a co-founder of ISIC. He has always adhered to the principle of paying equal attention to theoretical and applied research and practical results, organized and led a multidisciplinary scientific research team, and carried out long-term independent research and development of intelligent construction monitoring technology. Professor Xu also formed a series of research results with intellectual property rights. In 2011 and 2017, he presided over the compilation of China's first industry construction standards and product standards for intelligent compaction (IC) technology. He also published an IC monograph in Science Press and China Railway Press.

Dongsheng Wang Ph.D., is a Road and Railway Engineering Department Professor at Harbin Institute of Technology, China. Professor Wang is also an ISIC Steering Committee member and a member of the Heilongjiang Youth Federation. His main research areas are pavement mechanics and structural design theory, pavement materials, and constitutive relations. He has led over nine projects, including the National Natural Science Foundation of China, and won the second prize of the Jilin Province Science and Technology Progress Award and the first prize of the China Highway Society Science and Technology Award. Professor Wang has participated in the compilation of many industry standards. He was selected into the Harbin Institute of Technology's top-notch teaching talents program. He has won the school's gold-medal teaching teacher, the first prize for teaching excellence, the first prize of the National University Young Teacher Teaching Competition, and the person in charge of the school's graduate course "Pavement Mechanics and Analysis Methods."

Translators of the English Edition

George K. Chang Ph.D., P.E. (https://orcid.org/0000-0002-4945-8827) is the director of research of the Transtec Group, USA. Dr. Chang is a co-founder and president of ISIC. He is a world expert on pavement smoothness and intelligent compaction/construction technologies. His research, teaching, specification development, and software tools have helped make significant technological advancements in the above fields. He has been leading the US national deployment effort intelligent compaction since 2007. Dr. Chang has been the chairman of the Road Profile Users' Group (RPUG), TRB AFD90/AKP50 Pavement Surface Properties and Vehicle Interaction committee, and ASTM E17.31 Profile Measurement subcommittee. He is an Emeritus member of the TRB AFD90/AKP50 committee. Dr. Chang received many industry awards, including the US Highway Intelligent Compaction Innovation Technology Award, ASTM International awards, and a TRB AKP50 lifetime emeritus member.

Hao Wang is Associate Professor and Graduate Director of Civil and Environmental Engineering at Rutgers University, USA. Professor Wang's general research is on the sustainable, intelligent, and resilient built environment. His recent research focuses on (1) multi-scale modeling and characterization of pavement material; (2) development of multi-functional infrastructure material; (3) sustainable and innovative pavement in highways and airfields; (4) life-cycle analysis and assessment and pavement management system. His research has been sponsored by many US Federal, State, and local transportation agencies. He has authored over 150 journal and conference publications in pavement engineering and infrastructure material.

Fei Wang is Assistant Professor in Civil Engineering at the Tarleton State University, USA, a professional engineer in Missouri and Kanas, USA. Professor Fei Wang's research interests include Geo-Hazards Monitoring, Evaluation, and Mitigation, Soil-Structure Interaction, Performance of Buried Culverts, Tunneling, AI-Based Technology for Civil Engineering, Numerical Modeling in Geomechanics, Geosynthetic Reinforcement, Sustainable Material in Civil Engineering.

Shihui Shen is a Professor of Engineering at the Pennsylvania State University—Altoona, USA. Professor Shen is a professional engineer in Pennsylvania and a fellow American Society of Civil Engineers. She is also an affiliated graduate faculty member at Penn State College's Department of Civil and Environmental Engineering. She received her doctoral degree at the University of Illinois at Urbana—Champaign, USA. Dr. Shen studies pavement materials and structures for better durability, energy efficiency, and sustainability. In addition to her ongoing interest in civil material characterization and innovation, Dr. Shen has recently worked on structural health monitoring and modeling for pavements using wireless sensors and data-driven approaches. Her research has been funded by the US state DOTs, NSF, NCHRP, USDOT University Transportation Center, FAA, US Army Corps

of Engineering, and private sectors. Dr. Shen has published more than one hundred peer-reviewed technical papers and reports and serves on many research committees, journal editorial boards, and project panels for the professional community.

António Gomes Correia (https://orcid.org/0000-0002-0103-2579) is Professor at the University of Minho, Portugal. Professor Correia is an ISIC co-founder and vice president. He has been engaged in research, teaching, and consulting geotechnical and pavement engineering for over 35 years. His scientific research includes transportation geotechnical engineering, especially soil and road geotechnical material performance, modeling, compaction, soil improvement, foundation, geotechnical engineering design, management, etc., with more than 360 technical papers and 240 reports on these topics. He has also supervised 116 graduate students, including 30 doctoral students. From 1998 to 2001, Dr. Gomes Correia served as the chairman of the ISSMGE—European Technical Committee—ETC 11 on Geotechnical Aspects in Design and Construction of Pavements and Rail Track. In 2001, he became the chairman of the ISSMGE Technical Committee TC 3 on Geotechnics for Pavements, renamed in 2009 as TC 202—Transportation Geotechnics. He was the Chairman of TC 202 until 2013 and after a member of the Executive Group. From 2009 to 2013, Dr. Gomes Correia also served as a European Member of the Technical Oversight Committee (TOC) of ISSMGE. From 2004 to 2008, He was also President of the Portuguese Geotechnical Society. Professor Correia is a well-known European intelligent compaction expert and the editor-in-chief of the European Union's intelligent compaction standards. Professor Correia also demonstrated his leadership in starting a new international technical journal, *Journal of Transportation Geotechnics*, launched in September 2013 by Elsevier's Engineering Journals. He is currently the Editor-in-Chief of the *Journal of Transportation Geotechnics* and serves on the Editorial Boards of other National and International Journals.

Soheil Nazarian is Professor at the University of Texas at El Paso (UTEP) USA, the McKentas-Morkinson director of civil engineering, and the Transportation Infrastructure System Center of the school. Professor Nazarian is an ISIC co-founder and subcommittee leader. Dr. Nazarian has more than 25 years of experience in materials and non-destructive testing related to geotechnical and transportation infrastructure. He has been the PI and co-PI of more than 100 research projects funded by US federal and state agencies such as the Texas Department of Transportation, Federal Highway Administration, and Strategic Highway Research Program. Throughout his career at UTEP, he has supervised over 80 Master and Ph.D. students. Many work for the Texas Department of Transportation and other private and public transportation entities.