FUZZY HYBRID COMPUTING IN CONSTRUCTION ENGINEERING AND MANAGEMENT: THEORY AND APPLICATIONS

FUZZY HYBRID COMPUTING IN CONSTRUCTION ENGINEERING AND MANAGEMENT: THEORY AND APPLICATIONS

EDITED BY

AMINAH ROBINSON FAYEK
University of Alberta, Canada

United Kingdom – North America – Japan – India – Malaysia – China

Emerald Publishing Limited
Howard House, Wagon Lane, Bingley BD16 1WA, UK

First edition 2018

British Library Cataloguing in Publication Data
A catalogue record for this book is available from the British Library

ISBN: 978-1-78743-869-9 (Print)
ISBN: 978-1-78743-868-2 (Online)
ISBN: 978-1-78743-996-2 (Epub)

ISOQAR certified Management System, awarded to Emerald for adherence to Environmental standard ISO 14001:2004.

Certificate Number 1985
ISO 14001

INVESTOR IN PEOPLE

This book is dedicated to my son, Jack, whose life gives mine its greatest meaning.

Acknowledgements

First and foremost, the editor would like to thank the many authors who contributed their valuable research, without which this book could not have been produced. The chapters in this book are diverse in terms of both origin and content, and they are representative of the breadth and significance of the developments in the field of fuzzy hybrid computing in construction engineering and management.

For his thoughtful and stimulating Foreword, the editor would like to thank Dr Witold Pedrycz, whose insights will no doubt enrich the reader's experience.

The editor would also like to express gratitude to the reviewers, who volunteered their time to help ensure that the book's contents are of the highest quality, and that each chapter presents the latest advances in research and knowledge in the field of construction engineering and management.

The editor would like to thank and acknowledge Sarah Miller for her assistance in compiling, proofreading and preparing the final manuscript. Her dedication and expertise proved invaluable.

The editor would like to thank Emerald Publishing for their vision in covering this important topic and for their steady support throughout the publication process. Without them, the creation of this book would not have been possible.

Finally, the editor and publisher would like to acknowledge those who granted permission to reproduce material in the book.

Contents

List of Figures

Chapter 11

Chapter 12

Chapter 13

List of Tables

Chapter 6

Chapter 7

Chapter 8

Chapter 12

Chapter 13

About the Editor

Aminah Robinson Fayek, PhD, Professional Engineer, is Professor in the Faculty of Engineering at the University of Alberta, Canada. She holds a Tier 1 Canada Research Chair in Fuzzy Hybrid Decision Support Systems for Construction, and she is in her third term as Natural Sciences and Engineering Research Council of Canada (NSERC) Industrial Research Chair in Strategic Construction Modeling and Delivery. Applications of her research have led to improved efficiency across industry and helped shape construction practice in Canada. She is an Editor for the ASCE *Journal of Construction Engineering and Management* and the CSCE *Canadian Journal of Civil Engineering*.

About the Authors

Ernest Effah Ameyaw is a Lecturer and Research Associate in Quantity Surveying at Coventry University, UK. His doctoral work won the Faculty of Construction and Environment's *Outstanding PhD Award* in 2015 at Hong Kong Polytechnic University. Ameyaw is Scholar of the Commonwealth, which sponsored his MSc at the University of Exeter, UK.

Adam Ayinla works as a Senior Project Engineer for Shell Global Solutions, UK, delivering complex design and execution for offshore and onshore assets. He holds an MSc in Structural Engineering from Imperial College London, UK. Adam Ayinla is a Chartered Civil Engineer with the Institute of Civil Engineers (ICE) in the UK.

Ty Blackburn is a Project Management Director within Burns & McDonnell Corporate Operations, USA. Responsibilities include project management tools, processes and the training of Project Managers company-wide. His 30 years of experience as a Florida Professional Engineer and Florida Certified General Contractor includes project management in the Energy, Federal and Commercial sectors.

Denise M. Case, Consulting Engineer, Project Manager and Assistant Professor at Northwest Missouri State University, USA, holds a Chemical Engineering BS, Software Engineering MS and Computer Science PhD. Her work includes infrastructure analytics, soft computing and intelligent systems. She's a member of Tau Beta Pi, ACM, IEEE and a licenced Engineer in Kansas.

Albert P. C. Chan is a Chartered Construction Manager, Engineer, Project Manager and Surveyor by profession. Professor Chan has worked in a number of tertiary institutions both in Hong Kong and overseas. He is currently Head of Department of Building and Real Estate and Chair Professor of Construction Engineering and Management at Hong Kong Polytechnic University, Hong Kong.

Long Chen is currently a PhD Candidate in Construction Engineering and Management at the University of Hong Kong (HKU), Hong Kong. His research interests include the application of fuzzy sets and fuzzy logic in construction management, neuro-fuzzy systems and computational intelligence techniques applied in project scheduling.

Chau N. Dang is a member of Applied Computational Civil and Structural Engineering Research Group, Ton Duc Thang University, Vietnam. He received DEng in Construction Engineering and Management from Pukyong National University (South Korea), MEng in Construction Technology and Management and BEng in Civil Engineering from Ho Chi Minh City University of Technology, Vietnam.

Mohamed M. G. Elbarkouky is Chair of the Bachelor Degree Program of Technology in Construction Management at Northern Alberta Institute of Technology, Canada. Mohamed received his PhD at the University of Alberta. He has contributed to several publications in construction engineering and management, and he also has more than 20 years of experience in the construction industry.

Aminah Robinson Fayek is a Professional Engineer and a Professor in the Faculty of Engineering at the University of Alberta, Canada. Her research interests include improving construction productivity and performance, enhancing labour utilisation and effectiveness and developing real-time decision support systems for the construction industry using advanced fuzzy hybrid techniques.

Chris Gordon currently serves as a Professor in the Department of Construction and Associate Dean of the School of Engineering at Southern Illinois University, Edwardsville, USA.

Ka Chi Lam is a Civil Engineer, practised in infrastructure projects in Hong Kong and Taiwan. He joined City University of Hong Kong in 1990 and was Programme Director of the MSc in Construction Management for over 15 years. He is Associate Editor of the *Journal of Built Environment Project and Asset Management*.

Long Le-Hoai received his PhD in Construction Engineering and Management from Pukyong National University (South Korea), MSc in Engineering Mechanics from the University of Liege (Belgium) and BEng in Civil Engineering from Ho Chi Minh City University of Technology, Vietnam (HCMUT). He is a Lecturer of Civil Engineering at HCMUT.

Rodolfo Lourenzutti received BS and PhD degrees from Federal University of Espírito Santo, Brazil, in Statistics and Computer Science, respectively. He is currently a Postdoctoral Fellow in the Department of Civil and Environmental Engineering, University of Alberta, Canada. His research interests include decision-making, fuzzy modelling, multi-objective optimisation and statistical learning.

Nicolás Marín Ruiz received MS and PhD degrees in Computer Science, both from the University of Granada, Spain. He is an Associate Professor at the Department of Computer Science and Artificial Intelligence of the University of Granada, Spain. He has published around 100 papers in international journals and conferences.

María Martínez-Rojas is a Building Engineer from the University of Sevilla, having received MS and PhD degrees from the University of Granada, Spain. Since late 2016, she has done postdoctoral research at the University of Málaga, Spain. Her research interest is the management of information in the construction project domain.

Carlos Molina Fernández received MS and PhD degrees in Computer Science from the University of Granada, Spain, in 2002 and 2005, respectively. He is an Associate Professor in the Department of Computer Science, University of Jaén, Spain. His research interests include the fields of multi-dimensional modelling, data mining and soft computing.

Chau V. Nguyen is Deputy General Director at KCON Construction and Investment Co. Ltd. Group, Vietnam, and Adjunct Faculty member at the University of Da Nang (UDN) and Duy Tan University, Vietnam. He earned his MEng and PhD in Civil Engineering from the University of Transport and Communications and BEng in Bridge and Road Engineering from UDN.

Long D. Nguyen is an Associate Professor in the Department of Environmental and Civil Engineering at Florida Gulf Coast University, USA. He earned his MSc and PhD in Civil Engineering from the University of California, Berkeley, USA. His research interests include quantitative methods in construction and resilient and sustainable built environments.

Olalekan Shamsideen Oshodi was a PhD student at City University of Hong Kong (CityU). He has won several awards, including the 2016 Research Tuition Scholarship at CityU in recognition for his productivity as a research student. He is currently a Postdoctoral Research Fellow at the University of Johannesburg, South Africa.

Wei Pan is an Associate Professor in the Department of Civil Engineering at University of Hong Kong and Executive Director of the Centre for Innovation in Construction and Infrastructure Development (CICID). He specialises in zero carbon building, buildings' energy use and carbon emissions, off-site production, prefabrication, lean construction and decision-making of technological innovation.

Mohammad Raoufi is a Postdoctoral Fellow at the University of Alberta, Canada, an award-winning Researcher and industry professional, focused in Construction Engineering and Management. He has a demonstrated history of research in industrial construction, as well as working experience in oil and gas, power plants, the steel and aluminium industry and mining projects.

Juan Carlos Rubio-Romero is an Industrial Engineer and Full Professor in the School of Industrial Engineering, University of Málaga, Spain. He obtained his PhD in 2000 in Occupational Health and Safety in Industry. He has published a wide range of textbooks, reports and papers, especially on management of the workplace at construction sites.

Ahmad Salah, Assistant Professor at Imam Abdulrahman bin Faisal University, Saudi Arabia, has a civil engineering background, and has worked in various engineering companies from 2003 to 2010. In 2015, he received his PhD in Construction Engineering and Management from Concordia University, Canada. Dr Salah's research interests include construction, scheduling, risk management and modular construction.

Nasir Bedewi Siraj received his BSc and MSc in Civil Engineering from Mekelle University and Addis Ababa University, respectively. Currently, he is a PhD

Candidate in the Department of Civil and Environmental Engineering, University of Alberta, Canada. His research interests include risk management, fuzzy hybrid simulation techniques and fuzzy multi-criteria decision-making.

Nima Gerami Seresht is an award-winning Researcher in Construction Engineering and Management who currently serves as Postdoctoral Fellow on the Future Energy Systems research team at the University of Alberta, Canada. Nima's research interests and expertise lie in theory and applications of artificial intelligence and simulation techniques in construction.

José Manuel Soto-Hidalgo received MS and PhD degrees in Computer Science, both from the University of Granada, Spain. Since 2007, he is an Associate Professor in the Department of Computer and Electronic Engineering, University of Córdoba, Spain. His research interests include soft computing and data sensor management.

Chrysostomos Stylios is Professor of Computer Engineering, Technological Educational Institute of Epirus, Greece. He received PhD at Electrical and Computer Engineering, University of Patras, Greece (1999). His interests include fuzzy cognitive maps, soft computing, computational intelligence, modelling, DSS. He is Scientific Coordinator of many R&D projects and IEEE senior member.

Olubukola Tokede is a Lecturer of Construction Management at the School of Architecture and Built Environment, Deakin University, Australia. He holds a BSc (Hons) Civil Engineering and completed his MSc and PhD in the UK. Dr Tokede's research focuses on quantitative/qualitative performance measures of projects in retrofit buildings and civil engineering infrastructures.

Dai Q. Tran is an Assistant Professor in the Department of Civil, Environmental and Architectural Engineering at the University of Kansas, USA. He earned his PhD in Construction Engineering and Management and MSc in Statistics at the University of Colorado at Boulder. He earned an MSc in Structural Engineering at Georgia Tech.

María Amparo Vila Miranda is Full Professor of Computer Science and Artificial Intelligence at the University of Granada, Spain. Her research interests include databases and intelligent information systems. She has been advisor for 27 doctoral theses, responsible for more than 10 research projects and published more than 100 papers in SCI journals.

Sam Wamuziri is Professor of Civil Engineering and Dean for the College of Engineering at A'Sharqiyah University, Oman. He served as Acting Deputy Vice Chancellor for Academic Affairs from July 2015 to July 2016. Prior to this, Professor Wamuziri served for 20 years in various academic roles in the UK.

Xin Wang is currently an Associate Professor in the Department of Electrical and Computer Engineering, Southern Illinois University, Edwardsville. He received PhD in Electrical and Computer Engineering from Marquette University, USA. He is a senior member of IEEE, ASME and AIAA.

Foreword

This treatise is about a timely, important, and profoundly visible problem in construction engineering and management that can be solved with the aid of fuzzy sets and hybrid technologies.

With an increase in the complexity of systems and the associated problems with system analysis and synthesis, it is apparent that we are faced with the unavoidable issue of uncertainty. Information granularity – quite often formalised with the aid of fuzzy sets – supports various ways of representing and managing the uncertainty inherent in various branches of science and engineering. Construction engineering, with all its accompanying dimensions of complexities of management, is a visible and compelling example of where the benefits of the technology derived from fuzzy sets become tangible.

To take advantage of what information granules have to offer, a prudent formalisation of information granularity is required. There are many well-established directions that have been explored in the research, including probability, set theory (interval calculus), rough sets, fuzzy sets and random sets. Among these, fuzzy sets have established themselves as one of the most visible formalisms, and they have demonstrated several well-delineated advantages. The very nature of data, along with the structuralisation of experts' knowledge and fuzzy sets' abilities to cope with linguistically conveyed tidbits, are areas where fuzzy sets have shown their potential.

Fuzzy sets usually come hand in hand with other computational intelligence technologies, especially neurocomputing. Neural networks and fuzzy sets are highly complementary, and together they fully address the fundamentals of learning and knowledge representation. Their synergy is not only beneficial, but also essential, because in today's world, applications are a necessity for delivering advanced and practically viable problem-solving approaches.

The following well-known adages – attributed to Marr, the pioneer in image understanding, and originating from computer vision – are descriptive of the situations encountered in various domains of decision-making. The *principle of least commitment* emphasises the fact that there needs to be an adequate amount of experimental evidence before any decision, action or classification can be realised. It is therefore necessary to quantify this evidence or flag a lack of knowledge. The *principle of graceful degradation* is, in essence, a reformulation of the quest to endow solutions with a significant level of robustness. The relevance of these principles is apparent in all situations where one is faced with many poorly defined objectives, requirements and constraints. Fuzzy sets have emerged as an ideal vehicle for

making these principles implementable. There are numerous uncontrollable and not fully observable factors involved in decision-making processes, including human factors, ways of making judgements, methods of efficiently capturing domain knowledge and the expertise of professionals. All of these are a viable target of focused studies. They need to be studied, formalised and handled algorithmically if one wishes to arrive at meaningful and efficient real-world solutions.

This book is a well-balanced body of knowledge that covers the fundamentals of fuzzy sets in Part 1 and embraces the essentials of fuzzy sets – which are of visible relevance to any novice to the area – such as fuzzy set notions, logic operations and hybrid techniques. Part 2 includes a discussion on fuzzy arithmetic and an investigation into fuzzy simulation completed in the fuzzy set environment, which are important topics that deserve a great deal of attention considering the different approaches present in the existing literature. Fuzzy decision-making, with its fundamental ideas of fuzzy objectives, fuzzy constraints and consensus building, has been an area of intensive and fruitful study, and these topics are also authoritatively covered in Part 2. Part 3 is a testimony to the diversity of applications where fuzzy sets and their hybrid developments play a pivotal role. The spectrum of applied studies is remarkably broad and ranges from investment appraisal to risk modelling to construction management.

The editor, Dr Aminah Robinson Fayek, should be congratulated on putting forward a timely, important, and badly needed volume that delivers a holistic and systematic view of the state-of-the-art in the discipline. There is no doubt that this field of research and application will grow in importance, and the concepts, methodologies and algorithms presented in this volume in the area of construction engineering and management will also be of interest to those working in other engineering and management disciplines.

Witold Pedrycz
Professor, Electrical and Computer Engineering, University of Alberta
Canada Research Chair in Computational Intelligence
Fellow, Royal Society of Canada
IEEE Fellow

Preface

Introduction

The construction industry is a vital part of many national economies, contributing to a significant proportion of the gross domestic product. Construction industry productivity and performance are largely dependent on the effective planning, execution and control of construction projects, which occur in an environment of complexity and uncertainty. Many of the decisions and processes involved in construction projects are complex in nature due to numerous interacting factors and sometimes multiple conflicting objectives. Large projects with long durations, especially, involve many different disciplines and competing stakeholder interests. The interacting factors that must be accounted for when making project management decisions are complicated by the involvement of human activities and subjective reasoning. Given the often unique nature of each construction project, choices must be made in an environment that is characterised by high degrees of uncertainty, where quick decisions by experts must be taken that are based on complex systems and imprecise or unstructured variables. Uncertainty in construction has traditionally been treated as a random phenomenon that requires sufficient numerical project data for effective modelling. However, in construction, it is often the case that numerical project data do not meet the standards of quantity or quality required for effective modelling, or the data might not be completely reflective of new project contexts. Furthermore, in addition to random uncertainty, subjective uncertainty exists in construction, stemming from the use of approximate reasoning and linguistically expressed expert knowledge, the latter of which is often not formally documented.

To address the challenges related to subjective uncertainty in construction, researchers have applied fuzzy logic to construction process modelling and decision-making. Fuzzy logic is an effective technique for modelling approximate reasoning and computing with linguistic terms; it provides a means to draw definite conclusions from ambiguous information and in the absence of complete and precise data. However, fuzzy logic alone has a number of limitations, primarily in its inability to learn from data and its extensive reliance on expert knowledge for the development of often context-dependent models. These limitations can be overcome by integrating fuzzy logic with other techniques that have complementary strengths, thus leading to advanced and powerful fuzzy hybrid computing techniques.

Although fuzzy logic and fuzzy hybrid computing have a long history of application in a broad range of disciplines, their application in construction engineering and management is relatively new. A review of the literature shows an increase in the application of fuzzy hybrid computing in construction research over the past decades, and research topics based on fuzzy hybrid computing in the construction domain have become highly diversified. *Fuzzy Hybrid Computing in Construction Engineering and Management: Theory and Applications* reflects the increase in both the number and diversity of studies in this area.

Purpose and Structure of the Book

This book presents an overview of some of the many state-of-the-art fuzzy hybrid computing techniques developed in the construction domain, and it illustrates how researchers have used these techniques to solve a wide variety of construction engineering and management problems. Each chapter identifies key trends and future areas for research and development. Authors from around the world have contributed to this book, bringing unique perspectives on how to integrate fuzzy logic with other techniques and how to apply the resulting fuzzy hybrid techniques to solve practical construction industry problems.

This book is a guide for students, researchers and practitioners to the latest theory and developments in fuzzy hybrid computing in construction engineering and management. By providing an introduction to the basic theory related to fuzzy logic, a survey of the literature in fuzzy hybrid computing for construction engineering and management and explorations of both methodological and applied approaches, this book is a valuable resource for readers of all levels of knowledge and experience. Experienced researchers can use this book as a reference to the state-of-the-art in fuzzy hybrid computing techniques in construction, including an up-to-date literature review and references to the latest studies. By reading this book, both undergraduate and graduate students will be introduced to the field of fuzzy hybrid computing and exposed to examples of the latest advancements and practical applications in this field. Construction industry practitioners can use the book to develop a body of knowledge about the field, identify solutions to problems they face and consider these novel approaches for solving construction-related problems.

This book is organised in three parts. Part 1 provides an introduction to fuzzy logic in the context of construction engineering and management, including its basic concepts and suitability for construction modelling. Part 1 also includes a survey of the latest research in fuzzy hybrid computing and its applications in the context of construction engineering and management. Part 2 is comprised of several methodological chapters in the theory of fuzzy hybrid computing. These chapters discuss fuzzy arithmetic, fuzzy simulation, fuzzy consensus, fuzzy aggregation and fuzzy multi-criteria decision-making approaches. They also provide in-depth knowledge of the implementation of these approaches in construction. Part 3 presents several practical applications of fuzzy hybrid computing techniques in construction,

illustrating how many of the techniques presented in earlier chapters are applied to solve real-world problems in a wide range of situations.

Chapter Summaries

Part 1: Introduction to Fuzzy Logic and Overview of Fuzzy Hybrid Techniques in Construction Engineering and Management

Introduction to Fuzzy Logic in Construction Engineering and Management
Fayek and Lourenzutti present an introduction to fuzzy logic in construction engineering and management. The role of fuzzy logic in handling certain types of uncertainties that are common in construction problems – such as subjectivity, ambiguity and vagueness – is highlighted. The role of fuzzy logic in construction problems is contrasted with that of probability theory, showing the complementary link between both theories. The authors present the key definitions, properties and methods of fuzzy logic, including the definition and representation of fuzzy sets and membership functions, basic operations on fuzzy sets, fuzzy relations and compositions, defuzzification methods, entropy for fuzzy sets, fuzzy numbers, methods for the specification of membership functions and fuzzy rule-based systems. Lastly, the authors discuss some challenges that fuzzy methods alone cannot handle, illustrating the need for hybridisation with other techniques.

Overview of Fuzzy Hybrid Techniques in Construction Engineering and Management
Gerami Seresht, Lourenzutti, Salah and Fayek present an overview of common types of fuzzy hybrid techniques applied to construction problems between 2004 and 2018. The techniques are grouped into four main categories: fuzzy hybrid optimisation, fuzzy hybrid machine learning, fuzzy multi-criteria decision-making and fuzzy simulation. For each category of fuzzy hybrid technique, the limitations of the standard techniques for solving construction-related problems are discussed, and the ways in which these limitations are overcome by using fuzzy hybrid techniques are described. Papers were selected for review that illustrate the capability of these types of fuzzy hybrid techniques to address construction challenges in a variety of applications. Finally, some directions for future research are presented.

Part 2: Theoretical Approaches of Fuzzy Hybrid Computing in Construction Engineering and Management

Fuzzy Arithmetic Operations: Theory and Applications in Construction Engineering and Management
Gerami Seresht and Fayek discuss fuzzy arithmetic operations and their application in solving mathematical equations that include fuzzy numbers. They present the two approaches for implementing fuzzy arithmetic operations, the α-cut approach and

the extension principle approach. They illustrate both approaches using triangular fuzzy numbers, and they present computational methods for implementing both approaches. They provide an example of the application of fuzzy arithmetic operations in a construction earthmoving simulation, and they outline future areas of research to extend the computational methods presented.

Fuzzy Simulation Techniques in Construction Engineering and Management
Raoufi, Gerami Seresht, Siraj and Fayek present three different approaches for fuzzy simulation: fuzzy discrete event simulation, fuzzy system dynamics and fuzzy agent-based modelling. They present an overview of simulation techniques used in construction and the advantages of integrating fuzzy logic with simulation techniques in order to deal with subjective uncertainties in simulation modelling. They illustrate how fuzzy logic can be integrated with discrete event simulation, system dynamics and agent-based modelling to enhance the capabilities of each method and make them more suitable for construction modelling. They discuss the process of choosing a suitable fuzzy simulation technique based on the characteristics of the construction system being modelled, the features of the simulation technique and the abstraction level of the model. They then present different applications of fuzzy simulation techniques in construction, and they outline areas for future applications and development.

Fuzzy Set Theory and Extensions for Multi-criteria Decision-making in Construction Management
Chen and Pan present 19 different methods for fuzzy multi-criteria decision-making (FMCDM) in construction, two of which they improve upon. They discuss multi-criteria decision-making (MCDM) methods in the construction context, fuzzy sets and extensions of fuzzy sets. They illustrate how MCDM methods can be enhanced with the integration of fuzzy logic in order to deal with complex problems that involve diverse decision makers' interests, conflicting objectives and uncertain information. In addition to presenting theoretical formulations for FMCDM methods, they summarise recent applications of these techniques in construction management, and they present future research needs in the development and application of FMCDM in construction management.

Fuzzy Consensus and Fuzzy Aggregation Processes for Multi-criteria Group Decision-making Problems in Construction Engineering and Management
Siraj, Fayek and Elbarkouky present different fuzzy consensus-reaching processes and fuzzy aggregation methods that are applicable to multi-criteria group decision-making (MCGDM) problems in construction. They present the basic theory and formulation of these methods and provide numerical examples to illustrate the steps involved in applying them to MCGDM problems. They discuss the application of fuzzy consensus reaching and fuzzy aggregation in the construction domain and provide examples of various applications. Finally, they present areas of future work that highlight emerging trends and future needs in the development of fuzzy consensus-reaching and fuzzy aggregation methods to solve MCGDM problems in construction.

Fuzzy AHP with Applications in Evaluating Construction Project Complexity
Nguyen, Le-Hoai, Tran, Dang and Nguyen present an application of the fuzzy analytic hierarchy process (AHP) for evaluating construction project complexity. This fuzzy AHP is capable of accounting for the qualitative nature of the factors involved in assessing project complexity. The authors describe the components of fuzzy extensions of the AHP, and they discuss the challenges of combining fuzzy logic with the traditional AHP. They present an entropy-based fuzzy extension of the AHP and its application in the evaluation of construction project complexity, which is illustrated with a case study. They discuss future research needs related to both the fuzzy AHP and the analysis of construction project complexity.

Part 3: Applications of Fuzzy Hybrid Computing in Construction Engineering and Management

The Fuzzy Analytic Hierarchy Process in the Investment Appraisal of Drilling Methods
Tokede, Ayinla and Wamuziri describe an application of the fuzzy analytic hierarchy process (AHP) in assessing investment appraisal risks for oil drilling projects. They compare the fuzzy AHP approach to a Monte Carlo simulation approach using a case study, and they conclude that both give comparable assessments of the level of risk for different drilling options; however, the fuzzy AHP provides the advantage of being able to take into account qualitative criteria in addition to quantitative criteria. They discuss the advantages of using the fuzzy AHP in an environment characterised by subjective uncertainty and linguistic assessments, and they provide ideas for future applications of the fuzzy AHP in risk analysis.

Modelling Risk Allocation Decisions in Public–Private Partnership Contracts Using the Fuzzy Set Approach
Ameyaw and Chan present a methodology for calculating the risk management capabilities of public–private partnerships in order to reach better risk allocation decisions. The proposed methodology is based on integrating risk allocation decision criteria, the Delphi method and the fuzzy synthetic evaluation (FSE) technique, allowing decision makers to use linguistic evaluations in the assessment of risk management capabilities. The authors illustrate their methodology using empirical data collected through a three-round Delphi survey. They demonstrate how their methodology relies on clearly stated risk allocation criteria, rather than on decision makers' popular opinions and risk preferences. The authors then present future research directions for advancing and automating the proposed approach.

Flexible Management of Essential Construction Tasks Using Fuzzy OLAP Cubes
Marín Ruiz, Martínez-Rojas, Molina Fernández, Soto-Hidalgo, Rubio-Romero and Vila Miranda propose a fuzzy multi-dimensional data model and on line analytical processing (OLAP) operations to manage construction data and support the decision-making process based on previous experience. Their framework enables

the integration of data in a common repository and provides flexible structures for representing data in the main tasks of construction project management. Imprecision in construction data is handled by incorporating fuzzy methods in the framework, making the documentation and interpretation of such data more intuitive to users of the framework. Use of the framework is illustrated with a number of practical construction applications. The authors conclude with a discussion of future challenges in the fuzzy database domain.

Using an Adaptive Neuro-fuzzy Inference System for Tender Price Index Forecasting: A Univariate Approach

Oshodi and Lam present an application of an adaptive neuro-fuzzy inference system (ANFIS) to the problem of forecasting tender prices. They compare the performance of the ANFIS to a similar model developed using the Box-Jenkins method and one developed using a support vector machine (SVM), using a univariate modelling approach for all three models. The performance of the ANFIS model is found to be superior to the other two modelling approaches when compared to actual data in predicting a tender price index. They conclude that fuzzy hybrid modelling approaches, such as the ANFIS, show promise in accurately modelling nonlinear problems in construction engineering and management, and they give examples of construction-related problems that may benefit from the application of such approaches.

Modelling Construction Management Problems with Fuzzy Cognitive Maps

Case, Blackburn and Stylios use fuzzy cognitive maps (FCMs) to model construction management problems. They illustrate the development and use of FCMs in modelling the complex relationships of the numerous factors that impact the feasibility and performance of construction projects. Their approach incorporates fuzzy logic with cognitive maps to allow domain experts to define the cause and effect relationships between factors using linguistic terms. They describe how to develop FCMs for construction management problems and how they can be used to test various scenarios and make decisions in the context of cost, schedule and risk management. Finally, they propose extensions to their FCM approach for construction management.

Crane Guidance Gesture Recognition Using Fuzzy Logic and Kalman Filtering

Wang and Gordon propose a new approach to tracking and recognising human arm gestures for crane guidance on construction sites. The authors use data collected in real time from both a Kinect visual sensor and a Myo armband sensor to estimate Euler angles, angular velocity, linear acceleration and electromyography. Kalman filtering is applied for motion trajectory tracking, and a fuzzy inference system is used to interpret the crane operator's arm gestures. The methodology is illustrated in an experiment involving Kinect, the Myo armband and MATLAB/Simulink software using five different signals for crane guidance, illustrating the effectiveness and robustness of the method in crane guidance applications. They

propose future research to evaluate the robustness of their approach with an increase in the number of crane signals as part of automated crane control systems.

Future Directions

This book presents the latest advancements in both the theory and applications of fuzzy hybrid computing in construction engineering and management. It identifies emerging areas of inquiry and opportunities for future research and development. With the knowledge contained in this book, innovative solutions for problems facing the construction industry can be developed, helping this vital and important sector of the world economy thrive and become more profitable and competitive.

Some of the emerging areas of inquiry discussed in this book include:

(1) Improving methods of eliciting and aggregating expert knowledge, combining such knowledge with data-driven techniques, and integrating data in different formats for use in fuzzy hybrid systems. Capturing human expertise while simultaneously capitalising on the richness of data in different formats is essential for the development of fuzzy hybrid systems that are appropriate for the construction domain.
(2) Developing more robust and automated methods of specifying membership functions and determining the most appropriate fuzzy operations for fuzzy hybrid systems. Also discussed is the development of optimisation techniques for fuzzy hybrid systems that can help with selecting the best system configurations. Such research will reduce the amount of effort required to develop new systems for different applications.
(3) Developing methods of adapting and transferring fuzzy hybrid systems to contexts for which they were not developed in order to address the context-dependent nature of their application. These methods will reduce the effort required to develop a unique system for each new construction context.
(4) Identifying further opportunities to hybridise fuzzy logic with other techniques in order to create even more advanced fuzzy hybrid computing methods for dealing with different aspects of construction problems.
(5) Identifying new areas of application in construction engineering and management that would benefit from fuzzy hybrid modelling in order to provide practitioners with solutions to problems they face in the planning, execution and control of construction projects.

Furthermore, automating advanced fuzzy hybrid techniques in software platforms will make them more accessible to construction practitioners, who will not be required to have knowledge of the techniques on which the software is based. Such developments will facilitate more widespread acceptance and use of fuzzy hybrid techniques in construction practice.

I hope you find this book as interesting and thought-provoking as I have. It has been a great pleasure working with the many talented authors who have contributed their research and perspectives on fuzzy hybrid computing in construction engineering and management. We hope this book will be updated as the fuzzy logic and fuzzy hybrid computing community in construction continues to advance these techniques. With such advancements, we will find new ways of hybridising fuzzy logic with other techniques to develop innovative solutions to practical problems faced by construction industry practitioners, helping this important sector of the world economy become more technologically sophisticated, competitive and profitable.

Aminah Robinson Fayek, PhD, PEng
Professor, Civil and Environmental Engineering, University of Alberta
Tier 1 Canada Research Chair in Fuzzy Hybrid Decision Support Systems for Construction
NSERC Industrial Research Chair in Strategic Construction Modeling and Delivery