# CONSTRUCTION TECHNOLOGY

Edited by
Paul S. Chinowsky

CRITICAL CONCEPTS IN CONSTRUCTION

ROUTLEDGE

# CONSTRUCTION TECHNOLOGY

## Critical Concepts in Construction

*Edited by*
*Paul S. Chinowsky*

**Volume II**
**Simulation and Automation**

Routledge
Taylor & Francis Group
LONDON AND NEW YORK

First published 2014
by Routledge
2 Park Square, Milton Park, Abingdon, Oxon OX14 4RN

and Routledge
711 Third Avenue, New York, NY 10017

*Routledge is an imprint of the Taylor & Francis Group, an informa business*



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

*Library of Congress Cataloging in Publication Data*
A catalog record for this book has been requested

ISBN: 978-0-415-81825-4 (Set)
ISBN: 978-0-415-81827-8 (Volume II)

Typeset in 10/12pt Times NR MT
by Graphicraft Limited, Hong Kong

**Publisher's Note**
References within each chapter are as they appear in the original complete work

MIX
Paper from responsible sources
FSC® C013056

Printed and bound in Great Britain by
TJ International Ltd, Padstow, Cornwall

# ACKNOWLEDGEMENTS

The publishers would like to thank the following for permission to reprint their material:

ASCE for permission to reprint AbouRizk, S. M. and Halpin, D. W. (1990). 'Probabilistic Simulation Studies for Repetitive Construction Processes.' *Journal of Construction Engineering and Management*, 116(4), 575–594.

ASCE for permission to reprint Martinez, J. C. and Ioannou, P. G. (1999). 'General-purpose Systems for Effective Construction Simulation.' *Journal of Construction Engineering and Management*, 125(4), 265–276.

ASCE for permission to reprint Lu, M. (2003). 'Simplified Discrete-event Simulation Approach for Construction Simulation.' *Journal of Construction Engineering and Management*, 129(5), 537–546.

ASCE for permission to reprint AbouRizk, S., Halpin, D., Mohamed, Y., and Hermann, U. (2011). 'Research in Modeling and Simulation for Improving Construction Engineering Operations.' *Journal of Construction Engineering and Management*, 137(10), 843–852. SPECIAL ISSUE: Construction Engineering: Opportunity and Vision for Education.

ASCE for permission to reprint O'Connor, J. T., Rusch, S. E., and Schulz, M. J. (1987). 'Constructability Concepts for Engineering and Procurement.' *Journal of Construction Engineering and Management*, 113(2), 235–248.

ASCE for permission to reprint Fisher, D. J. and O'Connor, J. T. (1991). 'Constructability for Piping Automation: Field Operations.' *Journal of Construction Engineering and Management*, 117(3), 468–485.

ASCE for permission to reprint Fischer, M. and Tatum, C. B. (1997). 'Characteristics of Design-relevant Constructability Knowledge.' *Journal of Construction Engineering and Management*, 123(3), 253–260.

ASCE for permission to reprint Skibniewski, M., Arciszewski, T., and Lueprasert, K. (1997). 'Constructability Analysis: Machine Learning Approach.' *Journal of Computing in Civil Engineering*, 11(1), 8–16.

ASCE for permission to reprint Arditi, D., Elhassan, A., and Toklu, Y. C. (2002). 'Constructability Analysis in the Design Firm.' *Journal of Construction Engineering and Management*, 128(2), 117–126.

ASCE for permission to reprint Pulaski, M. H. and Horman, M. J. (2005). 'Organizing Constructability Knowledge for Design.' *Journal of Construction Engineering and Management*, 131(8), 911–919.

Taylor & Francis for permission to reprint Hartmann, T. and Fischer, M. (2007). 'Supporting the Constructability Review with 3D/4D Models.' *Building Research & Information*, 35(1), 70–80.

Taylor & Francis for permission to reprint Slaughter, E. S. (1999). 'Assessment of Construction Processes and Innovations through Simulation.' *Construction Management and Economics*, 17(3), 341–350.

ASCE for permission to reprint Zhai, D., Goodrum, P. M., Haas, C. T., and Caldas, C. H. (2009). 'Relationship between the Automation and Integration of Construction Information Systems and Labor Productivity.' *Journal of Construction Engineering and Management*, 135(8), 746–753.

ASCE for permission to reprint Watkins, M., Mukherjee, A., Onder, N., and Mattila, K. (2009). 'Using Agent-based Modeling to Study Construction Labor Productivity as an Emergent Property of Individual and Crew Interactions.' *Journal of Construction Engineering and Management*, 135(7), 657–667.

Elsevier for permission to reprint Nasirzadeh, F. and Nojedehi, P. (2013). 'Dynamic Modeling of Labor Productivity in Construction Projects.' *International Journal of Project Management*, 31(6), 903–911.

ASCE for permission to reprint Sanvido, V. E. and Medeiros, D. J. (1990). 'Applying Computer-integrated Manufacturing Concepts to Construction.' *Journal of Construction Engineering and Management*, 116(2), 365–379.

ASCE for permission to reprint Skibniewski, M. and Hendrickson, C. (1990). 'Automation and Robotics for Road Construction and Maintenance' *Journal of Transportation Engineering*, 116(3), 261–271.

ASCE for permission to reprint Bernold, L. E., Abraham, D. M. and Reinhart, D. B. (1990). 'FMS Approach to Construction Automation.' *Journal of Aerospace Engineering*, 3(2), 108–121.

Elsevier for permission to reprint Gambao, E., Balaguer, C., and Gebhart, F. (2000). 'Robot Assembly System for Computer-integrated Construction.' *Automation in Construction*, 9(5–6), 479–487.

IEEE for permission to reprint Kangari, R. and Riggs, L. S. (1989). 'Construction Risk Assessment by Linguistics.' *IEEE Transactions on Engineering Management*, 36(2), 126–131.

Taylor & Francis for permission to reprint Dawood, N. (1998). 'Estimating Project and Activity Duration: A Risk Management Approach Using Network Analysis.' *Construction Management and Economics*, 16(1), 41–48.

Taylor & Francis for permission to reprint Tah, J. H. M. and Carr, V. (2000). 'A Proposal for Construction Project Risk Assessment Using Fuzzy Logic.' *Construction Management and Economics*, 18(4), 491–500.

ASCE for permission to reprint Hastak, M. and Shaked, A. (2000). 'ICRAM-1: Model for International Construction Risk Assessment.' *Journal of Management in Engineering*, 16(1), 59–69.

Elsevier for permission to reprint Baloi, D. and Price, A. D. F. (2003). 'Modelling Global Risk Factors Affecting Construction Cost Performance.' *International Journal of Project Management*, 21(4), 261–269.

ASCE for permission to reprint Kokkaew, N. and Chiara, N. (2010). 'Modelling Completion Risk Using Stochastic Critical Path-envelope Method: A BOT Highway Project Application.' *Construction Management and Economics*, 28(12), 1239–1254.

## Disclaimer

# CONTENTS

## VOLUME II SIMULATION AND AUTOMATION

# INTRODUCTION

Volume II of the Construction Technology series emphasizes the role that simulation and automation has played from the introduction of computer technologies through today. This group of topics is significant in that it provides a separate lens through which computing technologies have impacted construction. In contrast to the foundational technologies presented in Volume I, the group of topics in Volume II presents the anticipated future directions for computing technologies. The potential impact of simulating operations, analysing constructability, and placing robotics in the field represented the early objectives and ambitions of construction computing researchers. These initial objectives and the subsequent follow-through are represented in this collection through the sections on Simulation, Constructability, Productivity, Robotics and Automation, and Risk Analysis.

As with Volume II, the first section, Simulation, sets the stage for the volume by spotlighting the technology that attracted significant attention to the construction sector for the potential impact it could provide for construction planning. Although many efforts deserve and receive attention in this overall collection, simulation stands apart as it represents a technology that is studied by individuals in all sectors of construction research and development. At the core of this attention is the work conducted by Halpin and his students over more than three decades. As a reflection of this impact, the first paper in this section is the paper by AbouRizk and Halpin that describes their work on the simulation studies. The remaining papers in this first section showcase the continued research in simulation through today. The impact and influence of the field continues to provide insights into the role of research in the construction sector and the potential for changing the way professionals approach project planning.

The second and third groupings of papers in this volume build upon the simulation influence by highlighting the potential of simulation in developing construction projects. The first of these sections, constructability, covers the history of research into the application of computing to constructability analysis. Although the peak of this research was in the mid-1980s and early 1990s, as indicated by the continuous publication dates in this section, the field of constructability continues to evolve. This evolution is highlighted by the Hartmann and Fischer paper which brings constructability into the domain of nD visualization. The future direction of constructability appears to be intertwined with visualization as seen in Volume III. The challenge for the next generation of researchers will be how to balance the core requirements of constructability analysis with the advanced visualization techniques that continue to emerge.

Complementing the constructability section is the third grouping of papers focused on productivity analysis. In contrast to the constructability research, the research effort in productivity has received renewed interest based on the core interest in productivity analysis. Although the evolution of visualization techniques is expanding the opportunities in productivity, the focus of the field remains centred on the idea of enhancing productivity on the construction site. The paper by Zhai et al. and the paper by Nasirzadeh and Nojedehi exemplify this focus as they utilize computer technologies to extend productivity analysis in the current age of research. However, visualization also needs to be recognized as having an influence in this sector.

The fourth group of papers in Volume II, Robotics and Automation, arguably represents the most discussed and debated research sector in the construction automation sector. Robotics has long been put forward as an area with perhaps the greatest promise for the construction industry. With the potential to automate repetitive and dangerous tasks, robotics could be a solution to many production issues that have challenged the construction industry for decades. However, the realization of that promise has yet to be fully achieved. The papers in this section represent the pursuit of that promise and the significant strides that have been taken to achieve the goal. Skibniewski and Bernold both provide perspectives on the field that capture progress through its history. These perspectives should be examined for the opportunity they still represent and the challenges that still remain for fulfilling the promise of robotics and automation in construction.

The final group of papers in Volume II deviates from the historic perspectives provided in the previous sections to turn to the topic of risk analysis. Although many individuals may not associate risk analysis with computer technologies, the area has in fact been permanently impacted by the advances in decision support technologies. As captured in the six papers within this section, the field of risk management has progressed from algorithmic approaches to analysing contracts to a new focus on utilizing advanced decision support techniques. The paper by Kokkaew and Chiara provides examples of how this field is applying new techniques to application areas that face increasing levels of risk. As the construction industry faces continuing issues with project financing and contractual disputes, the ability to utilize advanced techniques to mitigate risk is becoming increasingly important. From this perspective, risk analysis is emerging as a fundamental sector that is appropriate for new technology application.

The completion of Volume II closes the perspective on computer technology in the context of traditional or original sector applications. The papers in these two volumes represent an historical journey through the origins and evolution of computing in construction. However, these papers also provide the drivers for the emerging fields that are discussed in Volumes III and IV. Specifically, the areas of visualization and knowledge management have emerged as extensions to core processes. The reader is thus reminded that understanding the latest research fields requires an understanding of the foundation to fully gain the perspective of development within any of the computer technology sectors.

# Part 6

# SIMULATION

# 25

# PROBABILISTIC SIMULATION STUDIES FOR REPETITIVE CONSTRUCTION PROCESSES

*Simaan M. AbouRizk and Daniel W. Halpin*

Source: *Journal of Construction Engineering and Management*, 116:4 (1990), 575–94.

## Abstract

Before full adaptation of simulation techniques for the analysis and design of construction operations can be implemented, the appropriate statistical tools must be understood and applied as part of the simulation experiment. Most simulation models in construction can be treated as stochastic models. The proper analysis of such models requires: (1) Application of input modeling techniques; (2) appropriate analysis of output parameters of concern based on multiple runs; and (3) validation and verification of the results. This paper describes techniques applicable to the simulation of repetitive construction operations and presents a practical example application to demonstrate how they can be applied. Procedures for selecting input models, methods for solving for the parameters of selected distributions, and goodness-of-fit testing for construction data are reviewed. The discussions on output analysis were limited to simulation output that is normal because it is frequently encountered in construction simulation. Methods for checking the normality of output data, building confidence intervals for various output parameters, and validation of simulation models are also addressed.

## Introduction

Computer simulation of construction operations has been an active area of research for the past decade. Although not fully adopted as an analysis tool in the construction industry, it has been widely accepted in the research community. The majority of problems in simulation, in the context of construction, stem from the lack of a consistent approach that clearly defines all the steps and aspects of simulation. In many cases, practitioners find it difficult to learn how to use this operational tool due to the complexity associated with certain simulation methodologies. In the last two decades, progress has been made in introducing the use of simulation methodologies suitable for certain construction operations. Construction simulation systems have made it easier to understand and apply simulation. Recent attempts have also focused on making the input phase of simulation easy and attractive to the infrequent or inexperienced user. This was accomplished by enabling the user to enter a simulation model graphically and interactively on a computer (Riggs 1989). Deficiencies, however, remain in the area of experimentation.

Simulation is often defined as "the development of a mathematical-logical model of a system and the experimental manipulation of the model on a computer" (Pritsker 1985; Biles 1987). The modeling aspects of simulation (for construction processes) using the CYCLONE methodology is extensively documented in Halpin and Woodhead (1976) and a variety of other publications (Riggs 1980; Dabbas and Halpin 1982; Paulson 1978; Ioannou 1989). The experimentation phase of stochastic simulation is treated in this paper.

For a simulation experiment to be fruitful, the simulator should ensure: (1) Proper input in the form of statistical models for work-task durations, proper allocation of resources in the system, stopping rules for ending the simulation, etc.; (2) proper analysis of the output; and (3) validation and verification of the model. In addition, a simulator should also make use of variance-reduction techniques to reduce the number of runs required to arrive at some confidence interval for a particular output parameter.

Computer simulation can be classified as either deterministic or stochastic depending on its uncertainty content (Wilson 1984; Kelton 1986). In the first case, all aspects of the experiment would be constant and fixed throughout the simulation. Only a limited number of construction operations fall into this category. Construction operations are usually subject to variations and interruptions due to the nature of the construction environment itself. A detailed investigation of this issue can be found in Bernold (1985) and Hijazi (1989). One should, therefore, use stochastic simulation in modeling construction operations. For such simulation, randomness is usually driven by random (or pseudo-random) input processes.

This paper is concerned with reviewing some of the techniques that can be used in a simulation experiment, particularly as they apply to analyzing construction processes. The derivations of the techniques described are not addressed in this paper. However, the interested reader should refer to the literature cited in the References.

To demonstrate the techniques presented in a simplified context, a case study was modeled and simulated using the MicroCYCLONE system (Halpin 1973, 1977, 1989).