Simulation Foundations, Methods and Applications

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The modeling and simulation community extends over a range of diverse disciplines and this landscape continues to expand at an impressive rate. Over recent years, modeling and simulation has matured to become its own discipline, while continuing to provide support to other disciplines. As such, modeling and simulation provides the necessary conceptual insights as well as computational support which has an established record of significantly enhancing the understanding of dynamic system behavior and improving the system design process, as well as providing the foundations for computational sciences and practical applications, from cyber-physical systems to healthcare. Hybrid methods and combinations with artificial intelligence and machine learning open new possibilities as well. The ever-increasing availability of computational power and the availability of quantum computers make applications feasible that were previously beyond consideration. Simulation is pushing back the boundaries of what it can be applied to and what can be solved in practice. Its relevance and applicability are unconstrained by discipline boundaries.

Simulation Foundations, Methods and Applications hosts high-quality contributions that address the various facets of the modeling and simulation enterprise. These range from fundamental concepts that are strengthening the foundation of the discipline to the exploration of advances and emerging developments in the expanding landscape of application areas. The underlying intent is to facilitate and promote the sharing of creative ideas across discipline boundaries.

As every simulation is rooted in a model, which results from simplifying and abstracting the reference of interest to best answer research questions or support the application domain of interest, we understand the model development phase as a prerequisite for any simulation application. There is an expectation that modeling issues will be appropriately addressed in each presentation. Incorporation of case studies and simulation results will be strongly encouraged.

Titles of this series can span a variety of product types, including but not exclusively, textbooks, expository monographs, contributed volumes, research monographs, professional texts, guidebooks, and other references.

These books will appeal to senior undergraduate and graduate students, and researchers in any of a host of disciplines where modeling and simulation has become (or is becoming) an important problem-solving tool. Some titles will also directly appeal to modeling and simulation professionals and practitioners.

Michael Grieves · Edward Y. Hua
Editors

Digital Twins, Simulation, and the Metaverse

Driving Efficiency and Effectiveness in the Physical World through Simulation in the Virtual Worlds

Springer

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Foreword

Through compelling real-world use cases and case studies, Dr. Michael Grieves, Executive Director of the Digital Twin Institute, an internationally recognized expert in the fields of Digital Twins and Product Lifecycle Management, first introduced the core concept of Digital Twins and further developed and evolved the concept and Dr. Edward Hua, Tech Lead for Digital Twins Simulation Engineering at The MITRE Corporation's Modeling and Analysis Innovation Center, has compiled a comprehensive history of Digital Twin foundational elements, concepts, methodologies, frameworks, and implementations in the chapters comprising *Digital Twins, Simulation, and the Metaverse: Driving Efficiency and Effectiveness in the Physical World through Simulation in the Virtual Worlds.*

Immediately insightful and impactful, this significant body of work, authored by experts in their fields, provides a cross-sectional view where Digital Twins deliver real value and transformative outcomes across diverse market sectors, segments, and industries.

With adoption spanning virtually every primary industry and new applications and use cases continually emerging, readers can understand Digital Twin's growth and adoption, including its near symbiotic relation to the evolving Metaverse landscape. The Metaverse is currently an evolving and not yet clearly defined concept. In the editors' introductory book chapter, the characteristics of Digital Twin Metaverses are outlined to provide a roadmap for the needed future development.

From conceptual methodologies, foundational elements, standardizations, and frameworks, including composability, construction, verification and validation, and other constructs spanning the different lifecycle phases, to exploring AI approaches—including prescriptive to autonomous, such as ML, as described through the application of Reinforcement Learning over the Digital Twin lifecycle—to Generative AI, utilizing co-pilots and multi-agents that deliver increasing value, traditional to intelligent Digital Twin use cases are revealed in highly informative detail.

These include an impressive array of examples that range from Nuclear facilities to Healthcare and Biomedicine, to Smart manufacturing—including the overall value chain along with advances in robotics and battery lifecycle production, to sustainable semiconductor fabrication and the Digital Twin role as "the photorealistic, physics-based, and real-time capable Digital Twin" where in turn simulation is the main ingredient of the Industrial Metaverse.

Examples of Digital Twin applications in Transportation management—Urban Mobility and Distributed AI Modeling and Simulation for Smart Airport Digital Twin with multi-agent transportation management systems, including Metaverse applications, are among several other use cases.

Learnings include the strategic integration of Digital Twins infused with AI and the significant role that reality capture plays in a pioneering journey of a NASA "factory Digital Twin," where the Factory Twin's value is realized and "positioned as a dynamic entity capable of substantial ROI."

For those engaged in or interested in research, this book serves as a compass, helping to guide and provide an understanding of opportunities for both new and existing R&D pursuits. Each chapter includes valuable references for further investigation, pinpointing specific areas of interest.

Through evolving market and business landscape examples, this book further illustrates how industries are progressively innovating as new technologies—encompassing advances in extended reality (XR), AI, 5G, and Edge-Cloud Computing, among other enabling technologies—transform traditional business models and generate new opportunities.

Digital Twin characteristics, oriented to the Metaverse and viewed through a lens into the growth and evolution of this developing landscape, are presented. Historical and current market opportunities are detailed through specific areas of adoption across various APAC regions while also considering the developing future potential.

This compilation examines the development and progression of Digital Twins, including associated opportunities and challenges. The diverse collection of case studies and analyses provides insights into Digital Twin's key role in digital transformation. Fueled by AI-accelerated growth and as exemplified by the use cases described, Digital Twin's evolution and adoption show no signs of slowing, especially when coupled with the emerging Metaverse landscape.

San Francisco, USA Dan Isaacs
July 2024

Contents

Defining, Exploring, and Simulating the Digital Twin Metaverses 1
Michael Grieves and Edward Y. Hua

Contrasting Capabilities: A Comparative Analysis of Simulation and Digital Twin Technologies 33
Ana Wooley and Daniel F. Silva

Reinforcement Learning for Digital Twins 51
Deena Francis, Jonas Friederich, Adelinde Uhrmacher, and Sanja Lazarova-Molnar

A Framework for the Credibility Evaluation of Digital Twins 69
Han Lu, Lin Zhang, Kunyu Wang, Zejun Huang, Hongbo Cheng, and Jin Cui

On the Importance of Simulation and Digital Twin for Industrial Applications 95
Stefan Boschert, Christoph Heinrich, Vincent Malik, Roland Rosen, and Uliana Soellner

A Formal Framework for Digital Twin Modeling, Verification, and Validation 119
Mamadou Kaba Traore, Simon Gorecki, and Yves Ducq

Digital Twins for Advanced Manufacturing: The Standardized Approach 145
Guodong Shao, Deogratias Kibira, and Simon Frechette

NASA's Michoud Assembly Facility: Developing a Factory Digital Twin 171
Greg Porter, John Vickers, Robert Savoie, and Marc Aubanel

Distributed AI Modeling and Simulation for Smart Airport Digital Twin Applications 195
Kostas Alexandridis, Soheil Sabri, Jeff Smith, Bob Logan, Katalin Bartfai-Walcott, and Doug Migliori

The First Real-Time Digital Twin of a Nuclear Reactor 225
John Darrington, Ben-oni E. Vainqueur, and Christopher Ritter

Evolution of Simulation and Digital Twin in Health Care: From Discovery to Design and Integration 249
Yue Dong, Amos Lal, Alexander S. Niven, and Xiang Zhong

Digital Twins for Sustainable Semiconductor Manufacturing 267
Ala Moradian

Digital Twins for Robot Systems in Manufacturing 307
Ali Ahmad Malik, Guodong Shao, and Jane Tarakhovsky

Mobiliti: A Digital Twin for Regional Transportation Network Design and Evaluation 333
Jane F. Macfarlane and Ismaeel Babur

Digital Twin in the Battery Industry 363
Soumya Singh, Michael Oberle, Daniel Schel, Julian Grimm, Olga Meyer, and Kai Peter Birke

The Impact of Japanese Anime Games and AI on the Development of the Metaverse 395
Hiromi Komuro, Oussouby Sacko, Yu Yuan, Qiongzhao Ellen. Schicktanz, Ramesh Ramadoss, and Miyuki Komuro

The Latest Developments in China's Metaverse 425
Caichun Gong and Jin Qiu

Index 441