

Frontiers in Civil Engineering

Emerging Technologies, Sustainable Practices



DIGITAL TWINS
& BIM



SUSTAINABLE
PRACTICES



ARTIFICIAL
INTELLIGENCE



ROBOTICS &
AUTOMATION



SMART
INFRASTRUCTURE

INNOVATION
RESILIENCE
SUSTAINABILITY
FOR A BETTER
TOMORROW

*Building
Sustainable
and Resilient
Communities*



SMARTER
GREENER
SAFER
STRONGER

Chief Editor

Dr. K. Padma Kumari

Professor and HOD
Department of Civil Engineering
JNTUK, Kakinada

Editor

Dr. Kusuma Sundara Kumar

Professor and HOD
Department of Civil Engineering
Ramachandra College of Engineering, Eluru

PEOPLE | PLANET | PROGRESS

ENGINEERING A BETTER TOMORROW

Frontiers in Civil Engineering

Emerging Technologies, Sustainable Practices



DIGITAL TWINS
& BIM



SUSTAINABLE
PRACTICES



ARTIFICIAL
INTELLIGENCE



ROBOTICS &
AUTOMATION



SMART
INFRASTRUCTURE

INNOVATION
RESILIENCE
SUSTAINABILITY
FOR A BETTER
TOMORROW

*Building
Sustainable
and Resilient
Communities*



Chief Editor:

Dr. K.Padma Kumari

Professor & HoD, Department of Civil Engineering
JNTUK, Kakinada, India

Editor:

Dr. Kusuma Sundara Kumar

Professor & HoD, Department of Civil Engineering
Ramachandra College of Engineering (A), Eluru, Andhra Pradesh, India

Frontiers in Civil Engineering: Emerging Technologies, Sustainable

Chief Editor:

Dr. K. Padma Kumari

Professor & HoD, Department of Civil Engineering
JNTUK, Kakinada, India

Editor:

Dr. Kusuma Sundara Kumar

Professor & HoD, Department of Civil Engineering
Ramachandra College of Engineering (A), Eluru, Andhra Pradesh, India

ISBN : 978-81-69623-12-4

Page(s) : 419, xv

Price : Rs.1800/-

Published Year : September, 2026

Published by : Excellent Publishers

No. 38/48, Second street, Ellappa Nagar
Kanchipuram – 631501, Tamilnadu, India.
Cell +91-9842641794

excellentpublishers2013@gmail.com

www.excellentpublishers.com



Disclaimer :

The author is solely responsible for the contents of the book in this volume in any manner, Errors, if any are purely unintentional and readers are requested to communicate such errors to the authors to discrepancies in futures.

Note: No part of this publication may be reproduced or transmitted in any form or by any means, electronic or mechanical, including photocopying, recording, or any information storage and retrieval system, without permission in writing from the publisher.

Copyright © 2026 Excellent Publishers, All Rights Reserved

PREFACE

Dear Reader,

Civil engineering is entering an era of unprecedented technological and environmental change. The increasing complexity of infrastructure systems, rapid urbanization, climate variability, resource constraints, and the demand for safer and more sustainable development are creating new challenges for engineers. At the same time, advances in Artificial Intelligence, Internet of Things, Digital Twins, Building Information Modeling, remote sensing, data analytics, robotics, advanced materials, and other emerging technologies are opening new possibilities for addressing these challenges. This book, *Frontiers in Civil Engineering: Emerging Technologies, Sustainable Practices*, has been conceived to present these developments in an integrated and accessible manner.

The book brings together six broad dimensions of contemporary civil engineering. The opening section focuses on digital transformation through BIM, Digital Twins, AI-driven design, real-time simulation, IoT, edge and cloud computing, predictive maintenance, and construction robotics. These technologies demonstrate the transition from conventional engineering practices toward intelligent, connected, and data-driven infrastructure management.

The second section addresses emerging developments in transportation engineering, including smart transportation systems and connected technologies. The third section examines water resources and environmental engineering, with emphasis on smart water management, IoT-based monitoring, wastewater reuse, and climate-adaptive water infrastructure. The fourth section brings together GIS, BIM integration, remote sensing, augmented reality, and related geospatial technologies for modern infrastructure planning and management.

Sustainability forms a central theme throughout the volume. The chapters explore sustainable materials, life-cycle assessment, carbon reduction, climate mitigation, resilience, and responsible infrastructure development. The book recognizes that future civil engineering must address not only technical performance but also environmental responsibility, social equity, and long-term resilience.

The final section extends this perspective to disaster management, advanced structural systems, and emerging frontiers. Topics include seismic resilience,

multi-hazard design, probabilistic risk assessment, modular and prefabricated construction, and civil engineering applications in space and extreme environments. The chapter on extreme environments, for example, considers the Moon, Mars, Arctic and Antarctic regions, advanced construction technologies, and the lessons these environments offer for resilient infrastructure on Earth.

A distinctive feature of this book is its emphasis on the convergence of technology, sustainability, and engineering practice. Rather than treating emerging technologies as isolated developments, the chapters illustrate how AI, IoT, BIM, GIS, Digital Twins, advanced materials, and data-driven methods can work together to improve infrastructure performance, safety, efficiency, and resilience. The concluding discussions further emphasize the need for engineers to develop digital skills, interdisciplinary capabilities, ethical awareness, and a commitment to sustainable development.

The book is intended for undergraduate and postgraduate students, research scholars, faculty members, practicing civil engineers, planners, consultants, and infrastructure professionals who wish to understand the emerging directions of the discipline. It may also serve as a useful reference for those exploring the intersection of civil engineering with computing, environmental science, geospatial technology, materials science, and disaster management.

The preparation of this edited volume has been a collaborative effort involving authors from diverse academic and professional backgrounds. Their contributions reflect the rapidly evolving nature of civil engineering and the importance of knowledge sharing across disciplines. The editors sincerely acknowledge their valuable efforts in bringing together the ideas, applications, and perspectives presented in this volume.

It is hoped that *Frontiers in Civil Engineering: Emerging Technologies, Sustainable Practices* will encourage readers to look beyond conventional approaches, appreciate the opportunities offered by emerging technologies, and contribute to the development of smarter, safer, sustainable, inclusive, and resilient infrastructure for the future.

Dr. K.Padma Kumari
Dr. Kusuma Sundara Kumar

Frontiers in Civil Engineering: Emerging Technologies, Sustainable Practices

Table of Contents

Chapter Index

Part / Chapter	Title	Page
PART 1	FOUNDATIONS AND DIGITAL TRANSFORMATION (Chapters 1–5)	2
Chapter 1	Digital Twins and BIM in Civil Engineering	3
Chapter 2	Internet of Things (IoT) for Infrastructure Monitoring	17
Chapter 3	Artificial Intelligence and Machine Learning in Civil Design	32
Chapter 4	Big Data Analytics and Cloud Computing in Civil Engineering	46
Chapter 5	Robotics and Automation in Construction	60
PART 2	TRANSPORTATION ENGINEERING FRONTIERS (Chapters 6–9)	74
Chapter 6	Smart Transportation Systems	75
Chapter 7	Sustainable Pavements and Materials	90
Chapter 8	High-Speed Rail and Hyperloop Technologies	103
Chapter 9	Urban Mobility and Micromobility Integration	118
PART 3	WATER RESOURCES AND ENVIRONMENTAL ENGINEERING (Chapters 10–14)	133
Chapter 10	Smart Water Management Systems	134
Chapter 11	Advanced Wastewater Treatment Technologies	148
Chapter 12	Flood Risk Management with Geospatial Tech	162
Chapter 13	Emerging Technologies in Coastal and Hydraulic Engineering	176
Chapter 14	Groundwater Sustainability and Remediation	189
PART 4	GEOSPATIAL TECHNOLOGIES AND REMOTE SENSING (Chapters 15–18)	203

Chapter 15	GIS and BIM Integration for Infrastructure	204
Chapter 16	Satellite Remote Sensing in Civil Applications	218
Chapter 17	UAVs and Photogrammetry	231
Chapter 18	Augmented Reality in Geospatial Engineering	244
PART 5	SUSTAINABLE MATERIALS AND CLIMATE RESILIENCE (Chapters 19–24)	257
Chapter 19	High-Performance Sustainable Concretes	258
Chapter 20	Green Building Materials and Certification	271
Chapter 21	Climate Change Impacts on Infrastructure	284
Chapter 22	Climate Mitigation Strategies	298
Chapter 23	Life Cycle Assessment in Civil Engineering	310
Chapter 24	Bio-Inspired and Resilient Materials	323
PART 6	DISASTER MANAGEMENT AND ADVANCED STRUCTURES (Chapters 25–30)	336
Chapter 25	Seismic Resilient Structures and Earthquake Engineering	337
Chapter 26	Multi-Hazard Resilient Structures	350
Chapter 27	Disaster Management with AI and Big Data	364
Chapter 28	Tsunami and Coastal Disaster Mitigation	376
Chapter 29	Emerging Frontiers: Space and Extreme Environments	387
Chapter 30	Future Directions and Ethical Imperatives	401

Frontiers in Civil Engineering: Emerging Technologies, Sustainable Practices

TABLE OF CONTENTS

PART 1 — FOUNDATIONS AND DIGITAL TRANSFORMATION

Chapters 1–5

Chapter	Section / Subsection	Page
Chapter 1	Digital Twins and BIM in Civil Engineering	3
1.1	Evolution of BIM to Digital Twins	4
1.2	AI-Driven BIM for Design Optimization	6
1.3	Real-Time Simulation and Predictive Analytics	8
1.4	Case Studies: Smart Cities Implementation	11
1.5	Challenges: Interoperability and Cybersecurity	13
Chapter 2	Internet of Things (IoT) for Infrastructure Monitoring	17
2.1	IoT Sensors in Structural Health Monitoring	18
2.2	Edge Computing for Real-Time Data Processing	20
2.3	Integration with Cloud Platforms	23
2.4	Application in Predictive Maintenance	25
2.5	Sustainability Gains through IoT	28
Chapter 3	Artificial Intelligence and Machine Learning in Civil Design	32
3.1	Machine Learning Algorithm for Load Prediction and Optimization	33
3.2	Generative AI for Structural Topology	35
3.3	Explainable AI in Risk Assessment	38
3.4	Hybrid AI-Human Workflows	40
3.5	Ethical Considerations in AI Adoption	42
Chapter 4	Big Data Analytics and Cloud Computing in Civil Engineering	46
4.1	Handling Massive Geospatial and Sensor Datasets	47
4.2	Cloud-Based Simulation Tools	49
4.3	Data-Driven Decision Making in Projects	52
4.4	Privacy and Data Governance	54
4.5	Scalable Analytics for Mega-Projects	56
Chapter 5	Robotics and Automation in Construction	60
5.1	Autonomous Drones and Robots for Site Surveys	61
5.2	3D Printing of Building Components	63
5.3	Robotic Assembly Lines	66
5.4	Human-Robot Collaboration	68
5.5	Economic and Safety Impacts	70

PART 2 — TRANSPORTATION ENGINEERING FRONTIERS

Chapters 6–9

Chapter	Section / Subsection	Page
Chapter 6	Smart Transportation Systems	75
6.1	Intelligent Transportation System (ITS) with AI	76
6.2	Connected and Autonomous Vehicles (CAVs)	79
6.3	Traffic Flow Optimization using Machine Learning (ML)	81
6.4	V2X Communication Protocols	84
6.5	Equity in Smart Mobility	86
Chapter 7	Sustainable Pavements and Materials	90
7.1	Recycled Aggregates and Self-Healing Asphalt	91
7.2	Life Cycle Assessment (LCA) of Pavements	93
7.3	Bio-Based Binders and Low-Carbon Mixes	95
7.4	Performance Monitoring with Embedded Sensors	98
7.5	Resilient Design for Extreme Weather	100
Chapter 8	High-Speed Rail and Hyperloop Technologies	103
8.1	Maglev and Vacuum Tube Innovations	104
8.2	Aerodynamic and Seismic-Resistant Designs	106
8.3	Energy-Efficient Propulsion Systems	109
8.4	Integration with Urban Transit Networks	112
8.5	Global Case Studies (e.g., India's Bullet Train)	114
Chapter 9	Urban Mobility and Micromobility Integration	118
9.1	E-Scooters, Bike-Sharing, and Last-Mile Solutions	119
9.2	AI for Demand Forecasting	121
9.3	Multi-Modal Transport Hubs	124
9.4	Inclusive Design for Vulnerable Users	126
9.5	Carbon Footprint Reduction Strategies	129

PART 3 — WATER RESOURCES AND ENVIRONMENTAL ENGINEERING

Chapters 10–14

Chapter	Section / Subsection	Page
Chapter 10	Smart Water Management Systems	134
10.1	IoT for Leak Detection and Water Quality	135
10.2	AI-Optimized Distribution Networks	137
10.3	Wastewater Reuse and Circular Economy	139
10.4	Climate-Adaptive Reservoirs	141
10.5	Remote Sensing for Water Scarcity	144
Chapter 11	Advanced Wastewater Treatment Technologies	148
11.1	Membrane Bioreactors and Nanofiltration	149
11.2	AI-Controlled Treatment Processes	152
11.3	Resource Recovery (e.g., Energy from Sludge)	154
11.4	Zero-Liquid Discharge (ZLD) Systems	156
11.5	Environmental Impact Assessments (EIA)	158
Chapter 12	Flood Risk Management with Geospatial Tech	162
12.1	GIS and Remote Sensing for Flood Modeling	163
12.2	Machine Learning for Real-Time Flood Forecasting	165
12.3	Nature-Based Solutions (e.g., Sponge Cities)	167

12.4	Resilient Infrastructure Design	169
12.5	Policy and Institutional Frameworks for Flood Risk Management	172
Chapter 13	Emerging Technologies in Coastal and Hydraulic Engineering	176
13.1	Sea Wall Alternatives: Living Breakwaters	177
13.2	Wave Energy Harvesters Integrated with Protection	179
13.3	Numerical Modeling with CFD and AI	181
13.4	Erosion Control using Geosynthetics	183
13.5	Adaptation to Sea-Level Rise	185
Chapter 14	Groundwater Sustainability and Remediation	189
14.1	AI for Aquifer Mapping and Depletion Prediction	190
14.2	Managed Aquifer Recharge (MAR) Techniques	192
14.3	Nanotechnology for Contaminant Removal	194
14.4	Transboundary Water Governance	197
14.5	Life Cycle Assessment (LCA) of Groundwater Extraction Methods	199

PART 4 — GEOSPATIAL TECHNOLOGIES AND REMOTE SENSING

Chapters 15–18

Chapter	Section / Subsection	Page
Chapter 15	GIS and BIM Integration for Infrastructure	204
15.1	4D/5D GIS for Project Lifecycle Management	205
15.2	Spatial Data Analytics for Urban Planning	207
15.3	Drone-Based LiDAR Surveys	209
15.4	Open-Source GIS Tools	211
15.5	Accuracy Validation Protocols	214
Chapter 16	Satellite Remote Sensing in Civil Applications	218
16.1	Hyperspectral Imaging for Material Analysis	219
16.2	SAR for Deformation Monitoring	221
16.3	AI-Enhanced Change Detection	223
16.4	Applications in Disaster Mapping	225
16.5	Data Fusion with Ground Sensors	228
Chapter 17	UAVs and Photogrammetry	231
17.1	Multi-Rotor Drones for 3D Mapping	232
17.2	AI for Automated Feature Extraction	234
17.3	Thermal Imaging for Defect Detection	236
17.4	Regulatory and Ethical Issues	238
17.5	Cost-Benefit Analysis of UAVs and Photogrammetry	240
Chapter 18	Augmented Reality in Geospatial Engineering	244
18.1	AR for On-Site Visualization and Training	245
18.2	VR Simulations for Stakeholder Engagement	247
18.3	Integration with Mobile GIS	249
18.4	Field Applications in Surveying	251
18.5	Future: Metaverse for Civil Projects	254

PART 5 — SUSTAINABLE MATERIALS AND CLIMATE RESILIENCE

Chapters 19–24

Chapter	Section / Subsection	Page
Chapter 19	High-Performance Sustainable Concretes	258
19.1	Geopolymer and UHPC with Industrial Byproducts	259
19.2	Self-Sensing and Self-Healing Concretes	260
19.3	Life Cycle Assessment (LCA) and Embodied Carbon Reduction	263
19.4	Machine Learning (ML) for Mix Design Optimization	265
19.5	Case Studies from India	267
Chapter 20	Green Building Materials and Certification	271
20.1	Bio-Based Composites and Timber Hybrids	272
20.2	Cradle-to-Cradle Design Principles	274
20.3	LEED/GRIHA Integration with Technology	276
20.4	Recyclable Facades and Insulation	278
20.5	Supply Chain Sustainability	280
Chapter 21	Climate Change Impacts on Infrastructure	284
21.1	Thermal Expansion and Material Degradation	285
21.2	Extreme Weather Vulnerability Assessments	287
21.3	Adaptation Roadmaps using Scenario Modelling	289
21.4	Carbon Capture and Its Role in Reducing Infrastructure-Related Climate Impacts	292
21.5	Global vs. Regional Perspectives (India Focus)	294
Chapter 22	Climate Mitigation Strategies	298
22.1	Net-Zero Buildings and Districts	299
22.2	Renewable Integration in Civil Projects	301
22.3	AI for Energy Demand Prediction	303
22.4	Urban Heat Island (UHI) Mitigation	305
22.5	Policy and Financing Mechanisms	307
Chapter 23	Life Cycle Assessment in Civil Engineering	310
23.1	Advanced LCA Tools and Software	311
23.2	Uncertainty Analysis with Monte Carlo	313
23.3	Circular Economy Metrics	315
23.4	Comparative Studies: Traditional vs. Emerging Materials	317
23.5	Reporting Standards (ISO 14040)	319
Chapter 24	Bio-Inspired and Resilient Materials	323
24.1	Biomimicry in Structural Design	324
24.2	Shape-Memory Alloys for Earthquake Resistance	326
24.3	Nano-Engineered Composites	328
24.4	Durability under Climate Stressors	330
24.5	Lab-to-Field Translation	333

PART 6 — DISASTER MANAGEMENT AND ADVANCED STRUCTURES

Chapters 25–30

Chapter	Section / Subsection	Page
Chapter 25	Seismic Resilient Structures and Earthquake Engineering	337
25.1	Base Isolation and Dampers 2.0	338
25.2	AI for Seismic Wave Prediction	340
25.3	Performance-Based Design	342
25.4	Retrofitting Heritage Structures	344

25.5	Post-Earthquake Rapid Assessment with Drones	347
Chapter 26	Multi-Hazard Resilient Structures	350
26.1	Wind, Fire and Flood-Resistant Features	351
26.2	Probabilistic Risk Modeling	353
26.3	Modular and Prefab Systems	355
26.4	Community-Scale Resilience	358
26.5	Insurance and Economic Modelling	360
Chapter 27	Disaster Management with AI and Big Data	364
27.1	Early Warning Systems using Machine Learning	365
27.2	Real-Time Damage Assessment via Satellite	367
27.3	Crowdsourced Data Integration	369
27.4	Simulation for Evacuation Planning	371
27.5	Lessons from Recent Events (e.g., 2025 India Floods)	373
Chapter 28	Tsunami and Coastal Disaster Mitigation	376
28.1	Early Detection with Buoy Networks	377
28.2	Vertical Evacuation Structures	379
28.3	Mangrove-Based Natural Barriers	380
28.4	Tsunami Modeling with GPU Acceleration	382
28.5	International Protocols	384
Chapter 29	Emerging Frontiers: Space and Extreme Environments	387
29.1	Lunar/Martian Habitat Design Principles	388
29.2	Infrastructure in Arctic and Antarctic Environments	391
29.3	Additive Manufacturing in Harsh Conditions	392
29.4	Lessons for Earth-Based Resilience	395
29.5	Interdisciplinary Collaborations	397
Chapter 30	Future Directions and Ethical Imperatives	401
30.1	Convergence of AI, Quantum Computing, and Civil Engineering	402
30.2	Global Challenges: SDGs and Equity	404
30.3	Workforce Upskilling for Tech Frontiers	406
30.4	Ethical AI and Sustainable Innovation	408
30.5	Roadmap for India's Civil Engineering 2040	410

AUTHOR INDEX

Author	Page(s)
Alla Rajendra	32
Arunima Mahapatra, Dr.	176, 204
Ashok Kumar, S.	218
Ayyagari Lakshmi Prasanna	60, 284
Balla Satyanarayana, Dr.	258
Bandaru Venkata Shivakumar, Dr.	162, 189
Bhagya Lakshmi, Ch.	376
Chanapathi Tirupathi, Dr.	387
Divya, Kondeti	75
G. Radha Krishna, Dr.	271, 323
Hemasundar Balina	244
Killi Srinivas	231
Krosuru Kanaka Lakshmi	364
Kusuma Sundara Kumar, Dr.	3, 17
M. Lalitha Pallavi	90
M. Amareswari Reddy, Dr.	46
Nallagarla Gopinath	310
P. Parthiban	284
P. Sundara Kumar, Dr.	298
Pushadapu Vamsi Krishna	401
S. Ashok Kumar	218
T. Ganga Sai Kumar	103, 118
T. Mahesh Kumar	350
V. Rama Krishna, Dr.	148
Ch. Veerottam Kumar	103, 118
Dr. Anduri Srinivasulu	337
Dr. K. Saroja Rani	134