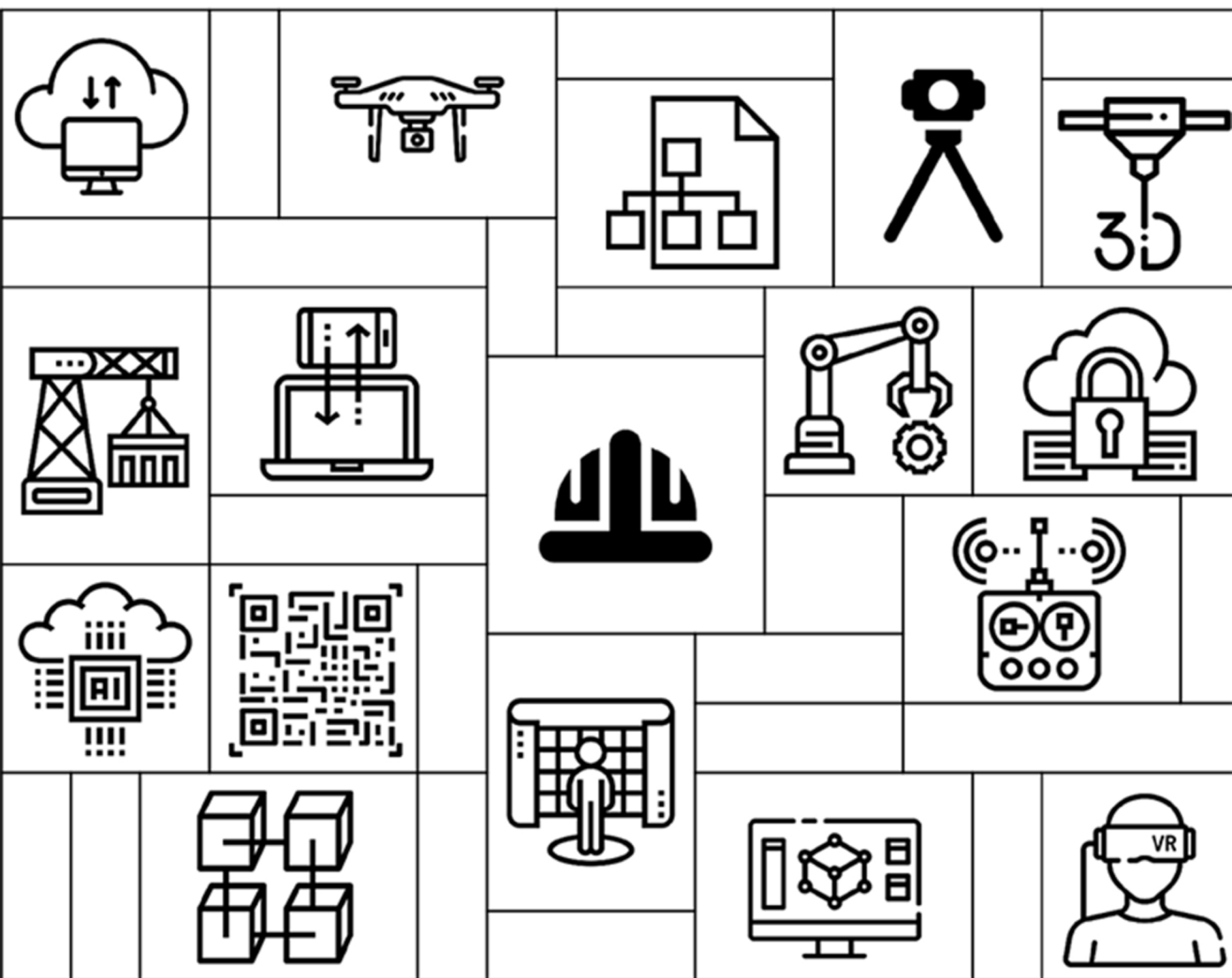


Edited by Anil Sawhney,
Mike Riley and Javier Irizarry



Construction 4.0

An Innovation Platform for
the Built Environment



CONSTRUCTION 4.0

Modelled on the concept of Industry 4.0, the idea of Construction 4.0 is based on a confluence of trends and technologies that promise to reshape the way built environment assets are designed, constructed, and operated.

With the pervasive use of Building Information Modelling (BIM), lean principles, digital technologies, and offsite construction, the industry is at the cusp of this transformation. The critical challenge is the fragmented state of teaching, research, and professional practice in the built environment sector. This handbook aims to overcome this fragmentation by describing Construction 4.0 in the context of its current state, emerging trends and technologies, and the people and process issues that surround the coming transformation.

Construction 4.0 is a framework that is a confluence and convergence of the following broad themes discussed in this book:

- Industrial production (prefabrication, 3D printing and assembly, offsite manufacture)
- Cyber-physical systems (actuators, sensors, IoT, robots, cobots, drones)
- Digital and computing technologies (BIM, video and laser scanning, AI and cloud computing, big data and data analytics, reality capture, Blockchain, simulation, augmented reality, data standards and interoperability, and vertical and horizontal integration)

The aim of this handbook is to describe the Construction 4.0 framework and consequently highlight the resultant processes and practices that allow us to plan, design, deliver, and operate built environment assets more effectively and efficiently by focusing on the physical-to-digital transformation and then digital-to-physical transformation. This book is essential reading for all built environment and AEC stakeholders who need to get to grips with the technological transformations currently shaping their industry, research, and teaching.

Anil Sawhney is Director of the Infrastructure Sector for the Royal Institution of Chartered Surveyors and Visiting Professor of Project Management at Liverpool John Moores University. Anil is a Fellow of the Royal Institution of Chartered Surveyors and a Fellow of the Higher Education Academy. He has over 20 years' academic and industry experience internationally and has over 200 academic publications. Anil is the co-editor of the *Construction*

Innovation journal and serves on the International Editorial Board of the *Journal of Civil Engineering and Environmental Systems* and *Journal of Information Technology in Construction*. He has consulted for numerous organizations including the World Bank.

Mike Riley is Pro Vice Chancellor, Engineering and Technology and Professor of Building Surveying at Liverpool John Moores University. He is Visiting Professor at the University of Malaya and at RICS School of Built Environment, Delhi, with over 25 years' academic and industrial experience, and is joint author of numerous textbooks on Construction Technology and Sustainability as well as numerous academic papers. Mike obtained his first degree from Salford University, followed by a Master of Science from Heriot-Watt University and PhD from Liverpool John Moores University. He is a Fellow of the Royal Institution of Chartered Surveyors and Fellow of the Royal Institution of Surveyors Malaysia, Senior Fellow of the Higher Education Academy, and Chartered Environmentalist.

Javier Irizarry P.E., PhD is an Associate Professor in the School of Building Construction at the Georgia Institute of Technology. A pioneer of research on Unmanned Aerial System applications in the built environment, Javier is Director of the CONECTech Lab, which aims to establish the framework for developing next generation technology enhanced solutions for construction problems by incorporating the cognitive processes of the human component of construction operations. He has over 20 years of academic and industry experience and has authored over 100 academic articles. Javier's research focuses on construction information technologies including virtual and augmented reality, HCI issues in mobile applications for AEC information access, reality capture technology, Situation Awareness driven information system design, and Unmanned Aerial Systems application in the AEC domain. He holds a B.S. in Civil Engineering from the University of Puerto Rico, Mayagüez, a Masters in Engineering Management from the Polytechnic University of Puerto Rico, and a PhD in Civil Engineering from Purdue University. Javier is also a registered Professional Engineer as well as a FAA Licensed Drone Pilot.

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Co-Editors: Anil Sawhney, Mike Riley, and Javier Irizarry

FOREWORD

With increasing pressures on the built environment sector to provide the infrastructures and homes that are the key economic enablers to city growth, and as people globally are entering our cities at the rate of 3 million people a week, the heat is on construction to design, build, modify, and operate these assets to our changing needs and that of the communities whose evolving demands occupy the space provided.

Construction has continued to innovate, but not at the rate or expectations demanded of it. Therefore, we need to consider the opportunity to radically transform our methods and approaches to construction that enable it to be more efficient and effective in adopting the technologies from other sectors and services to enable it to reshape the way our built environment assets emerge now and for the future. The time is now, because the demand is there for rapid supply, balanced against the costs of the intensification for the supply of skills and resources, coupled with the desire for improved and innovative design.

You will see from reading this book that the key to unlocking the potential and pace of a more rapid “right first time” mentality is putting the physical-to-digital and digital-to-physical transformation at the heart of the delivery process.

The book is timely, as we are at the tipping point of transformative change for construction with already establishing digital practices of Building Information Modelling (BIM), Modern Methods of Construction (MMC) as well as VR/AR, AI, 3D, and IoT as rapidly evolving technologies to expedite design, deliver, and operate are all coming to the fore, backed by the essential data to feed and inform.

There is no doubt that this is an exciting time for the built environment sector and for the transformation of the construction processes that deliver it. But there is a level of pace of change that is needed now to deliver, transform, and metamorphosize the sector and this book captures well the elements necessary to deliver that change.

With this in mind, this book provides the key to unlocking the potential of the built environment sector at a time where the sector needs unlocking to gear it to transform the delivery of

Foreword

our infrastructure, homes, and cities. The key to unlocking the change needed sits within these pages, with digital innovation at the heart, and the power of you to drive the transformation that will re-establish construction as a key economic enabler for growth.

*Amanda G Clack MSc BSc PPRICS FRICS FICE FAPM FRSA CCMI FIC CMC
Executive Director and Head of Strategic Advisory
CBRE Ltd
RICS Past President*

The 2017 McKinsey Global Institute’s publication “Reinventing Construction: A Route to Higher Productivity” showed that the greatest impact on productivity improvement in the construction industry is through the advancement and application of digital and technology solutions. Over the last few years there has been a significant investment by private equity funds in construction industry related digital and technology start-ups and tech companies which has fuelled tremendous growth and innovation in this part of the industry. In “Construction 4.0” the authors pull together all of the relevant elements of these essential solutions and practices and show how they will enable more effective and efficient planning, design, delivery, and operation of physical assets (i.e., capital projects) through a digital transformation. The industry has already made significant advancements over the past 2–3 years but much more is required among all members of the supply chain involved with capital projects. This publication presents a comprehensive review of these emerging solutions and systems and makes the connection of technology with people and processes. Companies and organizations that do not have a “digital strategy” will be able to understand better through “Construction 4.0” how each element complements one other and how each is able to improve performance across all phases of a capital project. While many companies in the industry have utilized BIM or VR/AR in one form or another, other advancements such as data analytics, Internet of Things (IoT) and use of artificial intelligence are shown to be significant disruptors to the traditional model of project development, design, and delivery with significant benefits to be realized by project owners, designers, and contractors. Construction performance and productivity has stalled tremendously since World War II compared to every other major industry and in order to be ready for the Fourth Industrial Revolution, industry players will need to change and “Construction 4.0” is an excellent guidebook to such transformation.

In addition to helping professionals working in the industry already, this handbook will be a useful resource for several folks in academia ... undergraduate and graduate students, researchers and scholars with a keen interest in the ongoing transformation of the construction industry using the Industry 4.0 framework.

Tim McManus, Adjunct Professor, Columbia University

CONTRIBUTORS

Ernest L. S. Abbott BSc (Special), MIMA, BA (Hons), MTh, PhD is a research fellow in the Department of Civil and Environmental Engineering, Faculty of Engineering at the National University of Singapore. He has worked in a variety of industries including machine makers, the retail oil industry, shipping – port automation, the finance industry and software development. His interests are eclectic to say the least. His recent research has included productivity improvements in off-shore rig construction, BIM to productivity in construction of public housing, Design for Safety using BIM, and Prefabricated Prefinished Volumetric Construction with RFID and BIM for intelligent logistic and process productivity.

Abiola A. Akanmu is an Assistant Professor in the Myers-Lawson School of Construction at Virginia Tech. She is Director of the Automated Systems Lab whose mission is to apply intelligence to the design, construction, and maintenance of building and civil infrastructure systems, and construction workforce education using information and communication technologies. Dr Akanmu's research interests involves tightly integrating visualization and sensing systems for improving progress monitoring, construction safety, facility management, and construction education so as to enhance predictability and control.

Chimay J. Anumba BSc (Hons), PhD, DSc, Dr hc, FEng, CEng, FICE, FStructE, FASCE is Professor and Dean of the College of Design, Construction and Planning at University of Florida. His research interests are collaborative design, construction engineering and informatics, intelligent systems, knowledge management, cyber-physical systems, and project management, with over 500 publications in these fields. He is Editor-in-Chief of the *Engineering, Construction and Architectural Management* journal and Co-Editor of the *Journal of Information Technology in Construction*.

Mehrdad Arashpour PhD, MASCE, MPMI, MRICS, MIEAust is an expert and leading researcher on automation and optimization of design, manufacturing, and assembling processes in offsite prefabrication. His research collaborations with Professor Wakefield on process integration and automation in construction have resulted in several publications in top tier journals and books. Dr Arashpour is one of the selected worldwide members of the Working

Commission on Offsite Construction (W121) and Infrastructure Task Group (TG91), established by the International Council for Building (CIB). He is the member of Editorial Boards for international journals including *Construction Innovation* and *Journal of Advances in Civil Engineering*.

Dayana Bastos Costa is Associate Professor from the Department of Structural and Construction Engineering at School of Engineering at Federal University of Bahia. She received her PhD in Civil Engineering and MSc in Civil Engineering both at Federal University of Rio Grande do Sul, Brazil. Dr Costa had opportunities to work as visiting scholar at Salford University, UK and Georgia Institute of Technology, USA. Dr Costa's research interest includes construction management and technology aiming the improvement of the industry performance. She works in business management and construction sites, involving aspects related to production, quality, safety, and sustainability, integrating with information technology and emergent technologies, such as Unmanned Aerial Systems and Building Information Modelling.

Weng-Fong Cheung has a PhD from Department of Civil Engineering of National Taipei University of Technology. His major study is about construction management and focuses on the categories of wireless sensor network (WSN), Building Information Modelling (BIM), digitalization in infrastructure management, construction safety management, and the relative integrated application in construction field. Cheung serves in the Department of Rapid Transit Systems (DORTS) of Taipei city government and acts as a specialist of the management and quality assurance of the construction project. He is also the supervisor and report signatory of the central civil laboratory of DORTS, which ensures the material quality of the metro system.

David Chua Kim Huat is a registered professional engineer in Singapore and Professor and Vice Dean at the National University of Singapore. He obtained his PhD from the University of California and has more than 35 years' research and industry experience. His research areas are lean construction, computer integrated and IT-based construction management, BIM, construction simulation, risk management, and construction safety. He has been Council Member of the Society of Project Managers and System Safety Society and a member of BCA's International Panel of Experts on BIM and Honorary Fellow of WSHi. He has served as editor for the *Journal of Construction Engineering and Management*, ASCE and other international journals and conferences.

Jorge Corker is senior researcher and Technical Director of the Granular Materials Characterization and Certification Unit lab at the Laboratory for Wear, Testing and Materials of Instituto Pedro Nunes (IPN), Portugal. He is taking his PhD in Civil Engineering at Brunel University London, and is responsible for the development of applied science research projects and specialized technical services in materials at IPN. He has participated in and coordinated several European FP7 and H2020 projects on development of advanced solutions and new insulation materials for construction. His research includes advanced materials for construction, nanomaterials, composites, and materials for energy efficiency and sustainability.

Ganesh Devkar is currently working as Associate Professor in the Faculty of Technology, CEPT University, Ahmedabad. He completed his PhD from Indian Institute of Technology Madras (IIT Madras), India, and his doctoral thesis focuses on identifying the competencies necessary for effective implementing Public Private Partnerships (PPPs) in infrastructure

service delivery and developing a framework that allows urban local bodies to assess their capability to successfully deliver projects through PPPs. His research interests are in the areas of lean construction, PPPs, and urban infrastructure development.

Mike Farragher graduated from Liverpool John Moores University in 1991 with a first class degree in Architecture. He is a Chartered Architect and member of the RIBA and has won government awards for Integrated Renewable Technology. He is a Fellow of the Higher Education Academy and has nearly 20 years of industry experience before moving into academia where he has taught at Henan University, China and in the UK. He has published on zero-carbon projects in the UK and is currently researching the development of sanitation systems in sub-Saharan Africa. He has been instrumental in the inception of and enabling works for a primary school in a rural location on the border of Uganda and South Sudan.

Xinghua Gao is an Assistant Professor with the Myers-Lawson School of Construction at Virginia Tech. He received his PhD degree in Building Construction and MSc in Computational Science and Engineering from Georgia Institute of Technology in 2019, MSc in Structural Engineering from Cardiff University, UK in 2012, and BEng in Civil Engineering from Central South University, China in 2010. Prior to pursuing his PhD, he worked as a structural/Building Information Modeling (BIM) engineer at the China Institute of Building Standard Design & Research. His research interests lie in BIM and Internet of things (IoT)-enabled smart built environments that encompass automated data collection, analysis, and visualization for more efficient and effective construction and facilities management.

Borja Garcia de Soto PhD, PE is an Assistant Professor of Civil and Urban Engineering at New York University Abu Dhabi (NYUAD) and holds an appointment as Global Network Assistant Professor in the Department of Civil and Urban Engineering at the Tandon School of Engineering at New York University (NYU). He is the director of the S.M.A.R.T. Construction Research Group at NYUAD and conducts research in the areas of automation and robotics in construction, cybersecurity in the AEC industry, artificial intelligence, lean construction, and BIM. Borja has extensive experience in the industry as a structural engineer, project manager, and construction consultant. He is a Professional Engineer (PE) with licenses in California and Florida and has international experience in multiple aspects of construction projects. Borja received his PhD from ETH Zurich in Switzerland. He also holds an MSc in Civil Engineering with a concentration in engineering and project management from the University of California at Berkeley, an MSc in Civil Engineering with a concentration in structural design from Florida International University (FIU), and a BSc in Civil Engineering (graduated cum laude) also from FIU.

David Jason Gerber received his Doctor of Design and Master of Design Studies from Harvard University Graduate School of Design. He also has an M.Arch from the Architectural Association DRL in London and BA in Architecture, University of California, Berkeley. He holds a joint appointment at USC's Viterbi School of Engineering and USC School of Architecture as Associate Professor of Civil and Environmental Engineering Practice and of Architecture and is Director for the Civil Engineering Building Science undergraduate programme. He has extensive international, professional experience with practices including Zaha Hadid Architects in London, Gehry Technologies in Los Angeles, Moshe Safdie Architects in Massachusetts, The Steinberg Group Architects in California, and for Arup as Global Research Manager.

Seyed Hamidreza Ghaffar BEng (Hons), PhD, CEng, MICE is the leader of Additive Manufacturing Technology in Construction (AMTC) research group in the Department of Civil and Environmental Engineering – Brunel University London. The main area of his research is on valorising construction and demolition waste using materials science and innovative technologies for achieving circular construction. The AMTC research group focuses on the recovery of resources from waste with industrially feasible approaches towards eco-innovative manufacturing of construction products which is an important element of the transition to a low-carbon economy.

Masoud Gheisari is an Assistant Professor in the Rinker School of Construction Management at the University of Florida where he is leading Human-Centered Technology in Construction (HCTC) research group. He received his PhD in Building Construction from Georgia Tech and considers himself an educator and a researcher focusing on theoretical and experimental investigation of human-computer/robot systems in construction. Dr Gheisari's research interests are in the areas of human-computer/robot interaction, Unmanned Aerial Systems/Vehicles (UAS/UAVs), real/virtual humans in mixed reality environments, and human-technology interaction in educational settings. He also teaches various courses in the area of Building Information Modelling and technology applications in construction.

Mani Golparvar-Fard is Associate Professor of Civil Engineering, Computer Science, and Technology Entrepreneurship at the University of Illinois, Urbana-Champaign (UIUC). He received his PhD degree in Civil Engineering and MS degree in Computer Science from UIUC and MASc in Civil Engineering from University of British Columbia. He received the 2018 ASCE Walter L. Huber award for Innovation in Civil Engineering, the 2017 ENR National Top 20 under 40, 2016 ASCE Dan H. Halpin Award for Scholarship in Construction, the 2013 ASCE James R. Croes Medal for innovation in Civil Engineering, and numerous conference paper awards. He is co-founder and COO of Reconstruct Inc, offering visual data analytics to construction projects.

Konrad Graser is researcher at the Chair of Innovative and Industrial Construction at ETH Zurich. He was the project manager and lead architect of the DFAB HOUSE, a full-scale architectural demonstrator of interdisciplinary research in digital fabrication technologies at the Swiss National Center for Competence in Research Digital Fabrication. He was Project Manager Facade Engineering at Werner Sobek Stuttgart, responsible for digital design and engineering of complex building envelopes. Konrad has been a Teaching Assistant at Yale School of Architecture, Adjunct Professor at California College of the Arts, and a technical advisor for at the Institute for Lightweight Structures (ILEK) at the University of Stuttgart.

Md. Aslam Hossain is an Assistant Professor at the Department of Civil and Environmental Engineering, Nazarbayev University. He obtained his PhD from the National University of Singapore (NUS) and graduated with BSc in Civil Engineering from Bangladesh University of Engineering and Technology. Prior his current appointment, Dr Hossain worked as a post-doctoral research fellow at NUS, Assistant Professor at Presidency University and the Islamic University of Technology, Dhaka and senior lecturer at University Malaysia Pahang. His research interests include Design for Safety (DfS), BIM, Construction 4.0, productivity improvement, concurrent engineering, and lean construction. He has published his research findings in premium journals and international conferences.

Aseel Hussien is Programme Leader of Building Surveying and Facilities Management in the Department of the Built Environment (BUE) at Liverpool John Moores University (LJMU). Hussien holds a BSc Degree in Architecture Engineering, and a MSc in Computing Information Systems with Speciality in Augmented Reality. She completed her PhD from the Department of the Built Environment at LJMU in 2017, in which she developed a novel integration of Augmented Reality (AR) technologies with Agile project management philosophy to enhance collaboration and decision-making within the construction industry. She has published many research papers in many peer reviewed international conferences and high impact journals.

Vineet R. Kamat PhD is a Professor and the John L. Tishman Faculty Scholar in the Department of Civil and Environmental Engineering at the University of Michigan. He directs the Laboratory for Interactive Visualization in Engineering and co-directs the Construction Engineering Laboratory. Dr Kamat's research is primarily focused on Virtual and Augmented Reality Visualization, Simulation, Mobile Computing, Robotics, and their applications in construction.

Keith Kaseman is Assistant Professor at the Georgia Institute of Technology School of Architecture, and coordinates the Master of Science in Architecture – Advanced Production, leads design and research studios and directs the interdisciplinary Spatial Futures Lab. His research focuses on AR, VR, MR, UAS, robotics, and other digital fabrication practices in multisystem design-production workflows and experimental spatial systems. Keith has held simultaneous academic posts at the University of Pennsylvania PennDesign, Columbia University GSAPP, and University of Tennessee, Knoxville. He is a partner of KBAS, a design practice launched in 2002 with Julie Beckman and has since led the firm through a diverse array of work utilizing customized design and advanced digital fabrication protocols.

Atul Khanzode leads DPR Construction's Technology and Innovation Group, responsible for the Virtual Design and Construction (VDC), Operations and Preconstruction Technologies, strategic technology initiatives, Innovation, Research & Development and consulting. He is a Board Member at WND Ventures, responsible for managing strategic investments and providing mentorship and operational guidance to leadership teams of the portfolio companies. Atul has a PhD in Construction Engineering and Management, focused on Integrated Practice, VDC, and Lean Construction, from Stanford University and a Master's Degree in Civil and Environmental Engineering from Duke University, Durham NC.

Eyuphan Koc is a PhD student with Dr Lucio Soibelman at University of Southern California Sonny Astani Department of Civil and Environmental Engineering. He obtained his Bachelor's degrees at Bogazici University, Istanbul, in Civil Engineering with minor in Industrial Engineering. His research, funded by Caltrans, focuses on smart cities with functionalities drawn from smart and resilient infrastructures. His current focus is designing multidisciplinary frameworks investigating resilience in transportation systems to leverage data and modelling from multiple fields including earthquake engineering, transportation systems analysis, and disaster economics. He previously worked for a design and engineering consultancy, a large real estate developer and a heavy civil contractor.

Olivier Lépinoy is part of Autodesk Business Development team for the AEC industry. He has led and contributed to wide-ranging projects across architecture, landscape, urban design, real estate, land development, management consulting, digital and new technologies. At Accenture,

Olivier was part of the team in charge of French general contractors, and was in charge of strategic initiatives in engineering and construction worldwide. At IBM, he was global leader for Engineering and Construction, taking part in multiple strategic initiatives around digital reinvention worldwide. Olivier holds Master's degrees in Civil Engineering (Ecole Spéciale des Travaux Publics, Paris) and Earthquake Engineering (UCLA, USA) and is a licensed architect and an urban designer (Ecole d'Architecture de Versailles).

Jacob J. Lin is a PhD candidate in the Department of Civil and Environmental Engineering at the University of Illinois at Urbana-Champaign (UIUC). His research focuses on developing and validating computer vision and machine learning algorithms with visual data and Building Information Modelling (BIM) for construction project controls. He has developed a production management system that integrates and visualizes 4D BIM with reality models and enables proactive management of schedule delays. He has awards and recognitions from the World Economic Forum, MIT Tech Review, and the 2015 American Society of Civil Engineers International Workshop on Computing in Civil Engineering for his work on visualizing big visual data for automated UAV-driven construction progress monitoring.

Yu-Cheng Lin is a Professor of Construction Engineering and Management at the Department of Civil Engineering of the National Taipei University of Technology. He received a MS degree in the construction management programme of civil engineering from the Polytechnic University, New York, USA (1997) and a PhD from the National Taiwan University (2004). His major research interests are the application of project management and information management in construction projects. His current research interests include construction knowledge management, Building Information Modelling, web-based project management system, IT technology application, IoT and sensors, and construction automation related topics.

Abel Maciel is Architect and Senior Research Associate at University College London, focusing on Computational Design, Artificial Intelligence and Distributed Ledger Technology (Blockchain). He is Director of Design Computation Ltd. and has worked, internationally, with some of the world's leading practices, including Foster + Partners, Zaha Hadid Architects, Herzog & de Meuron, Heatherwick Studio, Arup and BuroHappold. He has advised on numerous projects including Google Campus Mountain View, Google Headquarters London, Apple Park in Cupertino, and Vessel Hudson Yards, New York City. He is a Founding Director and Academic Lead of the Construction Blockchain Consortium (CBC) and Faculty Member of the UCL Centre of Blockchain Technologies.

Bharadwaj R. K. Mantha received his Masters and PhD in construction engineering and management at the University of Michigan. He is currently working as a Post-Doctoral Research Associate in the S.M.A.R.T. Construction Research Group at the New York University Abu Dhabi. Dr Mantha's research focuses on developing technological solutions to monitor, control, and sustainably operate buildings and civil infrastructure systems. To achieve this, he explores interdisciplinary approaches using tools, methods, and frameworks from robotics, cybersecurity, data analytics, simulation, and modelling.

Carol C. Menassa PhD is an Associate Professor and the John L. Tishman Faculty Scholar in the Department of Civil and Environmental Engineering at the University of Michigan. She

directs the Sustainable and Intelligent Civil Infrastructure Systems Laboratory. Dr Menassa's research focuses on understanding human-robot collaborative processes in the building sciences, modelling the impact of occupants on energy use in buildings, and developing decision frameworks to sustainably retrofit existing buildings.

Achim Menges is a registered architect in Frankfurt and professor at Stuttgart University, where he is the Founding Director of the Institute for Computational Design and Construction (ICD) and the Director of the Cluster of Excellence Integrative Computational Design and Construction for Architecture (IntCDC). In addition, he has been Visiting Professor in Architecture at Harvard University's Graduate School of Design and held multiple other visiting professorships in Europe and the United States. He graduated with honours from the AA School of Architecture, where he subsequently taught as Studio Master and Unit Master in the AA Graduate School and the AA Diploma School.

Paul Mullett BEng (Hons), CEng, FICE, FCI Arb, PSE is a Chartered Fellow of the Institution of Civil Engineers, Fellow of the Chartered Institute of Arbitrators and registered Professional Simulation Engineer with NAFEMS. An accomplished professional consultant with over 25 years' experience in a variety of technical and managerial roles, Paul has led or executed services including high-level engineering consultancy, specialist engineering, forensic engineering studies, and expert advice. He is Group Engineering and Technology Director for Robert Bird Group pursuing engineering excellence through the strategic application of transformative technologies, identification and adoption of value-adding innovation, and development of staff skills necessary for the future of engineering across the global business.

Ibrahim S. Odeh is the Founding Director of the Global Leaders in Construction Management program at Columbia University. His work seamlessly merges the worlds of industry and academia, spans the global construction market, and provides leading construction firms with unique market insights and growth strategies. Professor Odeh worked as an advisory committee member at the World Economic Forum on the Future of Construction initiative and as an advisory board member at Financial Times on a similar initiative. In the fall of 2016, Professor Odeh introduced a project focused on providing Massive Open Online Courses to educate global learners about Construction Management under the Coursera platform. In the program's first three years, the number of learners registered for his courses exceeded 80,000 from 195 countries, with an additional 400 new learners joining every week! Professor Odeh has won several awards and other recognition such as Columbia University's Presidential Award for Outstanding Teaching; Top 20 Under 40 by Engineering News Records; and Top 40 Under 40 by Consulting-Specifying Engineer. Professor Odeh received his PhD in Civil Engineering from the University of Illinois at Urbana-Champaign and he also holds an MBA.

Daniel Paes is a PhD candidate in Building Construction with a minor concentration in Cognitive Psychology and a research assistant in the CONECTech Lab, Georgia Institute of Technology. His research is at the intersection of basic and applied science and is centred on visual perception, presence, and learning in Immersive Virtual Reality (IVR) environments in architectural design, construction, and workforce training applications, identifying opportunities for revolutions in both usability metrics and virtual experiences in the field. His research interests also include Building Information Modelling (BIM), Augmented Reality platforms (AR), Unmanned Aerial Systems (UAS), Human-Computer Interaction (HCI) methods, Cognitive Psychology, and Ontologies.

Evangelos Pantazis is research assistant and PhD candidate at University of Southern California, Department of Civil and Environmental Engineering, Viterbi School of Engineering. He focuses on Multi Agent Design Systems and integration of generative design, numerical analysis and digital fabrication. He holds a Master's of Advanced studies, Computer Aided Architectural Design from ETH, Zurich and Diploma in Architecture from Aristotle's University of Thessaloniki and a degree in jewellery design and manufacturing from MOKUME jewellery design school. He is a registered architect in Greece and gained international experience including Graft Architects, Berlin; Studio Pei Zhu, Beijing and BuroHappold Engineering, Los Angeles. He co-founded Topotheque, engaging computational design with tangent disciplines, including architecture, furniture, and product design.

Erika A. Pärn is a Research Associate at the Institute for Manufacturing (IfM) and Centre for Digital Built Britain (CDBB), Cambridge University. Previously whilst working in industry, she led multiple research projects for the EU commission such as two H2020 initiatives on BIM, digitalisation of the renovation sector and sustainable green construction materials. Her PhD has evaluated the use of BIM and cloud-based technologies to streamline facilities management into the as-built BIM. During her time in academia as lecturer at Birmingham City University, she taught Architectural Technology. Her research focus is upon the multidisciplinary area of “digital built environment and smart city developments” but remains actively involved in broader “construction and civil engineering management” topics such as BIM and FM integration, cybersecurity, and networked and sensor-based BIM.

Pieter Pauwels is an Associate Professor at the Eindhoven University of Technology, the Department of the Built Environment. He previously worked at the Department of Architecture and Urban Planning at Ghent University (2008–2019). His work and interests are in information system support for the building life-cycle (architectural design, construction, building operation). With expertise in computer science and software development, he is involved in a number of industry-oriented research projects on topics affiliated to AI in construction, design thinking, Building Information Modelling (BIM), Linked Building Data (LBD), Linked Data in Architecture and Construction (LDAC), and Semantic Web technologies. He has initiated the BuildingSMART LDWG and the W3C LBD Community Group. He implemented and published an IFC-to-RDF conversion service and EXPRESS-to-OWL conversion service, to retrieve complex RDF data for building models. Furthermore, he is highly active as a teacher, leading courses on Fundamentals of BIM, Parametric Design, Building Informatics, and Linked Data in Architecture and Construction.

Pardis Pishdad-Bozorgi is Assistant Professor in the School of Building Construction at Georgia Tech. She focuses on developing innovative integrated Architecture/Engineering/Construction/Facility Management solutions for smart built environments, developing cutting-edge mechanisms that address process fragmentations in delivering and operating the built environment. Her publications are on emerging fields, such as Building Information Modelling, Internet of Things, Integrated Project Delivery, Flash Tracking, Trust-Building, and Lean Construction with around 40 articles in key journals and conferences. She holds a PhD degree in Environmental Design and Planning (Virginia Tech), Master's degrees in Civil Engineering (Virginia Tech), Project Management (Harvard), and Architecture (University of Tehran). She has received multiple awards, including Construction Management Association of America National Educator of the Year.

Dennis R. Shelden is Associate Professor of Architecture and Director of the Digital Building Laboratory at Georgia Tech. He is expert in applications of digital technology to building design, construction, and operations. His experience spans education and research, technology development, and professional practice across architecture, engineering, and computing disciplines. He directs Georgia Tech's PhD in Architecture and MS in Architecture: Building Information and Systems programmes. Prior to joining Georgia Tech, he led the development of Frank Gehry's digital practice as Director of R&D and Director of Computing and later as Co-founder and Chief Technology Officer of technology spin-off Gehry Technologies. He was Associate Professor of Practice in Computation and Design at MIT and has taught at UCLA and SCIARC.

Mirosław J. Skibniewski PhD is Professor of Civil Engineering and Construction Project Management at the University of Maryland and serves as Editor-in-Chief of *Automation in Construction*. He heads the e-Construction Group, focused on innovative applications of construction information and automation technologies, collaborating with leading American, Asian, and European academic and industry partners in construction automation and robotics R&D. He was Professor of Civil Engineering, Construction Engineering and Management at Purdue University, where he collaborated with major Japanese engineering and construction firms in construction robotics implementation.

Lucio Soibelman was Assistant Professor at University of Illinois at Urbana-Champaign and Associate Professor and Professor to the Civil and Environmental Engineering Department at Carnegie Mellon University. He joined the University of Southern California as Chair of the Sonny Astani Department of Civil and Environmental Engineering and is editor of the *Journal of Computing in Civil Engineering*. He is recipient of the FIATECH Outstanding Researcher Celebration of Engineering & Technology Innovation Award, and ASCE Construction Institute Construction Management award. He was appointed as Viterbi Dean Professor at USC and Distinguished 1,000 talent Professor at Tsinghua University. He focuses on advanced data acquisition, visualization, and mining for construction and operations of advanced infrastructure.

Ken Stowe P.E. is construction technology advisor, development strategist, and project systems coach at Autodesk, Inc. With 25 years of experience in construction management and project control on US and international projects as large as \$1.4 billion; 15 years in BIM, cloud software, ROI analysis, and big analytics experience in 22 countries, and contributions to four books, Stowe works with a team at Autodesk responsible for construction business development and strategy initiatives worldwide. Together, they leverage project performance research and pursue the synergy of technologies and construction performance improvement for measurably better decisions, planning, construction execution and asset performance. Kenneth holds two degrees from Dartmouth College and Thayer School of Engineering and Professional Engineering certification.

Shu Tang is currently a PhD student in Design Computation in the School of Architecture at Georgia Tech. She is conducting research in Digital Building Laboratory. She previously worked for years as a BIM Engineer for several BIM consultancy companies. Prior to joining Georgia Tech, Shu taught and conducted research at the University of Nottingham Ningbo China.

Shu's current research is a systematic investigation of defining data interoperability requirements between smart building systems for the Internet of Things (IoT) and Building Information Modelling (BIM), trying to extend digital systems (the Internet and the Web) into the physical realm (the built environment, the transportation system, etc.).

Cristina T. Pérez is a doctoral student of Engineering at Federal University of Bahia (UFBA) – Brazil. She completed her undergraduate studies at the University of Cantabria, Spain in 2011. Cristina received her MSc in Environmental and Urban Engineering at Federal University of Bahia, Brazil, in 2015. Since 2012, Pérez works as a researcher at the Department of Structural and Construction Engineering at the School of Engineering at UFBA. Pérez had opportunities to work as visiting researcher at Georgia Institute of Technology – USA in 2018–2019 and at Federal University of Rio Grande do Sul (UFRGS) – Brazil in 2014. Her doctoral research, in 2018, was recognized in a Brazilian competition with the Academic Innovation Award. Pérez has worked as an Assistant Professor at undergraduate and graduate programs at SENAI CIMATEC School of Technology, Ruy Barbosa DeVry University and Estacio de Sá University, all of them in Salvador, Brazil.

Kalyan Vaidyanathan is co-founder CEO of Nadhi Information Technologies Pvt Ltd, incubated out of IIT Madras research park. He has nearly 20 years' experience in managing construction projects and enterprise software development. He has won many awards, including the 2015 Technologist Innovator award: Construction Industry Development Council, Government of India. He was named Entrepreneur of the Year 2014 by CII, Chennai. He has published widely on modern construction technology and lean construction both nationally and internationally. "Overview of IT Applications in the Construction Supply Chain" was his chapter in the *Construction Supply Chain Management Handbook*. He holds an MS from Cornell University, USA and a B Tech in Civil Engineering from IIT Madras, India.

Koshy Varghese is Professor at IIT Madras in Building Technology and Construction Management Division, Department of Civil Engineering. His research interest is in computer-integrated construction and he has published widely in this area. He is a member of the editorial board of the *Journal of Automation in Construction* and the *Journal of Information Technology in Construction* and the past-president of the International Association for Automation and Robotics in Construction (IAARC). Varghese has been a visiting faculty at the University of Texas and Arizona State University, USA. He completed his PhD from the University of Texas at Austin, USA and a B.E. in Civil Engineering from the College of Engineering Guindy, Chennai, India.

Lauren Vasey is Research Associate and Doctoral Candidate at the Institute for Computational Design and Construction, University of Stuttgart. Lauren focuses on adaptive robotic construction processes, with sensor feedback tightly coupled to backend computational processing. She previously researched at University of Michigan Taubman College FABLab and ETH-Zurich, Chair for Architecture and Digital Fabrication. Her work has been recognized in international competitions including Kuka Innovation Award, Fast Company Innovation By Design, and AEC Hackathons. She has lectured at venues including ACM Siggraph and Advances in Architectural Geometry (AAG), and collaborated with research partners including Autodesk and the European Space Agency. Lauren is a member of the Board of Directors of ACADIA, Chair of the scientific committee, and editor of *International Journal of Architectural Computing*.

Atif Waraich PhD is Head of Department of Computer Science at Liverpool John Moores University. He was previously Head of Division of Digital Media and Entertainment Technology at Manchester Metropolitan University and founder and Director of the Manchester Usability Laboratory. His research focuses on the use of technology to enhance learning, specifically, how game-like environments can be used to promote learning and motivate learners to engage in their studies. He researches the use of usability engineering in developing and accessing gameplay for computer games and has a growing interest in the application of usability and behaviour modification techniques (including gamification) to Augmented and Virtual Reality environments.

Ron Wakefield is Professor of Construction, Deputy Pro Vice-Chancellor; International and Dean of the School of Property, Construction and Project Management at RMIT, Australia. Ron researches and teaches process simulation and modelling, residential and commercial construction and use of information technology in construction management. Prior to joining RMIT, he was the William E. Jamerson Professor of Building Construction in the Department of Building Construction and Associate Director for Building Technology Research at the Center for Housing Research, Virginia Tech. Ron has over 25 years' experience as an international researcher, consultant, and engineer in building construction. He is Director of Launch Housing and JJR Consulting and co-opted member of the Victorian Building Practitioners Board.

Justin K. W. Yeoh is a Lecturer at the Department of Civil and Environmental Engineering, National University of Singapore. He graduated with a BEng (Civil Engineering), and subsequently obtained his PhD. His research interests lie in Applied Optimization for Construction and Facilities Management, Semantics in Building Information Models (BIM), Process Re-engineering and Machine Learning for Construction Metrology. Prior to his current appointment, Dr Yeoh worked as a post-doctoral research fellow at NUS and Carnegie Mellon University. He has also worked as a project management consultant and BIM consultant, identifying good site practices for construction.

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PART I

Introduction and overview of Construction 4.0, CPS, Digital Ecosystem, and innovation



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1

CONSTRUCTION 4.0

Introduction and overview

Anil Sawhney, Mike Riley, and Javier Irizarry

1.1 Aims

- Provide an overview of Industry 4.0 and the Fourth Industrial Revolution.
- Provide a comprehensive review of the current state of the construction sector.
- Describe the overall Construction 4.0 framework.
- Articulate the purpose of Construction 4.0.
- Describe the handbook, its three parts, and its various chapters.

1.2 Introduction to Construction 4.0

With the advent of the Fourth Industrial Revolution (4IR) and the resulting framework of *Industry 4.0 (I4.0)* (MacDougall, 2014), the built environment sector also has the opportunity to leapfrog to more efficient production, business models, and value chains. Such a transformation is possible through the convergence of existing and emerging technologies that form part of the Industry 4.0 paradigm (Oesterreich and Teuteberg, 2016). This transformative framework is called the *Construction 4.0* framework in this handbook. Modelled after the concept of Industry 4.0, the idea of Construction 4.0 is based on a confluence of trends and technologies (both digital and physical) that promise to reshape the way built environment assets are designed and constructed.

In 4IR, the fundamental driver is the use of cyber-physical systems. *Cyber-physical systems* (CPS) are enabling technologies that bring the virtual and physical worlds together to create a truly networked world in which intelligent objects communicate and interact with each other (Griffor et al., 2017). A conceptual model of the CPS is provided in Figure 1.1.

The Construction 4.0 framework uses CPS as a core driver and links it with the concept of Digital Ecosystem where ‘A digital ecosystem is an interdependent group of enterprises, people and/or things that share standardized digital platforms for a mutually beneficial purpose, such as commercial gain, innovation or common interest’ (Gartner, 2017). The idea of a Digital Ecosystem is shown in Figure 1.2.

Construction 4.0 combines CPS and Digital Ecosystem to create a new paradigm for the design and construction of our built environment assets as shown in Figure 1.3.

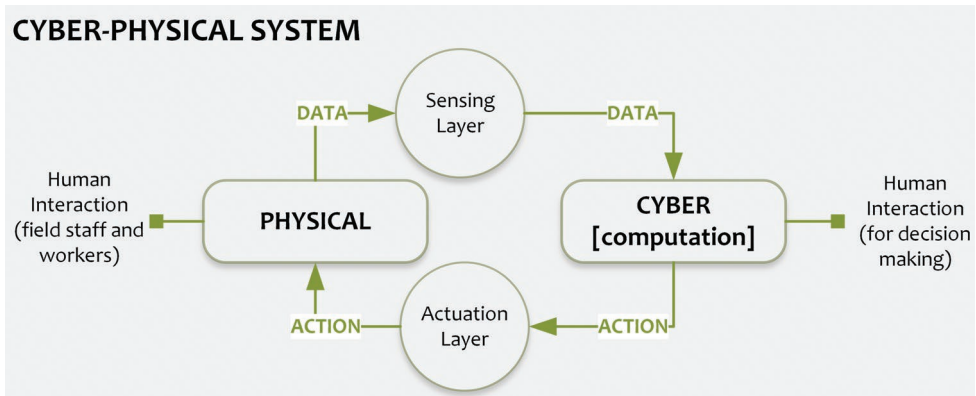


Figure 1.1 Conceptual model of CPS

Digital Ecosystem

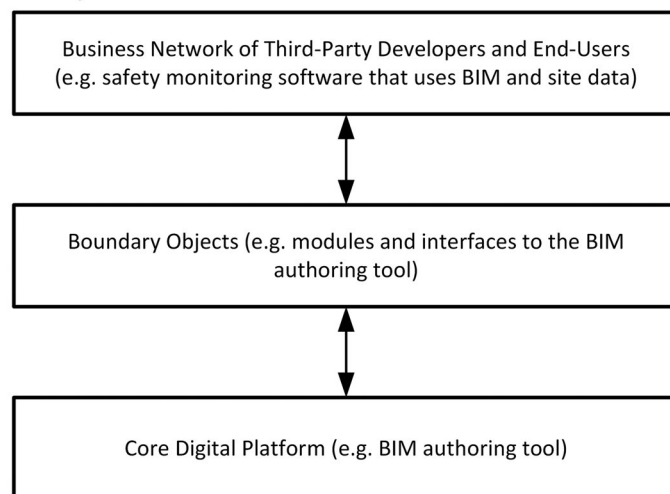


Figure 1.2 Conceptual model of a Digital Ecosystem

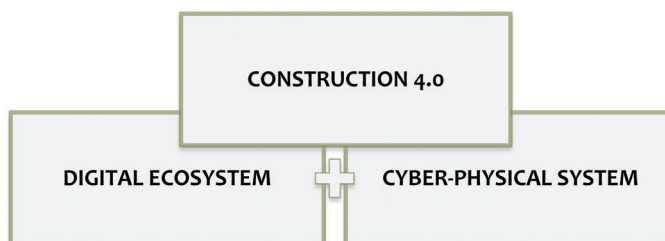


Figure 1.3 Construction 4.0 as a combination of CPS and Digital Ecosystem

Using the CPS, the cyber-physical gap that exists in the built environment can be bridged, and by concomitantly using the Digital Ecosystem the work processes to collaborate efficiently across the project delivery network to design and construct the asset can be enhanced. The Construction 4.0 framework, therefore, provides a mechanism via which we can:

- Digitally model the built assets that already exist in our physical world.
- Design new assets in the backdrop of what already exists or plan for the retrofit and rehabilitation of existing assets using these digital models.
- Once these assets are digitally captured and designed, use digital and physical technologies to deliver these physical assets.

The same framework can be adopted during the operation phase of the constructed asset by using similar digital and physical technologies to support Facilities Management (FM) functions. However, the focus of this handbook is limited to the design and construction phases.

The aim of this handbook is to describe the Construction 4.0 framework and consequently highlight the resultant processes and practices that allow us to plan, design, and deliver built environment assets more effectively and efficiently by focusing on the physical-to-digital transformation and then digital-to-physical transformation. This concept is illustrated graphically in Figure 1.4.

With the pervasive use of Building Information Modeling (BIM), lean principles, digital technologies, and offsite construction the industry is at the cusp of this transformation. The critical challenge is the fragmented state of our teaching, research, and professional practice in the built environment domain. The authors and editors of this handbook aim to overcome this fragmentation by describing Construction 4.0 in the context of current state, emerging trends and technologies, and people and process issues that surround the proposed transformation.

Construction 4.0 is a framework that is a confluence and convergence of the following broad themes:

- Industrial production (prefabrication, 3D printing, and assembly, offsite manufacture).
- Cyber-physical systems (robots and cobots for repetitive and dangerous processes, and drones for surveying and lifting, moving and positioning, and actuators).

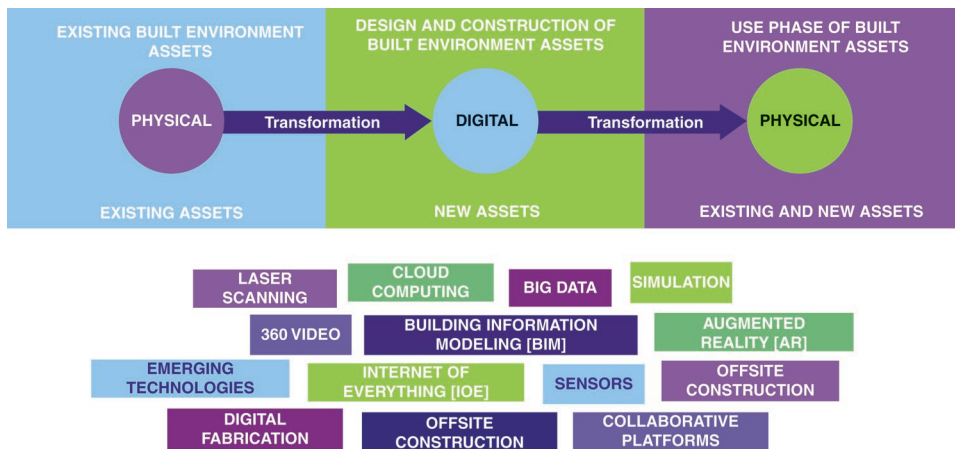


Figure 1.4 Physical to digital and digital to physical transformation



Figure 1.5 Themes of Construction 4.0

- Digital technologies (BIM, video and laser scanning, IoT, sensors, AI and cloud computing, big data and data analytics, reality capture, Blockchain, simulation, augmented reality, data standards and interoperability, and vertical and horizontal integration).

With this background and motivating factors, the handbook will address issues surrounding the key themes of people, processes and practice, and new technologies (as shown in Figure 1.5).

Modern digital and physical technologies are required to achieve the overarching vision of the 4IR (Jacobides, Sundararajan, and Van Alstyne, 2019) that underpins the Construction 4.0 framework, therefore, the framework relies on two broad paradigms: (1) cyber-physical systems and (2) Digital Ecosystems. Innovations in both cyber-physical and digital paradigms are necessary to advance the vision of Construction 4.0 in our industry.

1.3 Current state of the construction sector

Given the importance of the construction sector to their national economies, several countries have undertaken studies to identify the challenges and opportunities that the industry presents. For example, the UK has conducted several prominent studies to document the problems of the construction sector to put in place a program for improvement of the whole-of-the-sector. Sir John Egan, the chair of the Construction Task Force, published his report entitled *Rethinking Construction* in 1998 (Egan, 1998). It was instrumental in laying out a road map for the efficiency improvements within the construction industry in the UK. This came close on the heels of the report, titled ‘Constructing the Team’ authored by Sir Michael Latham and published in 1994. The Latham report identified inefficiencies and made recommendations for enhanced collaboration and coordination in the industry (Latham, 1994). More recently, the UK released a report by Mark Farmer entitled ‘Modernise or Die’ (Farmer, 2016) that used a ‘strong medical process analogy’. Around the time that this study was being conducted, the UK government also released their Construction 2025 industrial strategy with a plan to commit close to £75 million in research and development.

Other countries, such as the US, Australia, Canada, Singapore, and China, have also undertaken sector-wide studies. For example, a similar exercise was conducted in the US, where Construction Users Roundtable produced a detailed report to outline a path to competitive advantage for construction users.

Several developing nations have also undertaken such studies that identify the problems faced and listed the difficulties hindering growth (Al-Momani, 1995b, 1995a; Edmonds, 1979; Manoliadis, Tsolas, and Nakou, 2006; Moavenzadeh, 1978; Moore and Shearer, 2004; Ofori, 1989, 1994, 2000). This is even more important because in developing countries the construction sector’s capacity constraints impact the economic development process (Wells, 2001). These

studies have also developed action points necessary for the development of the construction industry (Ofori, 1994, 2000) including the importance of developing key performance indicators (Beatham et al., 2004; Ofori, 2000). A priority-based approach was proposed to rank solutions offered by the researchers and policymakers (Ofori, 1990) with several researchers presenting an optimistic case about the improvement plans (Koenigsberger and Groak, 1978; Turin, 1973).

The repeated nature of these national studies show that there is stagnation and barring some incremental improvements; the industry as a whole has still not managed to show major improvements. The results have been mostly disappointing (Chemillier, 1988; Ofori, 1984, 1990; UNCHS, 1990). Barring a few countries, the problems have persisted over a long period despite efforts made to overcome them. This has been pointed out in the Farmer report that states ‘construction has not even made the transition to “industry 3.0” status which is predicated on large scale use of electronics and IT to automate production’ (Farmer, 2016; Gerbert et al., 2017). Research has pointed towards a long-term strategic approach to be followed, which is related to the socio-economic needs of the country, often overseen by a steering committee (Farmer, 2016; Ofori, 1994).

The studies described above have generally identified a standard set of challenges or problems that the industry faces. In one such study a list of ten grand challenges (shown in Figure 1.6) faced by the construction sector in India were identified (Sawhney, Agnihotri, and Paul, 2014).

The following are the key challenges that have been collated from these studies (Farmer, 2016; Gerbert et al., 2017; Global Industry Council, 2018; Sawhney and Agnihotri, 2014; Witthoeft and Kosta, 2017):

1. Low levels of research and development leading to a lack of innovation and delayed adoption of technologies.
2. Workforce issues including shortage of young talent due in part to poor industry image.
3. Informal processes and lack of process standardization leading to structural fragmentation.
4. Low levels of cross-functional cooperation and limited collaboration leading to a lack of improvement culture.
5. Low productivity, predictability, and profits.
6. Adversarial transaction-based procurement regime.
7. Insufficient knowledge transfer from project to project.
8. Cultural and mindset issues that act as a blocker to any change.

These issues require a transformational change (Farmer, 2016) in the industry, and we envision that Industry 4.0 can provide a broad framework for such a change.

1.4 Overview of Industry 4.0

During the Hannover Messe in 2011, the German Federal Government released its vision for the future of the manufacturing sector under the broad umbrella term INDUSTRIE 4.0 (Roblek, Meško, and Krapež, 2016). It became part of the ‘High-Tech Strategy 2020’ project that continues to grow and evolve (MacDougall, 2014). This initiative later became a globally recognized paradigm that was broadly referenced as I4.0, also seen as a precursor to the Fourth Industrial Revolution (Drath and Horch, 2014). Other terms such as smart factory, smart manufacturing, smart production, etc., have also been used to define this broad paradigm (Oesterreich and Teuteberg, 2016).

Similar initiatives have also been launched by other countries. For example, the United States developed the ‘Advanced Manufacturing Partnership’ in 2014 (Rafael, Jackson, and

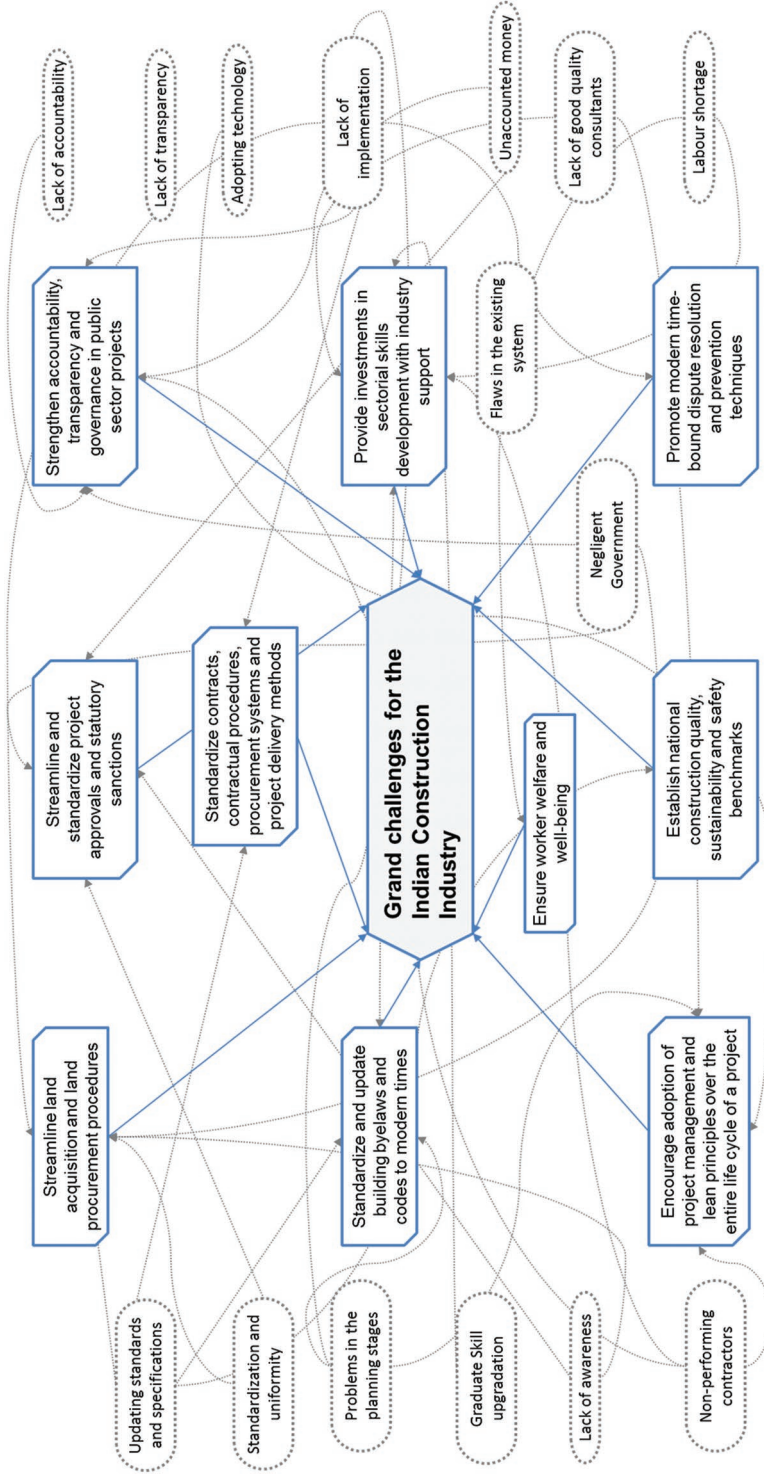


Figure 1.6 Key challenges faced by the construction sector (Sawhney, Agnihotri, and Paul, 2014) reproduced with kind permission of Emerald Publishing

Liveris, 2014) and updated it in 2016, the UK launched an initiative entitled ‘Future of Manufacturing’ (Foresight, 2013) and China is implementing the ‘Made in China 2025’ program (Liao et al., 2017).

While the First Industrial Revolution was catalyzed by steam-powered mechanical production, the second was driven by electrical-powered mass production; the third was based on electronics and automation, the Fourth Industrial Revolution has begun with the promulgation of CPS and related technologies (MacDougall, 2014; Pereira and Romero, 2017). It is envisioned that I4.0 will have far-reaching implications on the manufacturing sector that are, in turn, likely to have broad social and economic benefits for nations and societies that embrace this framework (Oesterreich and Teuteberg, 2016). Furthermore, I4.0 uses technologies such as service orientation, smart production, interoperability, cloud computing, big data analytics, and cybersecurity (Vogel-Heuser and Hess, 2016). I4.0 facilitates interconnection and computerization in traditional industries, which makes an automatic and flexible adaptation of the production chain and provides new types of services and business models of interaction in the value chain (Liao et al., 2017; Lu, 2017).

1.4.1 Definition of Industry 4.0

I4.0 is a broad term that has been presented as a ‘confluence of trends and technologies promises to reshape the way things are made’ (Baur and Wee, 2015). There are several definitions of I4.0 but no globally accepted one because the vision, mission, and components of I4.0 are still emerging and are being connected to more significant and broader themes such as sustainability and circular economy (Lopes de Sousa Jabbour et al., 2018; Müller, Kiel, and Voigt, 2018; Rajput and Singh, 2019).

The German government describes I4.0 as ‘a new technological age for manufacturing that uses cyber-physical systems and Internet of Things, Data and Services to connect production technologies with smart production processes’ (Kagermann, Wahlster, and Helbig, 2013; MacDougall, 2014) to make manufacturing smart. I4.0 has also been defined at a higher level as ‘a new level of value chain organization and management across the lifecycle of products’ (Hermann, Pentek, and Otto, 2016; Kagermann, Wahlster, and Helbig, 2013). It is also defined as the integration of machinery and devices with networked sensors and software that can be used to predict, control, and plan for better business and societal outcomes (Shafiq et al., 2015). In a way, I4.0 improves manufacturing organizations, business models that they use, and their production processes through the use of physical and digital technologies.

I4.0 is seen as a cross-cutting paradigm that can have broad social and economic benefits. It is seen as a way to revolutionize manufacturing and other major sectors, such as energy, health, smart cities, and mobility (MacDougall, 2014). The motivation behind this handbook is that I4.0 can also act as catalyst for the future of construction that is more industrialized and automated. We use this motivation to coin the term Construction 4.0.

1.4.2 Key components of I4.0

I4.0 is a very broad and encompassing term. Therefore, it is essential to understand the key components of I4.0. Researchers agree that the push towards I4.0 came from the evolution of embedded systems to more advanced cyber-physical systems (CPS) (Vogel-Heuser and Hess, 2016). This has also formed the basis of the vision developed by the German government. CPS is a set of technologies that connect the virtual and physical worlds together to create a genuinely networked production environment in which intelligent objects communicate and

interact with each other (Kagermann, Wahlster, and Helbig, 2013a). The journey towards I4.0 began with the embedded systems and their technological evolution towards CPS and further to provide an Internet of Things (IoT), Data and Services. Figure 1.7 shows this evolution of the embedded systems to CPS.

A CPS is defined as ‘a mechanism that is controlled or monitored by computer-based algorithms, tightly integrated with the Internet and its users’ (Monostori et al., 2016). CPS creates a virtual copy of the physical production system that is also called the digital twin. This is the first step towards I4.0, where a physical-digital-physical loop is created (Rutgers and Sniderman, 2018). The production environment in the factory that is created through this is also known as the Cyber-Physical Production System (CPPS) (Vogel-Heuser and Hess, 2016). CPPS results in a digitalized, smart, optimized, service-oriented, and interoperable production environment upon which other components of I4.0 are built.

Once the digital twin of a manufacturing environment is created, other business and technical aspects of the production process are linked into the I4.0 framework through the Internet of Things, Data and Services. Figure 1.8 shows the key components of I4.0. The very core of I4.0 is formed by the IoT layer that connects physical objects and things, collects data from these connected objects, and allows connected objects to communicate with each other. Based on this core layer are the CPS and CPPS layers of the I4.0. CPS helps create the digital twin of the physical world, in this case, the manufacturing unit. This allows a loop in which the physical components that are connected to each other relay data that can be used for a variety of purposes including decision making. Changes to the physical world can be made via actuators thereby completing the loop.

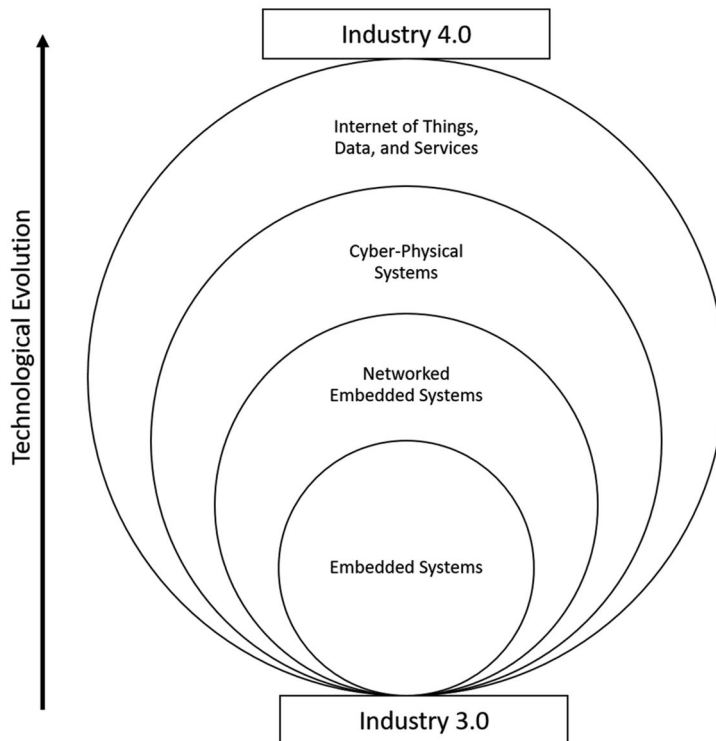


Figure 1.7 Evolution of embedded systems

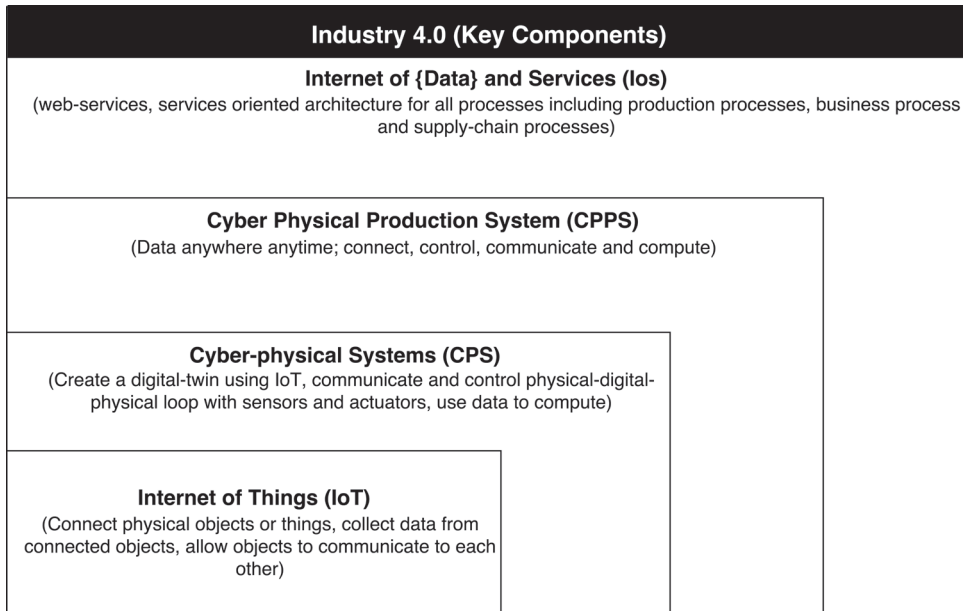


Figure 1.8 Industry 4.0 and its key components

The CPPS sits on top of the CPS layer and provides data about the physical world anywhere and anytime, and helps connect, control, communicate, and compute. CPPS provides an intensive connection with the surrounding physical world and its ongoing processes (Monostori et al., 2016). Finally, the topmost layer is the Internet of Data and Internet of Services (IoS). The IoS creates a service-oriented ecosystem and brings the end-user of customer centricity to the system (Hofmann and Rüsch, 2017). IoS allows the digital tools that support end-user functions to be available as a service on the Internet (Alcácer and Cruz-Machado, 2019). Both internal and cross-organizational services are offered and utilized by participants of the value chain (Reis and Gonçalves, 2018). The IoS helps create networks incorporating the entire manufacturing process that convert factories into a smart environment (Kagermann, Wahlster, and Helbig, 2013a).

1.4.3 Enabling technologies and key features

In addition to defining the I4.0 framework by describing its key components, the framework can also be defined by identifying its enabling technologies and key features. Liao et al. used over 224 research papers published over five years (2012–2016) to determine these technologies and key features of I4.0 (Liao et al., 2017). Figure 1.9 shows the enabling technologies and key features of I4.0 as determined by the literature review. The vision of I4.0 can be accomplished through a collective deployment of several related technologies (Alcácer and Cruz-Machado, 2019). These technologies work in conjunction with the IoT, CPS, CPPS, and IoS as identified in the previous section (Griffor et al., 2017). Based on the frequency of usage and mention in the literature these technologies are rank-ordered in Figure 1.9.

Similarly the key features of I4.0 from literature are also listed in rank order in the figure. From the literature it can be seen that both in research and practice significant attention is given to automation, integration, and collaboration. Less tractable features such as innovation, quality, and sustainability are still not prevalent.

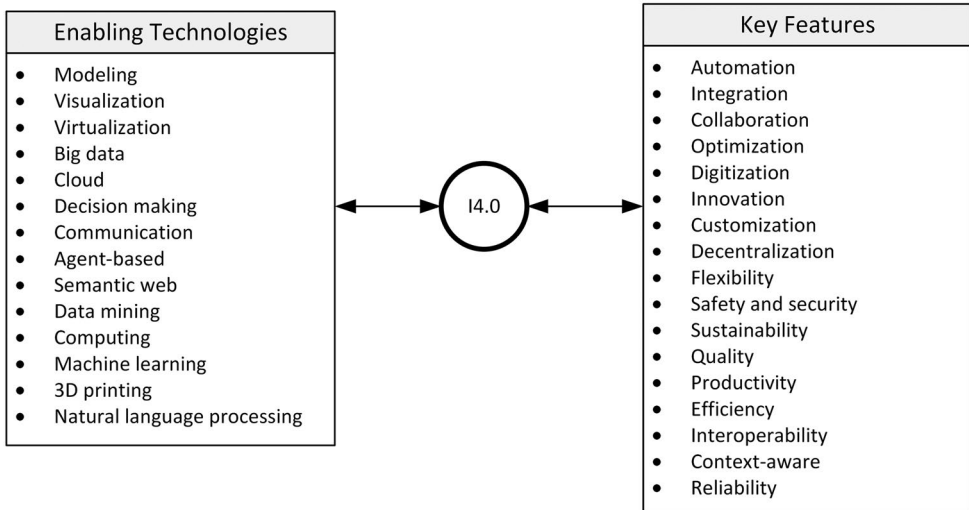


Figure 1.9 Enabling technologies and key features of I4.0

1.4.4 Interoperability and integration in I4.0

Integration and interoperability are two key drivers in the I4.0 framework (Kagermann, Wahlster, and Helbig, 2013a; Vogel-Heuser and Hess, 2016). Interoperability helps two or more systems work with each other to exchange data, information, and knowledge. Interoperability is achieved through a shared understanding of concepts, standards, languages, and relationships (Xu, Da, Xu, and Li, 2018).

I4.0 leads to the integration of processes, systems, applications, and organizations (Oesterreich and Teuteberg, 2016). It is anticipated that I4.0 will allow the following three levels of integration (Kagermann, Wahlster, and Helbig, 2013a):

- Horizontal integration through value networks.
- End-to-end digital integration of engineering across the entire value chain.
- Vertical integration and networked manufacturing systems.

1.4.5 Impact of Industry 4.0

There are several areas that can be impacted and improved by the application of I4.0 at the sector level (Kagermann, Wahlster, and Helbig, 2013; Oesterreich and Teuteberg, 2016; Rose et al., 2016):

1. Productivity improvement: I4.0 provides several improvements such as automation, real-time inventory management, and continuous optimization that lead to productivity enhancement.
2. Increased quality: ongoing monitoring and control of production allows for improved quality of products and services.
3. Increased flexibility: with a customer-centric approach, I4.0 allows manufacturing flexibility through automation and robotics.
4. Increased speed: with enhanced product life cycle management and physical-digital-physical integration, the speed of production is enhanced.

5. Safer and better working conditions: with increased automation, real-time monitoring of incidents, better-designed workstations, and enhanced work structuring, workers have safer and better working conditions.
6. Improved collaboration: as the availability of data is enhanced, and digital layer and physical layer are integrated the intra- and inter-organization collaboration is improved.
7. Sustainability: optimized use of resources, reduction in defects, and other environmental improvements make operations more sustainable.
8. Innovation: I4.0 leads to new ways of creating value and new forms of employment, for example through downstream services.

1.5 Construction 4.0 framework

Figure 1.10 shows the various layers and components of the Construction 4.0 framework. BIM and a cloud-based Common Data Environment (CDE) are central to the Construction 4.0 framework (Cooper, 2018; Oesterreich and Teuteberg, 2016). While BIM provides the modeling and simulation features that are a core component of the I4.0 framework, CDE acts as a repository for storing all the data that relates to the construction project over its life cycle.

The use of BIM and CDE creates a single platform that helps promote:

1. Integration of all phases of the project life cycle (vertical integration), all members of the project team (horizontal integration), and inter-project learning and knowledge management (longitudinal integration).
2. Linkage between the physical and cyber (digital) layer over the entire project life cycle. This allows the implementers of Construction 4.0 to utilize both physical and digital technologies in an integrated manner.

Within the Construction 4.0 framework, the following three transformational trends take place:

1. Industrial production and construction: by using prefabrication, 3D printing, and assembly, offsite manufacture, and automation, the issues and challenges caused by on-site construction techniques are significantly reduced. This type of industrialized process allows production to be digitally linked to BIM and CDE so that instructions can be directly delivered for physical production and any production-related information from the physical layer can be fed back to the digital layer.
2. Cyber-physical systems: the construction site under Construction 4.0 uses robotics and automation for production, transport, and assembly, actuators for converting digital signals into physical actions, and sensors and IoT to sense important information about physical objects (including people) from the physical layer.
3. Digital technologies: the digital transformation relies on the Digital Ecosystem that is developed in the digital layer of the Construction 4.0 framework. BIM and CDE provide the framework upon which integrated digital tools are built. With the help of video and laser scanning technology, artificial intelligence (AI) and cloud computing, big data and data analytics, reality capture, Blockchain, simulation, and augmented reality the delivery and business process is supported in the Construction 4.0 framework. While Digital Ecosystems provide the innovation needed for this support, data standards and interoperability also play an essential role in this overall transformation.

Figure 1.11 shows the components of the Construction 4.0 framework, the role they play in the framework and the layer in which they are present.

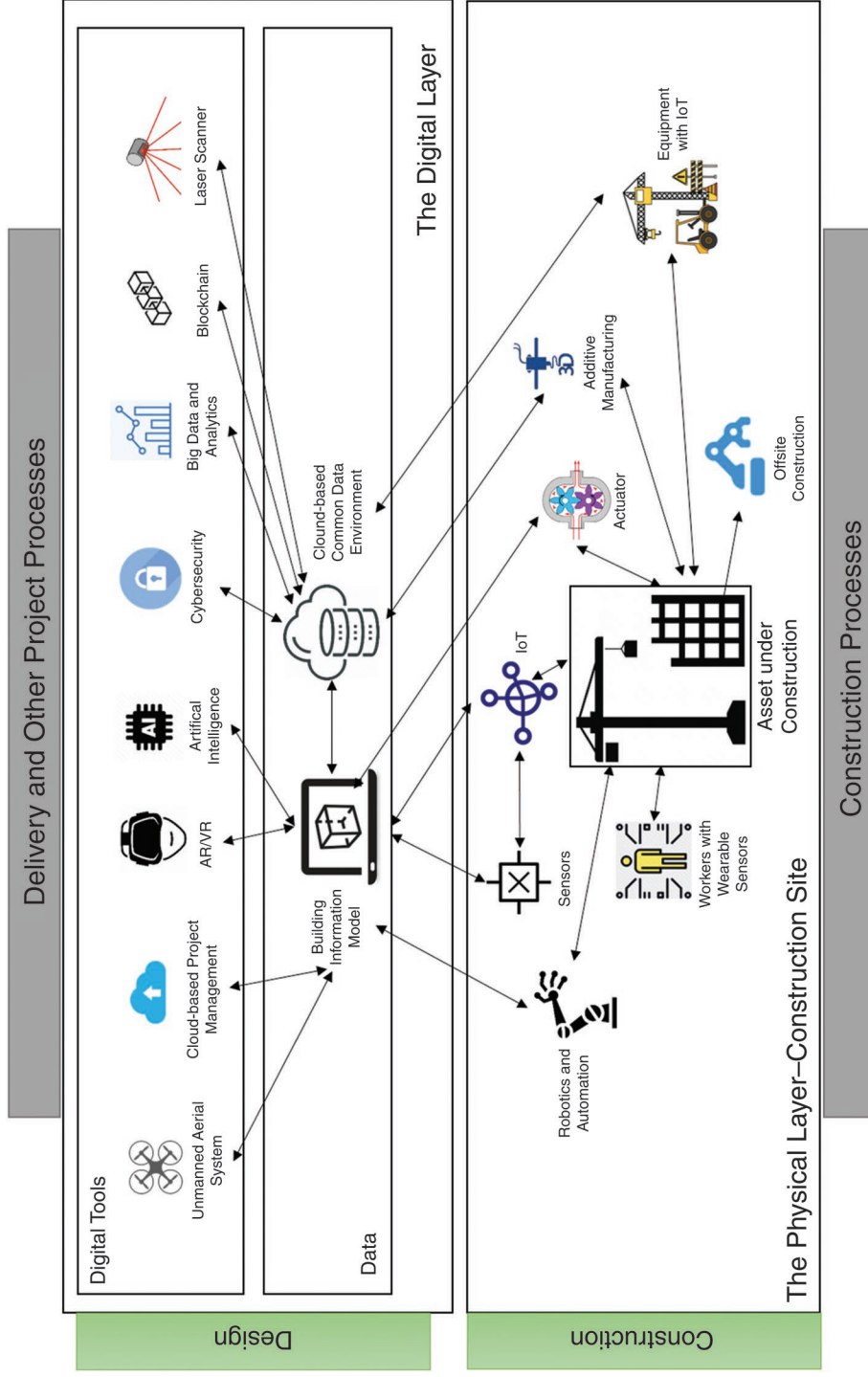


Figure 1.10 Conceptual illustration of Construction 4.0 framework



















Emerging Technology or Trend		Construction 4.0 Layer	Construction 4.0 Functions
	BIM	Digital	Modeling and simulation
	CDE	Digital	Collect, manage and disseminate documentation, the graphical model and non-graphical data for the whole project team
	Unmanned Aerial Systems	Digital	Aerial image collection
	Cloud-based Project Management	Digital	Digital tools to support delivery and business processes
	AR/VR	Digital	Virtual application in all phases and for all team members
	Artificial Intelligence	Digital	Classifying, predicting, image processing, mining and problem-solving
	Cybersecurity	Digital	Securing the physical-digital-physical loop
	Big Data and Analytics	Digital	Trend analysis and business intelligence
	Blockchain	Digital	Smart contracts, building trust, and maintaining records
	Laser Scanner	Digital	Point-cloud data collection
	Robotics and Automation	Physical	Transport, assembly and production
	Sensors	Physical	Collect location, temperature, humidity, and movement information
	IoT	Physical	Connectivity of things, people and data
	Workers with wearable sensors	Physical	Collect location, temperature, humidity, and movement information
	Actuators	Physical	Convert digital interactions into physical action
	Additive Manufacturing	Physical	Print parts and products using the BIM model
	Offsite Construction	Physical	Use manufacturing to produce parts and products
	Equipment with Sensors	Physical	Assembly of parts and products in a location aware environment

Figure 1.11 Components of Construction 4.0 framework

1.6 Benefits of Construction 4.0

Several recent studies have attempted to define the I4.0 framework in general and provide a road map for research and implementation based on a detailed literature scan (Alcácer and Cruz-Machado, 2019; Liao et al., 2017; Pereira and Romero, 2017). Similar attempts are being made in regards to Construction 4.0 (Cooper, 2018; Dallasega, Rauch, and Linder, 2018; Oesterreich and Teuteberg, 2016). These studies focus on identifying the sectoral benefits of the Industry 4.0 concept in general and Construction 4.0 in particular. Based on these studies, the benefits of the Construction 4.0 framework are listed below:

1. Enabling an innovative environment: the Construction 4.0 framework may provide the right mix of enablers to allow the innovation mindset to take root in the industry. Through

an integration of the physical and digital layer, it is likely that this innovation will lead to integrated solutions that will strike at the heart of horizontal, vertical, and longitudinal fragmentation that currently dominates the industry.

2. Improving sustainability: the integrated framework of Construction 4.0 allows the industry to fully embrace a life cycle approach and ensure prudent use of resources with a significant reduction in energy usage and emissions.
3. Improving the image of the industry: the construction industry suffers from an image problem caused by several factors. It is well known for its harsh working environment and its low level of automation and digitization (Farmer, 2016; Oesterreich and Teuteberg, 2016). The digital and physical technologies of Construction 4.0 can improve the image of the industry by transforming the work, the worker, and the workplace, and make it more attractive for recruitment and retention of talent.
4. Cost savings: use of industrialized construction supported by digital technologies, BIM, and CDE, can help reduce inefficiencies and waste. Robotics and automation can result in a reduction in direct costs. Real-time access to the physical layer with abundance of data will improve decision making and provide financial incentives for project teams to collaborate and innovate.
5. Time savings: modern methods of construction like prefabrication, additive manufacturing, and on-site assembly will improve the speed of construction. With real-time access to field data, any potential delays can be avoided, resulting in time savings.
6. Enhancing safety: Construction 4.0 will enhance site safety. Augmented Reality/Virtual Reality (AR/VR) based training, wearable technologies, IoT based connectivity of objects, things, and people, image and video processing can enhance safety.
7. Better time and cost predictability: with real-time monitoring, automated site data collection, image processing, AI, and analytics tools the time and cost predictability of ongoing projects can be improved. Availability of large volumes of historical data and information can help set benchmarks for early time and cost prediction of new projects, thereby allowing longitudinal integration.
8. Improving quality: the horizontal and vertical integration resulting from the adoption of Construction 4.0 framework allows the monitoring and control of the design and production processes, thereby improving the quality of construction.
9. Improving collaboration and communication: use of cloud-based project management tools, Blockchain, central repository of information and real-time data access enhances trust among the project team members and enhances communication, coordination, and collaboration.
10. Customer and end-user centric world view: with the reduction in tedious and repetitive tasks, the project team focuses on creating value and focusing on what matters most to the customer.

1.7 Challenges to implementation of Construction 4.0

The Farmer report documented the reluctance of the construction sector to embrace technology and summarized that the industry missed the Industry 3.0 transformation (Farmer, 2016). Dallasega, Rauch, and Linder and Oesterreich and Teuteberg based on an extensive literature review developed the following list of implementation challenges the sector faces while implementing Construction 4.0 framework (Dallasega, Rauch, and Linder, 2018; Oesterreich and Teuteberg, 2016):