
Automation and Manufacturing for the Built Environment

This page intentionally left blank



Automation and Manufacturing for the Built Environment

Steve Thompson

Published by Emerald Publishing Limited, Floor 5,
Northspring, 21–23 Wellington Street, Leeds LS1 4DL.

ICE Publishing is an imprint of Emerald Publishing Limited

Other ICE Publishing titles:

*Digital Twins for Smart Cities: Conceptualisation, challenges
and practices*

Li Wan, Timea Nochta, Junqing Tang and Jennifer Schooling.
ISBN 9780727766007

*Structural Design of Buildings: Fundamentals in Design,
Management and Sustainability*

Feng Fu and David Richardson. ISBN 9781835495773

Additive Manufacturing for Construction

Biranchi Panda, Pshtiwan Shakor and Vittoria Laghi.
ISBN 9780727766410

A catalogue record for this book is available from the British Library

ISBN 978-1-83608-599-7

© Emerald Publishing Limited 2025

Permission to use the ICE Publishing logo and ICE name is granted under licence to Emerald from the Institution of Civil Engineers. The Institution of Civil Engineers has not approved or endorsed any of the content herein.

All rights, including translation, reserved. Except as permitted by the Copyright, Designs and Patents Act 1988, no part of this publication may be reproduced, stored in a retrieval system or transmitted in any form or by any means, electronic, mechanical, photocopying or otherwise, without the prior written permission of the publisher, Emerald Publishing Limited, Floor 5, Northspring, 21–23 Wellington Street, Leeds LS1 4DL.

This book is published on the understanding that the author is solely responsible for the statements made and opinions expressed in it and that its publication does not necessarily imply that such statements and/or opinions are or reflect the views or opinions of the publisher. While every effort has been made to ensure that the statements made and the opinions expressed in this publication provide a safe and accurate guide, no liability or responsibility can be accepted in this respect by the author or publisher.

While every reasonable effort has been undertaken by the author and the publisher to acknowledge copyright on material reproduced, if there has been an oversight please contact the publisher and we will endeavour to correct this upon a reprint.

Cover photo: TierneyMJ/Shutterstock.com

Commissioning Editor: Michael Fenton
Content Development Editor: Cathy Sellars

Production Editor: Emma Sudderick
Typeset by: KnowledgeWorks Global Limited
Index created by: Madelon Nanninga

*For Lucy, Freddie, Henry,
Digby and my parents.*

This page intentionally left blank

Contents

About the author	xv
Glossary	xvii
Abbreviations	xxi

Section 1 – Setting the scene 1

1	Introduction	3
	1.1. The challenge	3
	1.2. The role of technology and manufacturing	4
	1.3. The way forward	6
2	The built environment	11
	2.1. Introduction	11
	2.2. The existing building stock	12
	2.3. The need for flexibility	18
	2.4. Moving forward	19
3	The construction industry	21
	3.1. What is the construction industry?	21
	3.2. How is the industry structured?	22
	3.3. How does the industry perform?	27
	3.4. Process	29
	3.5. Plan	29
	3.6. People	30
	3.7. Product	31
	3.8. Plant	32
	3.9. Moving forward	32
4	Why automation and manufacturing-led construction?	35
	4.1. Introduction	35
	4.2. Manufacturing-led construction	36
	4.3. Automation	43
	4.4. Summary	44
5	Learning from other industries	47
	5.1. How does construction compare to other industries?	47
	5.2. Challenges facing the construction industry	49
	5.3. Systems engineering	51
	5.4. The move to model-based systems engineering (MBSE)	53
	5.5. A move to more agile delivery	54
	5.6. Robotics and physical automation	56
	5.7. Digitisation, digitalisation and digital transformation	56
	5.7.1. Digitisation	57
	5.7.2. Digitalisation	57
	5.7.3. Digital transformation	57

	5.8. Digital twins – merging the physical and virtual worlds	57
	5.9. Virtual automation – artificial intelligence	58
	5.10. Summary	59
6	The modelling framework	61
	6.1. The modelling framework	61
	6.2. Vertical orientation	61
	6.3. Horizontal orientation	64
	6.4. Perpendicular orientation	64
	6.5. Conclusion	64
	Section 2 – Enable	67
7	Enabling change and manufacturing-led construction	69
	7.1. Introduction	69
	7.2. Business models and change management	70
	7.3. Define	71
	7.4. Systemise	72
	7.5. Automate	72
	7.6. Optimise	73
	7.7. Conclusion	73
8	No-regret decisions	75
	8.1. Introduction	75
	8.2. Enable	75
	8.3. Define	76
	8.4. Systemise	77
	8.5. Automate	77
	8.6. Optimise	77
	8.7. Conclusion	77
9	Connectivity	79
	9.1. Introduction	79
	9.2. Connectivity across disciplines, stages and sectors	79
	9.3. Design connectivity	80
	9.4. Integration connectivity	81
	9.5. In use connectivity	82
	9.6. Conclusion	83
10	Product and service data	85
	10.1. Introduction	85
	10.2. The importance of product data	85
	10.3. The Building Safety Act 2022, the golden thread and product data	87
	10.4. Construction digital product and material passports	88

	10.5. Mapping data sources and requirements through data models	89
	10.6. Structuring product data	93
	10.7. Manufacturing and supply chain data requirements	96
	10.8. Product data requirements through delivery and asset operation	99
	10.9. Data interoperability	101
	10.10. Data security and integrity	102
	10.11. Conclusion	103
	Section 3 – Define	105
11	Defining the need	107
	11.1. Introduction	107
	11.2. Outputs, outcomes, benefits and value	107
	11.3. The Green Book and the Five Case Model	108
	11.4. The Value Toolkit	110
	11.5. National TOMs framework	113
	11.6. Standardisation across interventions	114
12	Requirements management	117
	12.1. Introduction	117
	12.2. Levels of definition	118
	12.3. Project or product requirements	120
	12.4. Writing requirements	122
	12.4.1 Identification	122
	12.4.2 Specification	123
	12.4.3 Mapping	124
	12.4.4 Validation	124
	12.4.5 Tracking	124
	12.4.6 Maintenance	125
	12.5. Systems engineering	125
	12.6. Quality function deployment (QFD)	125
	12.7. Verification and validation of requirements	126
	12.8. Requirements management software solutions	126
	12.9. Conclusion	127
13	Product platforms	129
	13.1. Introduction	129
	13.2. Product platforms in the built environment	131
	13.3. The platform rulebook	134
	13.4. Summary	134

	Section 4 – Systemise	137
14	Premanufacturing and integration models	139
	14.1. Introduction	139
	14.2. Premanufactured value	139
	14.3. Production methods	141
	14.4. Types of integration	142
	14.4.1 Vertical integration	143
	14.4.2 Horizontal integration	145
	14.4.3 Multidirectional integration	145
	14.4.4 Life cycle integration	147
	14.5. Summary	150
	Section 5 – Automate	153
15	Technology timeline	155
	15.1. Introduction	155
	15.2. 4D modelling	155
	15.3. Additive manufacturing	155
	15.4. Advanced ground scans	155
	15.5. Asset management software	156
	15.6. Automated design	156
	15.7. Blockchain	156
	15.8. Building automation systems (BAS)	156
	15.9. Computer vision	156
	15.10. Connected autonomous plant (CAP)	156
	15.11. Connectivity platforms	156
	15.12. Design configurators	156
	15.13. Digital handover software	157
	15.14. Digital twins	157
	15.15. Drone scans	157
	15.16. Generative detailed design	157
	15.17. Generative form-finding design	157
	15.18. IoT sensors	157
	15.19. Laser scans	158
	15.20. Leak detection systems	158
	15.21. Location systems	158
	15.22. Logistics and supply chain software	158
	15.23. Low-code platforms	158
	15.24. Machine learning (ML)	158
	15.25. Natural language processing (NLP)	158
	15.26. Physical robots	159
	15.27. Predictive analytics	159
	15.28. Procurement software	159
	15.29. Programme optimisation	159

	15.30. Robotic process automation (RPA)	159
	15.31. Route optimisation	159
	15.32. Safety software	159
	15.33. Site communication	159
	15.34. Site management and reporting software	160
	15.35. Smart contracts	160
	15.36. Supply chain digital twins (SCDTs)	160
	15.37. Waste management software	160
	15.38. Workforce management software	160
	15.39. Technology timeline	160
16	Business casing construction delivery	163
	16.1. Introduction	163
	16.2. Business cases for project delivery	164
	16.3. Business cases within the supply chain	165
	16.4. Business cases and manufacturing-led construction	166
	16.5. Analogue or digital business case processes	167
	16.6. Conclusion	167
17	Design automation and manufacturing automation	169
	17.1. Introduction	169
	17.2. Early-stage design development	170
	17.3. Design development	173
	17.4. Design to manufacturing	180
	17.5. Model quality and checking	181
	17.6. Technology relevance summary	181
18	Supply chain management and procurement automation	183
	18.1. Introduction	183
	18.2. Procuring for value	184
	18.3. Procuring for manufacturing-led construction	188
	18.4. Automating procurement	188
	18.4.1 Onboarding	188
	18.4.2 Define	189
	18.4.3 Procure	189
	18.4.4 Deliver	190
	18.4.5 Verify	190
	18.4.6 Pay	190
	18.5. Benchmarking and cost modelling	190
	18.5.1 Benchmarking	191
	18.5.2 Should cost models (SCMs)	191
	18.5.3 Cost modelling	192
	18.6. Supply chain management	193
	18.7. Technology relevance summary	194

19	Integration automation	197
	19.1. Introduction	197
	19.2. Observing the environment	197
	19.3. Programme automation and 4D modelling	198
	19.4. Connected autonomous plant (CAP)	200
	19.5. Robotics	202
	19.6. Temporary site-based factories	205
	19.7. Workforce management and communication	205
	19.8. Material and performance management	206
	19.9. Progress tracking, verification and reporting	207
	19.10. Technology relevance summary	209
20	In-use automation	211
	20.1. Introduction	211
	20.2. Scanning the built environment	212
	20.3. Monitoring the built environment	213
	20.3.1 Condition monitoring	213
	20.3.2 Performance and use monitoring	215
	20.4. Sensors and other smart measurement technologies	215
	20.5. Active control and management	216
	20.6. Technology relevance summary	217
	Section 6 – Optimise	219
21	Circularity enablement	221
	21.1. Introduction	221
	21.2. Use less	222
	21.3. Use for longer	223
	21.3.1 Reconfiguration	223
	21.3.2 Performance updates	224
	21.3.3 Service life planning	225
	21.4. Reuse	225
	21.4.1 Design for disassembly	226
	21.4.2 Re-entering the supply chain	226
	21.5. Information management	228
	21.6. Conclusion	229
22	The future of work	231
	22.1. Introduction	231
	22.2. Future of work assessment	232
	22.3. Occupational automation examples	236
	22.3.1 Architects	236
	22.3.2 Civil engineers	237
	22.3.3 Brick layers	237
	22.4. The impact of automation on wellbeing	238
	22.5. Conclusion	239

23	An automated construction industry: 2035 scenarios	241
	23.1. Introduction	241
	23.2. Scenario 1	242
	23.3. Scenario 2	243
	23.4. Scenario 3	243
	23.5. Summary	244
24	Conclusion	247
	24.1. Introduction	247
	Appendix – Assessing the impact of automation	251
	Index	255

This page intentionally left blank

About the author

Steve Thompson is an architect by profession and has over 25 years of experience in the construction industry, having worked across many sectors including residential, commercial, transportation and education. He has significant experience in building manufacturing, having worked for a global product manufacturer for over 10 years, where he was heavily involved in international research and development projects, product and system developments and real-world projects. He has developed several building systems and new business models to support alternative construction methods. He also has significant knowledge of the implications of digitalisation on construction and manufacturing, having been the founding chair of BIM for Manufacturers and Manufacturing, and a nominated expert on product data on international standards development. Steve has also led the development of automation technologies including regulations checking, viability assessments and generative design, and is driven by making technologies accessible to small businesses as well as large.

This page intentionally left blank

Glossary

Term	Description
Application programming interface	A software intermediary that enables two or more applications to communicate with each other
Automation	Where digital or physical technologies are used to remove the need for human involvement
Benefits	The measurable improvement resulting from an outcome or outcomes
Building automation system	Uses sensors and controls to monitor and adjust a building's services such as heating and lighting
Building management system	Manages a building's services such as heating and lighting. An intelligent BMS can bring together control systems and data from a number of different sources and in complex assets
Built environment sectors	Wider services including construction, manufacturing, MMC providers, professional services and asset management
Common data environment	A cloud-based location where information on construction projects is stored and accessible by all project participants with the relevant permissions
Computer-aided facilities management	A comprehensive asset management software solution that may include space management, maintenance scheduling and asset tracking
Conceptual data model	A high level, solution-agnostic description of the real-world information requirements of a business or businesses
Configurator	A digital tool that is used to create a design using an identified set of standard components or systems
Connected autonomous plant	Also known as connected automated plant, is equipment that can operate either entirely or partially without the involvement of humans
Data	Raw, unorganised facts such as individual weights, volumes or temperatures. Data can be structured (such as in spreadsheets and databases) or unstructured such as raw data from sensors
Delivery model assessment	An analytical, evidence-based approach to reach a recommendation on how a contracting authority should structure the delivery of a project or programme
Digital transformation	Business transformation enabled by digital technologies
Digitalisation	Uses data and digital technologies to improve processes. Examples include using product data to determine expected performance of a wall construction instead of calculating manually or tracking progress of a product delivery

Digitisation	Changing something from analogue to digital, for example scanning a paper document or entering product data into a spreadsheet or online tool so that the data can be accessed and used more readily
Engineered to order	The product is made to meet the specific requirements of a customer who has placed an order
FAC-1	A Framework Alliance Contract, a multiparty umbrella contract designed to integrate the activities of consultants, integrators, subcontractors, suppliers and others, and to align interests. It sits above other contracts and agreements and defines relationships and processes not covered by those contracts
Five case model	A means of developing a business case based on five dimensions: strategic, economic, commercial, financial and management
Full-time equivalent	Refers to the number of hours considered to be the normal workload of a full-time employed person
Functional requirement	A requirement that describes what a solution must do in order to fulfil a need: what a solution must achieve
Generative design	Computer-generated design solutions, usually creating many potential solutions based on a series of input parameter ranges
Golden thread	Involves keeping a digital record of crucial building information – starting from the design phase and continuing throughout the building’s life cycle, and must be stored digitally
Human capital	In the context of the built environment this includes employment opportunities, skills development, health and wellbeing
Industrialised built environment	The use of physical and digital systems to deliver, maintain and reconfigure or upgrade assets through their life cycle, with very little to no abortive work in a plug-and-play fashion
Industrialised construction	The combined use of building assemblies and automation technologies to deliver virtually or totally complete assets
Industry 4.0	The Fourth Industrial Revolution. It involves a range of technologies that combine the physical and digital worlds
Information	Data that has been put into context to make it useful
Installed product data	Data relating to the product in use in the final built asset
Logical data model	Developed from a conceptual data model and solution agnostic, provides much more detail on data structures and relationships, typically in the form of relational tables
Machine learning	A form of artificial intelligence where algorithms are used to process large volumes of data and learn from it. Once taught, ML models then make predictions or identify patterns without being programmed to do so, and as such are more advanced than simple rules-based models

Made to order	The product is made following an order being placed by a specific customer
Made to stock	The product is made without a specific customer in mind, and without an order being placed
Manufacturing-led construction	Construction where manufactured systems or manufacturing processes are used and materially change the way an asset is delivered from a traditional on-site model: includes MMC, off-site construction and DFMA
Mass customisation	The benefits of mass production combined with the benefits of customisation for specific user requirements
Master data management (MDM)	Management of all data across a business, and potentially its supply chains, whether product or nonproduct information
Metadata	Data that describes other data, providing a structured reference that helps to sort and identify attributes of the information it describes
Model-based systems engineering	The formalised application of modelling to support system requirements, design, analysis, verification and validation activities, beginning in the conceptual design phase and continuing throughout development and later life cycle phases
Most economically advantageous tender	A tender which, using a cost-effectiveness approach or price/quality ratio, offers the best price (this will not necessarily be the lowest price)
Natural capital	In the context of the built environment this values the natural environment and addresses solutions to climate impacts through the life cycle of assets
Nonfunctional requirement	Describes the qualities of a solution: what it should be
Obtainable product data	Data that describes a product as a thing, and its properties, but which is application- and project-agnostic
Operational design domain	A limiter on where, when and in what conditions a CAP system can operate
Outcome-based procurement	Procurement focused on outcomes. It involves clearly defining required outcomes and then procuring a provider based on their capability to deliver against those outcomes rather than defining how an outcome should be achieved
Outcomes	The change in state or condition of the capital due to intervention activities
Outputs	Products or services created, or by-products or waste from a process
Physical data model	Developed from a logical data model, includes the solutions that will be used in operating the model and so can form the design of a database to manage all the relevant data

Platform	A group of technologies that are used as a base on which other applications, processes or technologies are developed
Premanufactured value	A measure of the value of work carried out off-site as a proportion of the total value of work on a project
Produced capital	In the built environment this is a combination of capital and operational costs, man-made assets and their efficiency and quality
Product application data	Data on the use of the product in a certain context, whether application-, sector- or project-specific
Product data sheet	A product data template that has been completed with information on a specific product or system
Product data template	A template for the consistent sharing of data on a particular product or system type
Product information management (PIM)	Centralised systems used to manage product information consistently, both internally and potentially to share with customers and other stakeholders
Product lifecycle management (PLM)	Covers the development lifecycle of products, from initial concept through to market maturity and finally retirement of a product
Product platform	A collection of assets that are shared by a number of products. Those assets are not necessarily shared physical products but can also be processes, plant, planning (knowledge) or people
Production data	Data required for the manufacture and distribution of products
Real-time location system	A system that enables the accurate 3D location of something relative to something else, for example location within a building where GPS cannot be used
Robot	Automatically controlled, reprogrammable multipurpose manipulators, programmable in three or more axes, which can be either fixed in place or fixed to a mobile platform for use in automation applications in an industrial environment
Should cost model	Pretender estimates of what a project should cost over its whole life (delivery phase plus its full design life)
Single task construction robot	Systems that execute one specific construction task
Social capital	In the built environment this refers to influence and consultation, equality and diversity as well as changes to people experience
Supply chain digital twin	A supply chain digital twin model can be used to record the real-time condition, location and state of product and service transactions
Systems engineering	An interdisciplinary approach to the requirements definition, design, integration and management of complex systems
Value	Quantifiable financial or nonfinancial worth which is important to clients and their stakeholders in the context of an intervention

Abbreviations

Term	Description
AI	artificial intelligence
API	application programming interface
BAS	building automation system
BAU	business as usual
BCIS	building cost information service
BIM	building information modelling
BMS	building management system
bSDD	buildingSMART data dictionary
CAFM	computer-aided facilities management
CAM	computer-aided manufacturing
CAP	connected autonomous plant or connected automated plant, the meaning is the same
CDE	common data environment
CIH	construction innovation hub
CIOB	Chartered Institute of Building
CLC	Construction Leadership Council
CMC	capabilities for modern construction
CPQP	construction product quality planning
DFD	design for disassembly
DFMA	design for manufacture and assembly
DLUHC	Department for Levelling Up, Housing and Communities
DMA	delivery model assessment
DoP	declaration of performance
ECI	early contractor involvement
EPC	energy performance certificate
EPD	environmental product declaration
ESG	environmental social governance
ESI	early supply chain involvement
FTE	full time equivalent
GDP	gross domestic product
GIIG	Government and Industry Interoperability Group

GIRI	Get It Right Initiative
GPR	ground penetrating radar
GUID	globally unique identifier
GVA	gross value add
IA	intelligent automation
ICE	Institution of Civil Engineers
IFC	industry foundation classes
IM	information management
ISMS	information security management system
MBSE	model based systems engineering
MDM	master data management
MEAT	most economically advantageous tender
ML	machine learning
MMC	modern methods of construction
NLP	natural language processing
NUAR	national underground asset register
ODD	operational design domain
p-DFMA	product design for manufacture and assembly
PIM	product information management
PLM	product lifecycle management
PMV	premanufactured value
QFD	quality function deployment
RIBA	Royal Institute of British Architects
RPA	robotic process automation
RTLS	real-time location system
SCDT	supply chain digital twin
SCM	should cost models
SCOR	supply chain operations reference model
SDG	sustainable development goals
SFCECA	standard form of civil engineering cost analysis
SIC	Standard Industrial Classification
SKU	stock keeping unit
SME	small- and medium-sized enterprise
STCR	single task construction robot

Section 1

Setting the scene

This page intentionally left blank

Steve Thompson

ISBN 978-1-83608-599-7

<https://doi.org/10.1108/978-1-83608-598-020241001>

Emerald Publishing Limited: All rights reserved

Chapter 1

Introduction

1.1. The challenge

The world in the first half of the 21st century holds significant promise for the future in terms of technology development, living standards and health and wellbeing, arguably more so than at any other time throughout history. However, there are also real and significant global challenges ahead. One of the questions this book looks to answer is how can new approaches to delivering and maintaining built assets help address the pressing challenges faced, and provide a sustainable built environment for all? It aims to show how, with the right balance of technologies and manufacturing-led approaches, project and wider societal value are not mutually exclusive; they can be aligned and addressed simultaneously.

One challenge is the formidable expansion rate of the world's population, combined with increasing expectations for the built environment as urbanisation increases. Globally, the world's urban population is expected to grow by 2.3 bn between now and 2050 (UN DESA, 2019). That means the equivalent of requiring over 2300 new apartment buildings being delivered every day between now and 2050, each housing 100 people. When necessary supporting infrastructure and services are added to that, it is estimated that globally over 230 bn m² of additional built floor area will need to be added between now and 2060 to keep up with demand – the equivalent of delivering the built area of Japan every year (zu Ermgassen *et al.*, 2022). All of this means that the need for new assets has never been greater.

Another challenge facing the built environment is quality. The impact of poor quality, inefficient built assets is covered in Chapter 2, but a key issue is that carbon emissions from the built environment are significant. The demand for meeting space requirements seems at odds with the need to reduce overall emissions: this is not only a case of balancing increasing demand with delivery but also about delivering better performing assets. Studies have shown that part of the problem in reducing emissions is that many buildings do not perform as they were intended to, emitting an average of 3.8 times the emissions that they were designed to (Innovate UK, 2016). In 2019, global carbon dioxide emissions from the operation of buildings reached 10 GtCO₂ per year, which equates to 28% of all emissions. When the emissions from the construction industry were added, the total energy-related emissions from construction and the built environment reached 38% of the total (UNEP, 2020).

To help minimise climate change, the UK government's Climate Change Act 2008 has committed the UK to achieving net zero greenhouse gas emissions by 2050 (HMG, 2019), with an interim target of achieving 78% lower emissions than in 1990 by 2035. To achieve anything like these targets will require a significant change in the way the world operates – for example, a greater than 6% reduction in emissions from buildings will be required every single year to 2030 to contribute to this goal (UNEP, 2020), a target which is not currently being met. Business as usual projections

suggest that if the UK continues its current path, the UK will only achieve a 60% reduction in emissions from 1990 levels by 2050, falling significantly short of its net zero target (UKGBC, 2021). Therefore, if the UK is to meet its 2050 targets, it is crucial that emissions from the built environment are reduced to zero. So, assets also need to perform better.

Put simply, the construction industry exists to deliver and maintain the built environment, which itself supports the communities and individuals it serves. But what does the construction industry of the early 2020s look like, and how is it likely to change between now and 2050? Chapter 3 covers today's construction industry in some detail but, to simplify the story, many buildings and infrastructure assets that are built today would have been constructed in a very similar way many decades ago. Brick and block are still the most common materials used in constructing new homes, and on-site productivity has decreased since the early 1970s (ONS, 2021). At the same time, productivity across all industries has increased by 49% and, looking forward, material use across all industries is forecast to more than double by 2060, with over a third of that rise being used in construction, which is unsustainable. So, as there will be an ever-increasing demand for new or refurbished assets, the construction industry needs to deliver significantly more and more efficient assets, with fewer resources, and with an ever-increasing skills shortage. This simply cannot be achieved using the same approaches that have been used in the past, and Chapter 3 will describe some of the green shoots of change that have begun to develop over recent years. Further chapters will then describe how the carefully considered application of automation and manufacturing-led construction can support a move to an industrialised construction industry (how assets are delivered), and even potentially an industrialised built environment (how assets are maintained, operated and upgraded). However, there are risks involved if the role these technologies play is not carefully considered from the outset, so this book will describe important considerations and decisions that need to be made to succeed. Just using technology to deliver assets quicker is not the answer to the world's challenges.

1.2. The role of technology and manufacturing

The last two decades have seen rapid developments in technologies that have changed the way we live our lives. The first iPhone was launched in 2007, and now the equivalent of over 78% of the world's population has a smart phone (Statista, 2022). Over 90% of the world's data has been produced in the last two years, and every 18 months to two years the amount of data doubles. Since 2018 there have been more devices connected to the internet than there are people on the planet. But what does all this technology development mean to the construction industry and the built environment? Yes, there are an increasing number of smart devices in our homes, such as learning thermostats, robotic vacuum cleaners and voice-controlled devices, but the construction industry is often described as one of the least digitalised industries and one of the least productive. The next few chapters will discuss whether this is a fair assessment and how the industry can improve. So how can technology help? There are many new terms being used such as industrialisation, the Fourth Industrial Revolution, Industry 4.0 or even Construction 4.0, and new approaches or methodologies, such as BIM (building information modelling), IM (information modelling), automation, AI (artificial intelligence), IA (intelligent automation), blockchain, generative design, offsite manufacturing, MMC (modern methods of construction) and product platforms, but what do they all mean, and are they likely to improve the industry?

Box 1. Industry 4.0

Industry 4.0 is another term for what is known as the Fourth Industrial Revolution.

The First Industrial Revolution was brought about using water and steam power to drive the mechanisation of production in factories in the late 18th century. It changed the economy from an agriculture- to a production-led economy, bringing together disparate workers in the textiles industries into large cotton mills in towns and cities. Over time it led to increases in output, in wages and in quality of life for the general population. The Second Industrial Revolution was driven by the use of electricity and mass production in the late 19th and early 20th centuries, and the Third Industrial Revolution from the last third of the 20th century to today has developed the use of computers, digitalisation and electronics to support mass customisation (where the benefits of mass production can be combined with the ability to customise output instead of mass-producing identical products). As with the first two industrial revolutions, this promises to improve wages and living standards for many. However, while there is little doubt the Third Industrial Revolution is still being experienced, many believe that society is also now at the beginning of a Fourth Industrial Revolution, or Industry 4.0, running alongside the third. Building on the developments of the third, it is characterised by a fusion of technologies that is blurring the lines between the physical and digital worlds and promises new services and business models driven by the creation of cyber-physical systems (systems that include the integration of digital systems that can control physical systems and vice versa). Common principles included in the vision of Industry 4.0 (iscoop, 2022) include

- interoperability between systems, both physical and digital
- information transparency
- decentralisation and autonomous decisions
- real-time capability, data and decision making
- service orientation (human–machine interaction)
- modularity
- individualisation or personalisation of products with highly flexible production
- customer-centric.

Boston Consulting Group (BCG) refers to Industry 4.0 as the convergence of the following nine technologies (BCG, 2016)

- advanced robotics
- additive manufacturing
- augmented reality
- simulation
- horizontal/vertical integration
- industrial internet
- cloud
- cybersecurity
- big data and analytics.

While the first three industrial revolutions were typically focused on the factory and production systems, Industry 4.0 extends much further into other areas of our lives and industries, which is where terms such as Construction 4.0 fit.

This book touches on each of them, but more specifically looks at what automation and manufacturing-led construction mean in the context of the built environment and what practical steps can be made to take advantage of technologies. It will look to describe how they are currently being implemented, with real-world examples, and what impact they are likely to have on a future built environment. Critical to all these technologies, however, is data; they all rely on it to function. They depend on how data is captured, structured, exchanged and used, and this will be covered in more detail in Chapter 10.

The use of data and technology can have significant impacts on individuals and whole communities alike in other ways too. A prime example of this is Engel's pause; a term used to describe one of the impacts of the First Industrial Revolution. While mechanisation was great for factory owners and increased per capita GDP, it took generations before the working classes saw increases in wages as a result, leading to increased social inequality. There is a commonly held fear that the same may occur with Industry 4.0; that robots may steal the jobs of humans, that automation may replace entire occupations and it may take generations for new roles to be created for those that are displaced. Chapter 22 looks at the future of work and the implications of automation and manufacturing-led construction in the short, medium and long term.

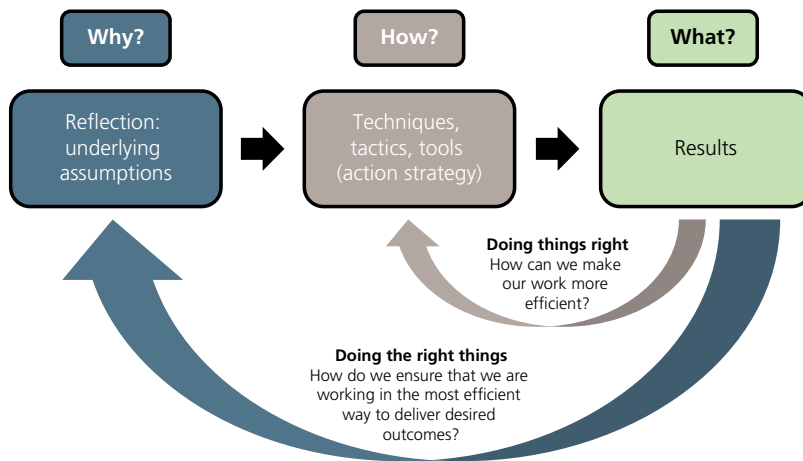
While there is potential risk associated with jumping into using new technology and data to change the way we live and work, this book offers guidance to ensure that automation technologies can realise the significant benefits to clients, industry and society that they promise, on projects large and small. To mitigate potential risks, it is crucial to carefully define and plan future strategies for technology adoption, and Chapters 7 and 8 outline how to enable such change, including 'no regret' decisions that will provide solid foundations for the future.

It is important to highlight that Industry 4.0 is still a long way off becoming a widely held reality and is generally still only a vision for the future. To implement it fully requires systemic change across industries, but instead of waiting for that to become possible while the world's challenges continue to deepen, there are aspects which can be delivered today without being a detriment to future applications. Therefore, this book does not cover Industry 4.0 in its entirety but describes some aspects of it that can be realised today, with real examples and benefits. Different levels of adoption of automation will then be considered as part of the future scenarios described in Chapter 23.

1.3. The way forward

Making the wrong decisions today on what we build and how we operate the built environment could lock the country into emissions in the future that mean national targets cannot be met, but can also lead to the wrong assets in the wrong location. So careful consideration needs to be given, and simply continuing to build more of the same is unlikely to be the answer. Equally, the wrong application of technologies can be inefficient, expensive and disruptive. [Figure 1.1](#) illustrates part of the challenge; in delivering a built environment that meets society's needs, it is important to ensure that the construction industry is not just delivering things well, but also delivering the right things. Construction is historically a project-based industry, with a focus purely on meeting a specific project's objectives, whereas there is a gradual move in recent years to incorporate broader social value using tools such as the Construction Innovation Hub's Value Toolkit or the Government's

Figure 1.1 Doing the right things, not just doing things right (Author's own)



Green Book (HMT, 2022). Care needs to be given to clearly defining what is needed through the lifecycle of an asset and potentially as part of a larger portfolio of assets.

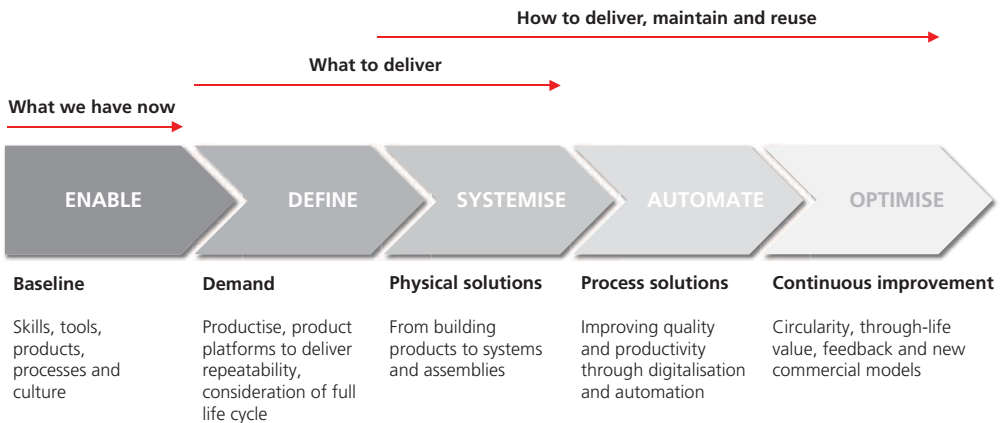
In the UK, for several years there has been a notional target from successive governments of delivering 300 000 new homes per year. However, this target has never been met. Importantly however, if the industry were to deliver that many additional homes, their delivery and subsequent use would single-handedly consume England's total cumulative carbon budget between now and 2050 (zu Ermgassen *et al.* 2022). That is not to say that more homes should not be built, but that there needs to be consideration on what and where homes need to be delivered.

On top of the housing need, there is a need for supporting infrastructure to support communities, such as schools, transport, hospitals and assets supporting employment. Approximately 80% of the UK's building stock in 2050 already exists, so it is important to recognise the critical role that our existing assets need to play; it is not simply a challenge to build better new buildings but also to maximise the use of what already exists. By extending the life of existing assets, the overall carbon footprint of the built environment can be reduced as the need to replenish stock is reduced.

To coherently describe how to get from where the industry is now to one which is more optimal to meet the challenges of today and tomorrow, Figure 1.2 illustrates five key stages to go through. In this gradual approach, each stage builds on the previous one and adds more value. If you systemise before clearly defining what is needed, you run the risk of delivering the wrong things quicker, locking in problems for the future and limiting future applicability of systems. If you automate before you systemise, you limit value in the short and long term.

The core of this book is structured into sections relating to each of the steps to achieve maximum value; however, the intention is that each chapter can also be used in isolation to describe different aspects of automation or manufacturing-led approaches. To improve an industry requires systemic change, not just changes in small pockets of the industry. However, it will not usually be the case that the whole supply chain can be steered in a new direction together, so it remains

Figure 1.2 Stages for implementing automation and manufacturing-led delivery (Author’s own)



important to highlight the benefits that can still be achieved when working in more focused areas with a similar vision.

The book focuses on a time frame up to 2035 to illustrate the potential of automation and manufacturing-led construction, as within that timeframe significant change is expected, and indeed needs to occur if the industry is to meet its medium- to long-term targets described in this chapter. 2035 sits 5 years after the deadline to achieve the UN’s Sustainable Development Goals, and 15 years before the UK Government’s net zero targets, so the book presents three scenarios for the construction industry in 2035, which will incorporate different levels of industrialisation and automation.

In continuing to set the scene, Chapter 2 looks at the built environment in more detail to describe the situation today, and what future demands are likely to be to make sure that real, enduring value is delivered through the built environment. Chapter 3 then looks at the construction industry today, including its structure from small- and medium-sized enterprises (SMEs) to large multinationals. It highlights how in recent years parts of the industry have begun to change to a value-based approach, considering the whole lifecycle of an asset, and as a result focusing more on refurbishment of existing structures than has previously been the case.

Chapter 4 describes what is meant by automation and manufacturing in the context of the construction industry and how they can act in unison to deliver greater value through a more responsive built environment.

Chapter 5 provides lessons that can be learned from other industries to support transformation of the construction industry, such as the use of digital twins to provide real-time feedback and different supply chain and value-driven industrialisation.

The last chapter, Chapter 6, in the *Setting the scene* section outlines the modelling framework that will be used throughout the book to describe and quantify the potential impact of automation and manufacturing-led construction through the lifecycle of an asset.