ICE Publishing

Lu, Xie, Parlikad, Schooling and Pitt
ISBN 978-0-7277-6580-2
https://doi.org/10.1680/dtbe.65802.001

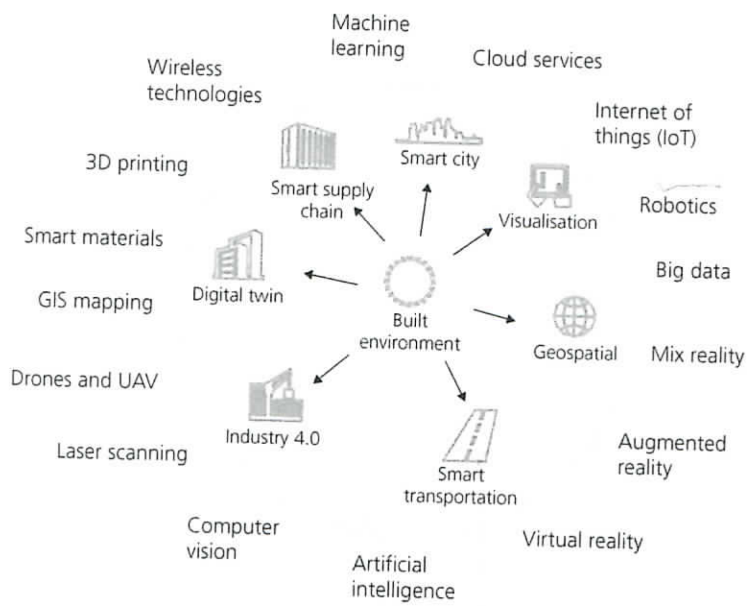
Chapter 1
Introduction

1. Scope of this book

The digital age is approaching. Various digital concepts and technologies are transforming our built environment, such as big data, robotics, laser scanning and digital twins (as shown in Figure 1.1).

A digital twin (DT) refers to a digital replica of physical assets, processes and systems. Digital twins integrate artificial intelligence, machine learning and data analytics to create living digital models that are able to learn and update from a number of data sources, and to represent and predict the current and future condition of their physical counterparts. Digital twins align well with other related emerging paradigms, such as cyberphysical systems and Industry 4.0, and it is predicted that half of the large industrial companies will use digital twins by 2021, resulting in those organisations gaining a 10% improvement in effectiveness (Gartner, 2017). Moreover, from the perspective of research, the number of publications (with 'digital twin' in the title) has increased significantly, to more than 1200 since 2018, based on keyword search results.

Figure 1.1 Brief summary of digital concepts



In the architecture, engineering, construction (AEC) and facilities management (FM) sectors, digital twins have increasingly gained attention and widespread interest. Parts of digital twin concepts are also being examined in the context of smart cities or buildings. For instance, Mohammadi and Taylor (2017) provided predictive insights into a city's smarter performance and growth based on virtualisation and digital twinning of the city. Ma *et al.* (2018) also explored the role of big data in urban physical, social and cyber spaces in constructing smart cities. Moreover, Oliver *et al.* (2018) provided a practical investigation of developing digital twins using the example of the new University College London campus. However, unified guidance and multipurpose applications at different levels were still limited in their research. A number of studies and implementations have started to use digital twins; however, digital twins' potentials are not fully released. For instance, the restoration team of the Sydney Opera House designed a unified central data repository, integrating different resources to support effective operations and maintenance (O&M) management (CRC Construction, 2007), where digital twins could provide enhanced benefits and potential. From an architectural and engineering or construction point of view, activities related to digital twins are still at an early stage with respect to buildings and other infrastructure assets. A completed and systematic view of digital twins, including well-organised guiding principles, a clearly defined system architecture, possible implementations, extensions with advanced technologies and case studies to supervise digital twin development in both industry and academia, is urgently needed. This will help identify the shortcomings of current approaches and provide roadmaps for future development in digital twin areas. These are missing in current developments, and thus form the core focus of this book.

The aim of this book is to provide a new, comprehensive, systematic and clear view of digital twin development in the AEC and FM sectors. This book is intended to provide useful information and guidance, and enlighten new thinking on digital twins for asset owners, consultants, facility managers, contractors, designers, policymakers and researchers. Systematic and structured approaches to the creation and use of digital twins in AEC and FM sectors are provided, including principles, system architecture, data structure, descriptions and methods of creating the proposed architecture's five layers (data acquisition, data transmission, digital model, data–model integration and services), and practical use cases of digital twin implementation at the built asset, building and city levels. The available multi-tier architectures and data structures, for example, the internet of things (IoT), are many and varied, with new concepts and technologies emerging all the time. The system architecture and data structure presented in this book are developed based on current research into multi-tier architectures, verified by use cases. The contents of this book follow this proposed architecture and also outline the first steps of digital twin development for effective operation and maintenance of assets, buildings and cities. The book also presents subsequent directions, and summarises specific efforts to promote the implementation and development of digital twins at different levels.

2. Companion publications

Ever since the UK National Infrastructure Commission proposed the concept of a national digital twin in their report *Data for the Public Good* (NIC, 2017), the importance of and focus on digital twins in the AEC and FM sectors have increased significantly. However, until now, there has been no specific book providing a holistic view of digital twins from the asset level to the city level. *Digital Twin Technologies and Smart Cities* (Farsi *et al.*, 2020) has been published; however, that publication is focused on value delivery for smart cities. This digital twin book has been published by one of the first teams to focus on the whole digital twin journey for the AEC and FM sectors, and we believe it fills an important gap in the market. In addition, this book will be the first to take the reader on a rewarding tour of hierarchical digital twin implementations. It facilitates the idea of creating a national digital twin by bringing together existing and evolving digital twins at different scales and granularity using a common language.

The main authors have produced a series of companion publications related to the digital twin in the built environment.

- The basic understanding of digital twins: *Moving from building information models to digital twins for operation and maintenance* (Lu *et al.*, 2020a).
- System architecture and a case study of the digital twin: *Developing a dynamic digital twin at building and city levels: a case study of West Cambridge Campus* (Lu *et al.*, 2020b).
- Digital twin implementation (anomaly detection): *A digital twin-enabled anomaly detection system of asset monitoring for operation and maintenance management* (Lu *et al.*, 2020c).
- Digital twin extension with other technologies (augmented reality): *Visualised inspection system development for monitoring environmental anomalies in daily O&M management* (Xie *et al.*, 2020).
- Geometrical digital twin creation:
  - *Semi-automatic geometric digital twinning for existing buildings based on images and CAD drawings* (Lu *et al.*, 2020d)
  - *Image-driven fuzzy-based system to construct as-is IFC BIM objects* (Lu *et al.*, 2018)
  - *Image-based technologies for constructing as-is building information models for existing buildings* (Lu and Lee, 2017).

3. Outline

This book is aimed at both practitioners and academics and will focus on both theoretical and practical aspects of digital twins.

The five main authors are responsible for the main chapters (Chapters 1 to 9) of this book, extension with other technologies (Chapter 10 part 1), asset level case studies (Chapter 11), a building level case study (Chapter 12 part 1) and the introductions for the remaining chapters.

Invited authors provide modelling approaches, in Chapter 7, extension with other technologies (Chapter 10 part 2), case studies (Chapters 12 and 13), and the digital future (Chapter 14).

Chapter 2 reviews the definitions and principles of digital twins in the AEC and FM sectors and the manufacturing sectors. Chapter 3 provides an overview of typical digital twin implementations – capabilities, technologies and Gemini Principles. Chapter 4 is mainly concerned with introducing the system architecture of digital twins. Chapters 5 to 9 introduce the five layers of the proposed architecture separately, including the data acquisition layer, transmission layer, digital modelling layer, data–model integration layer and services layer. Chapter 7 part 1 (by Professor Jack Cheng) describes scan-to-building information model (BIM) approaches and Chapter 7 part 2 (by Dr Long Chen) introduces image-to-BIM approaches. Chapter 10 mainly focuses on how the digital twins can be extended using other technologies, for example, Chapter 10 part 1 looks at augmented reality supported digital twin systems for monitoring environmental anomalies and Chapter 10 part 2 (by Dr Eirini Konstantinou) describes a QR code-supported digital twin system for maintenance prioritisation.

Case studies at the built asset, building and city levels are provided in Chapters 11 to 13: Chapter 11 presents studies of digital twin implementations at the asset level, Chapter 12 looks at digital twin implementations at the building level and Chapter 13 explores digital twin implementations at the region or city level, using the examples of Cambridge Biomedical Campus (Chapter 13 part 1, by Dr Li Wan) and Smart Poli Town in China (Chapter 13 part 2, by Ms Jiayi Yan).

Finally, Chapter 14 (by Professor Chimay Anumba and Dr Qiuchen Lu) summarises the whole book and provides a direction towards a digital built environment.

REFERENCES

CRC Construction (2007) *Adopting BIM for facilities management: Solutions for managing the Sydney Opera House*. Cooperative Research Centre for Construction Innovation, Brisbane, Australia. http://www.construction-innovation.info/images/CRC_Dig_Model_Book_20070402_v2.pdf (accessed 06/04/2021).

Farsi M, Daneshkhah A, Hosseinian-Far A and Jahankhani H (2020) *Digital Twin Technologies and Smart Cities*. Springer, Cham, Switzerland.

Gartner (2017) Prepare for the Impact of Digital Twins. https://www.gartner.com/smarterwithgartner/prepare-for-the-impact-of-digital-twins/ (accessed 06/04/2021).

Lu QC and Lee S (2017) Image-based technologies for constructing as-is building information models for existing buildings. *Journal of Computing in Civil Engineering* **31(4)**: 04017005.

Lu QC, Lee SH and Chen L (2018) Image-driven fuzzy-based system to construct as-is IFC BIM objects. *Automation in Construction* **92**: 68–87.

Lu QC, Xie X, Parlikad AK, Schooling JM and Konstantinou E (2020a) Moving from building information models to digital twins for operation and maintenance. *Proceedings of the Institution of Civil Engineers – Smart Infrastructure and Construction*. https://doi.org/10.1680/jsmic.19.00011.

Lu QC, Parlikad AK, Woodall P *et al.* (2020b) Developing a digital twin at building and city levels: case study of West Cambridge Campus. *Journal of Management in Engineering* **36(3)**: 05020004. https://doi.org/10.1061/(ASCE)ME.1943-5479.0000763.

Lu QC, Xie X, Parlikad AK and Schooling JM (2020c) A digital twin-enabled anomaly detection system of asset monitoring for operation and maintenance management. *Automation in Construction* **118**: 103277.

Lu QC, Chen L, Li S and Pitt M (2020d) Semi-automatic geometric digital twinning for existing buildings based on images and CAD drawings. *Automation in Construction* **115**: 103183.

Ma Y, Li G, Xie H and Zhang H (2018) City profile: using smart data to create digital urban spaces. *ISPRS Annals of Photogrammetry, Remote Sensing & Spatial Information Sciences* **IV-4/W7**: 75–82.

Mohammadi N and Taylor JE (2017) Smart city digital twins. *2017 IEEE Symposium Series on Computational Intelligence (SSCI)*. IEEE, Piscataway, NJ, USA, https://doi:10.1109/SSCI.2017.8285439.

NIC (National Infrastructure Commission) (2017) *Data for the Public Good*. https://nic.org.uk/app/uploads/Data-for-the-Public-Good-NIC-Report.pdf (accessed 31/07/2021).

Oliver D, Adam D and Hudson-Smith AP (2018) Living with a Digital Twin: Operational management and engagement using IoT and Mixed Realities at UCL's Here East Campus on the Queen Elizabeth Olympic Park. *Proceedings of the 26th Annual GIScience Research UK Conference.*

Xie X, Lu QC, Parlikad AK and Schooling JM (2020) Visualised inspection system development for monitoring environmental anomalies in daily O&M management. *Engineering, Construction and Architectural Management* **27(8)**: 1835–1852.