CONSTRUCTION 4.0

A GUIDE FOR DIGITAL TRANSFORMATION

CIDB MALAYSIA

CONSTRUCTION 4.0

A Guide for Digital Transformation

> **"The journey towards digital transformation is a continuous process of learning and adaptation. Let's embrace the change and build a better future together."**

CONSTRUCTION 4.0 - A Guide For Digital Transformation

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Editorial

The Construction Industry Development Board (CIDB) Malaysia developed **Construction 4.0: A Guide for Digital Transformation**. We want to thank the following members for their contributions and support.

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Editorial

Preface

Excellent technological and scientific advances have been made in appreciation of the Industrial Revolution, which mainly focuses on computers and cyber-physical systems. The construction industry has also benefitted from this progress and is, thus, evolving at a rapid pace, resulting in Construction 4.0. This term refers to the latest fourth industrial revolution (IR4.0) in the construction sector, which has gained significant recognition recently. Although the Construction 4.0 definition has dynamically evolved, it can still be described as a meta-concept that embraces major areas of transformation- production and construction, cyber-physical systems, and digital technologies.

To propel innovation and digitalisation forward, the government has implemented several initiatives to support and advance the revolution agenda, including the National 4.0 Industry Policy (Industry4WRD), Shared Prosperity Vision 2030, Malaysian National IoT Strategic Roadmap, Smart City Framework, and Digital Economic Policy. In 2021, CIDB established the Construction 4.0 Strategic Plan 2021-2025, highlighting and mapping twelve emerging technologies in the construction supply chain. This C4.0 has been classified into three clusters- Modelling and Simulation, Digitalisation and Virtualisation, and Smart Construction. The highlighted twelve emerging technologies that have been mentioned include Building Information Modelling (BIM), Internet of Things (IoT), Cloud & real-time collaboration, Big Data Analytics (BDA), Artificial Intelligence (AI), Blockchain, Augmented Reality (AR) & Virtual Reality (VR), Prefabrication & Modular Construction, Photogrammetry & 3D Scanning, Additive Manufacturing (AM), Advanced Building Materials, and Autonomous Construction. Leveraging technologies offers new opportunities to increase competitiveness, optimise the process, improve efficiency and quality of work, enhance safety, improve productivity, and achieve the goals of a sustainable building environment towards significant contribution to Environmental, Social, and Governance (ESG) goals.

This guidebook offers a framework for comprehending and executing Construction 4.0 in the Malaysian Construction Industry. Additionally, it serves as the primary source for the Construction Industry Standard CIS 18: Manual for IBS Content Scoring System (IBS Score). This manual emphasises solutions that enhance productivity and technology adoption to achieve a favourable IBS Score in the scoring system. This document also sets the principles that provide direction to support the implementation of the Industrial Building System (IBS) in construction projects. Transformation of the construction method from conventional to IBS is essential to help mould Malaysia's construction to adopt technological advancements.

Ultimately, this guide is the central pillar in our mission to shape competitiveness among stakeholders and game changers in the construction industry's landscape.

About This Guide

This guide is a comprehensive resource for implementing Construction 4.0 (C4.0) in the Malaysian construction industry. The importance of this guide is underscored by recent research findings that reveal a low level of understanding of C4.0 technology within the industry. The guide addresses this gap and facilitates the industry's transition into the digital era. The significance of this guide is multi-dimensional and can be summarised as follows:

01

Industry Education:

This guide is an educational tool that demystifies C4.0 technology and facilitates its adoption and implementation. It empowers the industry by enhancing its understanding of C4.0.

02

Familiarising with Available Technologies:

The guide emphasises the significance of comprehending the various technologies in C4.0 and their benefits. This knowledge is essential for the Malaysian construction sector, as it helps score points under Part 3: IBS Score for Other Simplified Construction Solutions in CIS 18: Manual for IBS Content Scoring System (IBS Score).

03

Enhancement of Efficiency and Effectiveness:

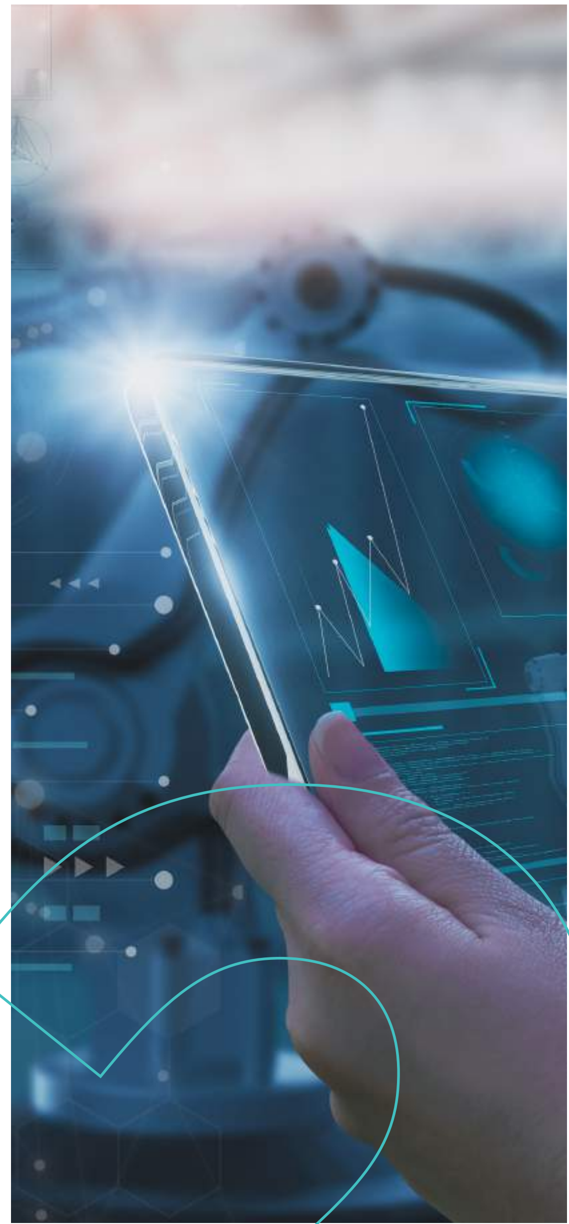
The guide explains how C4.0 integrates various digital technologies and procedures to enhance the efficiency and effectiveness of construction projects. It offers a roadmap for achieving operational excellence.

04

Successful Implementation of C4.0:

With accurate information from this guide, the Malaysian construction industry can successfully implement C4.0 and reap its numerous benefits.

The guide is structured into five chapters, each addressing a distinct aspect of C4.0:



1. Chapter 1: Introduction:

This chapter provides an overview of Construction 4.0 (C4.0), a strategic plan that has been launched by the Malaysian government to revolutionise the productivity and competitiveness of the construction industry by embracing the principles and technologies of the Fourth Industrial Revolution (IR 4.0). The plan aligns with key national initiatives to transform Malaysia into a digitally driven, high-income nation. It identifies four key enablers and 12 breakthrough technologies that are expected to transform the construction landscape. The chapter also defines C4.0 and discusses the three technology clusters in C4.0- Modelling and Simulation, Digitalisation and Virtualisation, and Smart Construction. It will emphasise the advantages of implementing C4.0, contributing to Environmental, Social, and Governance (ESG) objectives and Sustainable Development Goals (SDGs), leading to a more efficient, secure, and sustainable future in the construction sector.

2. Chapter 2: Modelling and Simulation:

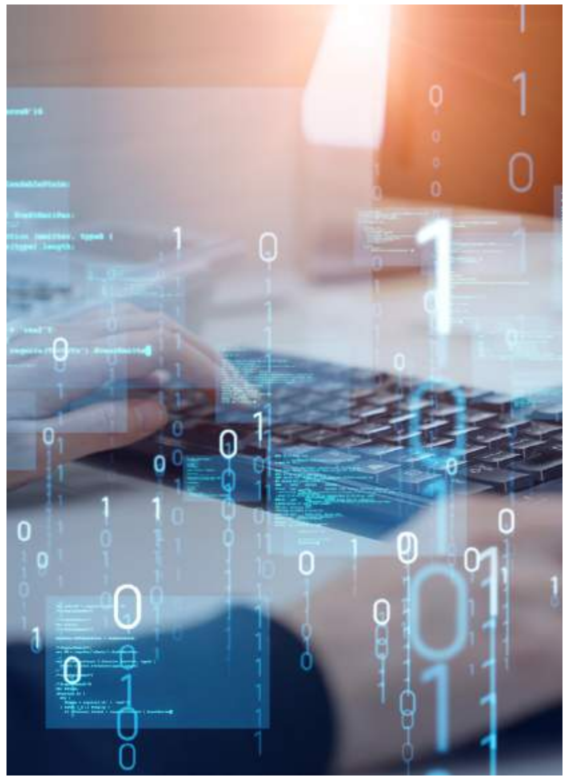
This chapter discusses the role of modelling and simulation in the construction industry, particularly the use of Building Information Modelling (BIM). The section provides an overview of Building Information Modelling (BIM), a process that allows construction professionals to create and manage information about a built asset. It discusses the role of ISO 19650, an international standard for managing information over the whole life cycle of a built asset using BIM. The section also explains the concept of BIM levels and the methodology for BIM model development. It highlights the benefits of BIM implementation in the construction industry, such as increased productivity, improved communication, and cost savings. The section concludes with a discussion of the future advancements in BIM development, including integrating BIM with emerging technologies such as IoT, Clouds, and real-time collaboration and GIS.

3. Chapter 3: Digitalisation and Virtualisation:

This chapter, "Digitalisation and Virtualisation," discusses the transformative roles of these two technologies in the construction industry as part of the Construction 4.0 Strategic Plan (2021-2025). It explores how IoT, cloud and real-time collaboration, BDA, AI, blockchain, and AR and VR are reshaping project management and execution, enhancing safety, reducing costs, and improving visibility and control. The chapter differentiates between digitalisation, which involves using digital technologies to transform business models, and virtualisation, which consists of creating virtual versions of resources. By digitalising project information and creating virtual models, construction firms can enhance efficiency, safety, health, quality and customer satisfaction, contributing to a more efficient and improved construction industry.

4. Chapter 4: Smart Construction:

This chapter delves into Smart Construction, a vital component of the Construction 4.0 Strategic Plan (2021-2025), which leverages modern technologies to boost efficiency, accuracy, and safety in construction projects. It discusses advanced tools such as prefabrication and modular construction, photogrammetry and 3D scanning, AM, advanced building materials, and autonomous construction. Integrating these technologies can revolutionise the construction industry, leading to quicker, more precise, and more cost-effective project completion. Additionally, these technologies can contribute to reduced labour costs, improved safety, enhanced productivity, better resource utilisation, and increased competitiveness, thus making the construction industry more efficient, sustainable, and resilient.



5. Chapter 5: Best Practices:

This chapter presents various case studies highlighting innovative practices in the construction industry. It is divided into two sections: building projects and infrastructure projects. The building projects section includes case studies on the TNB Platinum, the TRX Residences Plot 1C, and the Pembinaan Bangunan Tambahan Di SK Taman Scientex, showcasing how these projects revolutionised, innovated, and transformed their respective areas. The infrastructure projects section delves into the MRT Putrajaya Line Project, the Pan Borneo Highway Sarawak, and the Projek Penswastaan Lebuh Raya Bertingkat Sungai Besi - Ulu Kelang (SUKE), demonstrating how these projects innovated and revolutionised infrastructure development. These case studies collectively illustrate the application of the best practices in the construction industry.

In conclusion, the adoption and implementation of C4.0 in the Malaysian construction industry mark a transformative step towards increased efficiency and effectiveness. This guide serves as a comprehensive resource for understanding and applying C4.0 technologies. By embracing these advancements, the industry can anticipate a future of improved project outcomes and significant growth. Remember, the journey towards digital transformation is a continuous process of learning and adaptation. Embrace the change, and let's build a better future together.

INTRODUCTION

"This chapter provides an overview of Construction 4.0 (C4.0), a strategic plan that has been launched by the Malaysian government to revolutionise the productivity and competitiveness of the construction industry by embracing the principles and technologies of the Fourth Industrial Revolution (IR 4.0). The plan aligns with key national initiatives to transform Malaysia into a digitally driven, high-income nation. It identifies four key enablers and 12 breakthrough technologies that are expected to transform the construction landscape. The chapter also defines C4.0 and discusses the three technology clusters in C4.0- Modelling and Simulation, Digitalisation and Virtualisation, and Smart Construction. It will emphasise the advantages of implementing C4.0, contributing to Environmental, Social, and Governance (ESG) objectives and Sustainable Development Goals (SDGs), leading to a more efficient, secure, and sustainable future in the construction sector."

1.0 Introduction

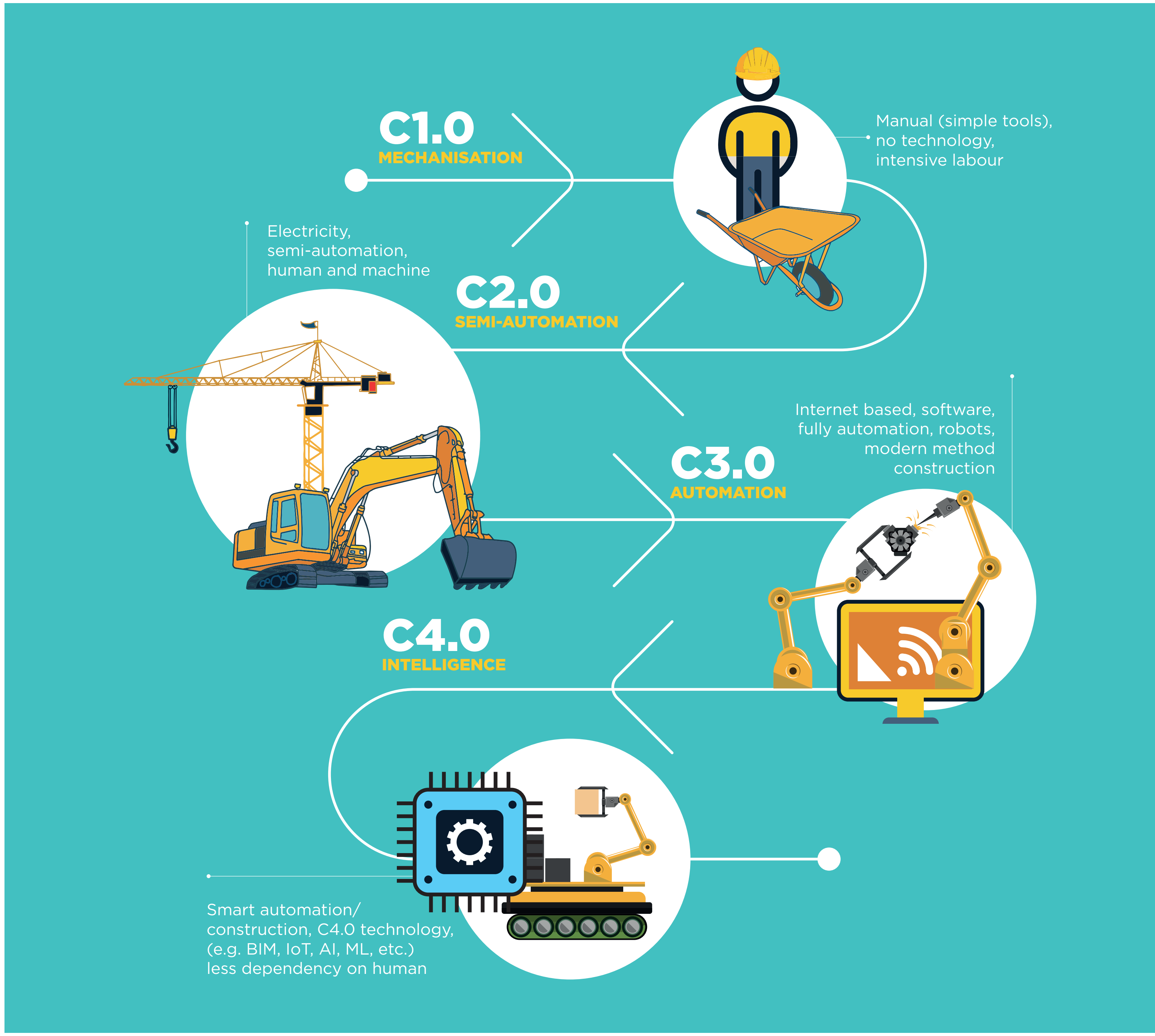
1.1 Overview of Construction 4.0

The Malaysian government has recognised the transformative potential of the Fourth Industrial Revolution (IR 4.0) and has taken proactive steps to ensure that the local construction industry is not left behind. Through the Ministry of Works and the Construction Industry Development Board (CIDB), the government has launched the Construction 4.0 Strategic Plan (2021-2025). This strategic plan is designed to revolutionise the productivity and competitiveness of the Malaysian Construction Industry by embracing the principles and technologies of IR 4.0.

The Construction 4.0 Strategic Plan aligns with several national key initiatives, including the Shared Prosperity Vision 2030, the National Policy on the IR 4.0 (Industry4WRD), the National Internet of Things (IoT) Strategic Roadmap, the Malaysia Smart City Framework, and the Digital Economy Blueprint. These initiatives collectively aim to transform Malaysia into a digitally driven, high-income nation that is inclusive and sustainable.

The strategic plan identifies four key enablers and 12 emerging technologies expected to transform the future of the construction landscape. These technologies range from advanced robotics and 3D printing to big data and artificial intelligence. The government's investment in the construction industry since the 1980s has already begun to yield results, transforming the industry from a manual labour-intensive sector to a more advanced and technology-driven as shown in **Figure 1.1**.

The government's strategic direction aims to help the construction industry navigate the changes brought about by the Fourth Industrial Revolution. Through this approach, it ensures that the sector remains competitive and continues to contribute to national economic growth. The adoption of C4.0 has already brought significant benefits to the industry and the broader economy, and with continued investment and support, these benefits are only expected to grow. The construction industry's future in Malaysia looks bright, with C4.0 paving the way for a more efficient, safe, and sustainable future.



Adapt from CIDB Malaysia, 2021

Figure 1.1 Revolution of construction

1.2 Construction 4.0 Definition

Construction 4.0 is the process of implementing modern technology to encourage the digitalisation of the construction industry and its supply chain.

- Construction 4.0 Strategic Plan (2021-2025) -

"Construction 4.0" refers to integrating digital technologies and innovative approaches in the construction industry. This concept emphasises using advanced technologies, such as AI, robotics, and the IoT, to optimise processes and improve efficiency throughout the construction life cycle. By leveraging these technologies, C4.0 aims to enhance safety, reduce costs, and increase sustainability in construction projects. Ultimately, this approach enables the industry to keep up with the demands of an ever-changing world by embracing the latest technological advancements.

1.3 Technology Clusters in Construction 4.0

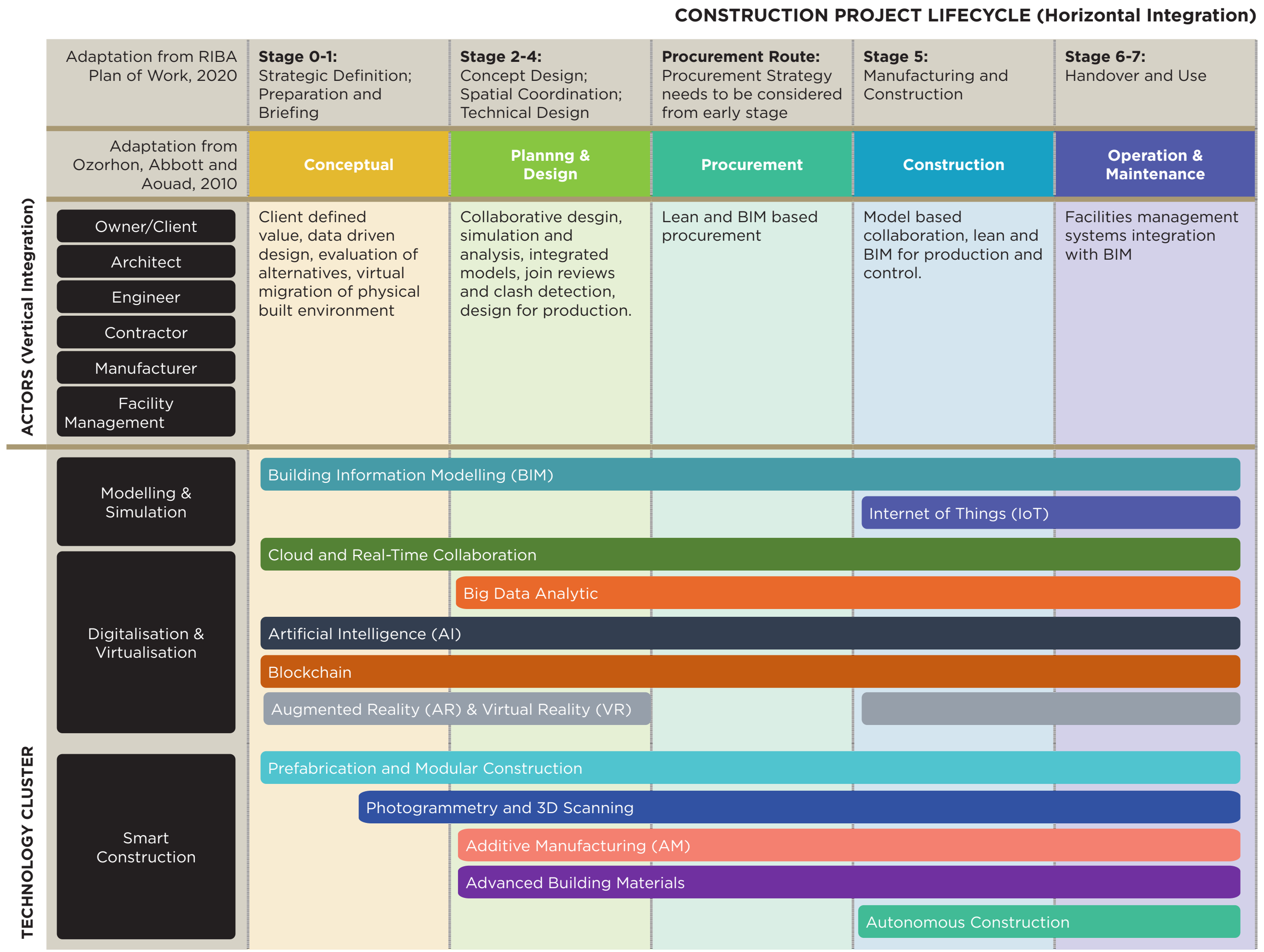
The twelve emerging technologies in C4.0 are grouped into three clusters:

1. **Modelling and Simulation:**
This cluster is central to C4.0 as every construction project is unique, complex, and is influenced by local external factors. BIM adoption under the Standardised Information Management Approach can be applied to construction projects and organisation management to improve the build asset life cycle and contribute to the creation of smart cities.

2. **Digitalisation and Virtualisation:**
This cluster offers various simulation tools, models, and frameworks for project planning, resource planning, and or project management. These digitalisation and virtualisation technologies focus on the interoperability of digital project data, information management, or digitalisation in general.

3. **Smart Construction:**
This cluster comprises a wide range of technologies and concepts to automate the construction process, creating a "Smart Construction" ecosystem for the construction industry. The corresponding technologies of this cluster would be able to accommodate the digital integration of engineering, regarded as one of the critical features of C4.0

These clusters of technologies interlock with each other and drive the nation's vision even further. This clustering is to organise the technologies based on their functionalities and applications in the construction industry. Significantly, this helps in understanding how these technologies interact and provide a structured approach to their implementation. **Figure 1.2** shows the twelve emerging technology implementations throughout the construction supply chain in their respective clusters.



Adapt from CIDB Malaysia, 2021

Figure 1.2 Emerging technology implementation throughout the construction supply chain.

1.4 Key Enablers of Construction 4.0

C4.0 is not only about technology but being able to allocate suitable resources to implement the transition effectively. Adoption of appropriate strategies and supporting measures are essential to implement digital technologies in the context effectively. According to the Strategic Plan of Construction 4.0 for 2021-2025, the four (4) key enablers are:

(a) **People**
This refers to the human resources that are involved in the construction industry. It is about upskilling and reskilling the workforce to adapt to new technologies and methods. This includes training programs, workshops, and continuous learning opportunities to ensure that the workforce has the necessary skills to operate in a digitalised environment.

(b) **Integrated Technology**
This is about adopting and integrating advanced technologies such as BIM, AI, IoT, and more into the construction processes. The aim is to improve efficiency, productivity, safety, health, and quality while reducing costs and environmental impact.

(c) **Governance**
This involves establishing policies, regulations, and standards to guide the implementation of C4.0. It includes the development of a legal and regulatory framework that supports the adoption of digital technologies, protects stakeholders, and promotes fair competition.

(d) **Economy**
This refers to the financial aspects of implementing C4.0. It involves assessing the economic feasibility of technology adoption, securing funding and investments, and understanding the economic benefits and returns on investment. It also includes exploring financial schemes and incentives that can support the transition to C4.0.

The integrated adoption of both technology and these enablers directs the industry to the missions and objectives of C4.0 in a strategic and structured manner. It is about creating a sustainable and resilient construction industry that is ready for the future.

1.5 Goals & Benefits of Adopting Construction 4.0

C4.0 integrates digital, physical, and biological technologies to revolutionise the construction industry. This signifies a new era in which technology and digitalisation play pivotal roles in boosting productivity, improving safety, and promoting sustainable construction practices. **Figure 1.3** illustrates the 17 Sustainable Development Goals outlined by the United Nations, while **Figure 1.4** depicts the relationship between ESG and SDGs when adopting C4.0.

Sources The official United Nations Sustainable Development Goals website, 2024

Figure 1.3 United Nations Sustainable Development Goals: A Universal Call to Action.

Figure 1.4 Relationship between ESG and SDGs adopting C4.0.

Adopting C4.0 can significantly contribute to the Environmental, Social, and Governance (ESG) goals and the Sustainable Development Goals (SDGs):

(a) Environmental, Social, and Governance (ESG) benefits:

ESG factors have become increasingly important in the construction industry. The adoption of C4.0 technologies can significantly enhance ESG performance in several ways:

i. Environmental:

Advanced technologies such as BIM, 3D printing, and automated machinery can optimise resource usage, reducing waste and minimising the environmental footprint of construction activities. C4.0 promotes prudent use of resources and significantly reduces carbon usage and emissions for helping to achieve Malaysia's carbon-neutrality target of 2050. It also supports sustainable practices such as using sustainable materials and reducing waste materials. Technologies enable green building design optimisation and provide incentives to reduce Carbon Emissions.

ii. Social:

C4.0 improves worker safety through technologies such as wearables and drones for site inspections, reducing the risk of accidents. It also enhances transparency and stakeholder engagement through real-time project updates. Smart construction considers the impact on local communities such as noise reduction, minimised disruption, and positive community engagement contribution. Training workers in digital tools and technologies improve their skills and employability, benefiting the workforce. The digitalisation of existing buildings enhances building safety and facilitates urban renewal for promoting well-being and living quality.

iii. Governance:

Digital tools enable better project management, improving efficiency, and accountability. They also support regulatory compliance, for instance, through accurate tracking of environmental metrics. Digital data platforms enable transparent project management where stakeholders can access real-time data, financial information, and progress reports. A smart construction approach helps identify and mitigate risks related to project delays, cost overruns, and compliance issues. By adhering to governance standards and efficient compliance checks, construction companies demonstrate accountability and ethical practices.

(b) Sustainable Development Goals (SDGs) benefits:
The integration of C4.0 technologies can significantly contribute to the achievement of the United Nations Sustainable Development Goals (SDGs) in the following ways:

i. No Poverty and Decent Work and Economic Growth (SDGs 1 & 8):

C4.0 can create new job opportunities and upskill the workforce, contributing to economic growth and poverty reduction.

ii. Industry, Innovation, and Infrastructure (SDG 9):

Technologies such as BIM, AI, and IoT drive innovation in construction processes and infrastructure development.

iii. Sustainable Cities and Communities (SDG 11):

Digital tools enable the construction of sustainable and resilient buildings and infrastructure, promoting sustainable urban development.

iv. Responsible Consumption and Production (SDG 12):

C4.0 optimises resource usage, reducing waste and promoting circular economy principles in the construction sector.

v. Climate Action (SDG 13):

Advanced construction technologies can reduce the industry's carbon footprint, contributing to climate change mitigation.

In conclusion, these benefits highlight how C4.0 can help the construction industry meet its ESG and SDGs, leading to more sustainable and responsible practices. It is a step towards a more efficient, safe, and sustainable future. Adopting C4.0 is about using new technologies and changing how we think and approach construction. It is an exciting time for the industry as we move towards a more efficient, safe, and sustainable future.

2 MODELLING AND SIMULATION

2.1 Building Information Modelling (BIM)

“This chapter discusses the role of modelling and simulation in the construction industry, particularly the use of Building Information Modelling (BIM). The section provides an overview of Building Information Modelling (BIM), a process that allows construction professionals to create and manage information about a built asset. It discusses the role of ISO 19650, an international standard for managing information over the whole life cycle of a built asset using BIM. The section also explains the concept of BIM levels and the methodology for BIM model development. It highlights the benefits of BIM implementation in the construction industry, such as increased productivity, improved communication, and cost savings. The section concludes with a discussion of the future advancements in BIM development, including integrating BIM with emerging technologies such as IoT, Clouds, and real-time collaboration and GIS.”

2.0 Modelling and Simulation

Modelling and simulation are integral clusters in the Construction 4.0 Strategic Plan (2021-2025), playing a crucial role in the construction industry. These clusters employ computer-generated designs and simulations to assist with project planning, design, and construction. The technology that is used in this cluster is known as **Building Information Modelling (BIM).**

Modelling and simulation can create a virtual construction project model before the commencement of the actual project, providing designers and engineers with a better understanding of the project and identifying any potential issues that may arise. This technology can also test various materials and techniques before implementation in a real-world scenario, reducing potential Variation Order (VO) and number of Extensions of Time (EOT).

Modelling can help identify potential hazards and risks that are associated with the project. By running simulations, designers can identify potential safety concerns and mitigate these risks, ensuring that the project is completed safely and efficiently.

Modelling and simulation can also analyse project performance by identifying areas where improvements can be made. This technology can help recognise opportunities to refine existing processes and improve outcomes. By simulating various scenarios, designers and engineers can analyse the project's performance over time and identify areas of improvement.

In addition to Building Information Modelling (BIM), several modelling and simulation tools or platforms are commonly utilised in the construction industry. These include Geographic Information Systems (GIS), Civil/City/Construction Information Modelling (CIM), Structure Information Modelling (SIM), Virtual Design and Construction (VDC), and Landscape Information Modelling (LIM).

(a) Geographic Information Systems (GIS):
GIS is a framework that facilitates collecting, managing, and analysing data about a construction project's physical location. It is a valuable tool for engineers to gather and analyse geographic information.

(b) Civil/City/Construction Information Modelling (CIM):
CIM, an extension of BIM, focuses on urban planning and design. It is a process based on 3D model management of large areas or complex systems with several BIM models.

(c) Structure Information Modelling (SIM):
SIM creates digital replicas of below-ground structures such as utilities, tanks, voids, and bedrock.

(d) Virtual Design and Construction (VDC):
VDC is a management tool for integrated project delivery, focusing on using multi-disciplinary performance models for design-construction projects.

(e) Landscape Information Modelling (LIM):
LIM is a concept used in landscape architecture. It is an extension of BIM that focuses on the planning, design, and management of landscapes.

These modelling techniques have unique applications and benefits for the construction industry. They can often be used with a more comprehensive approach to construction project management.

2.1 Building Information Modelling (BIM)

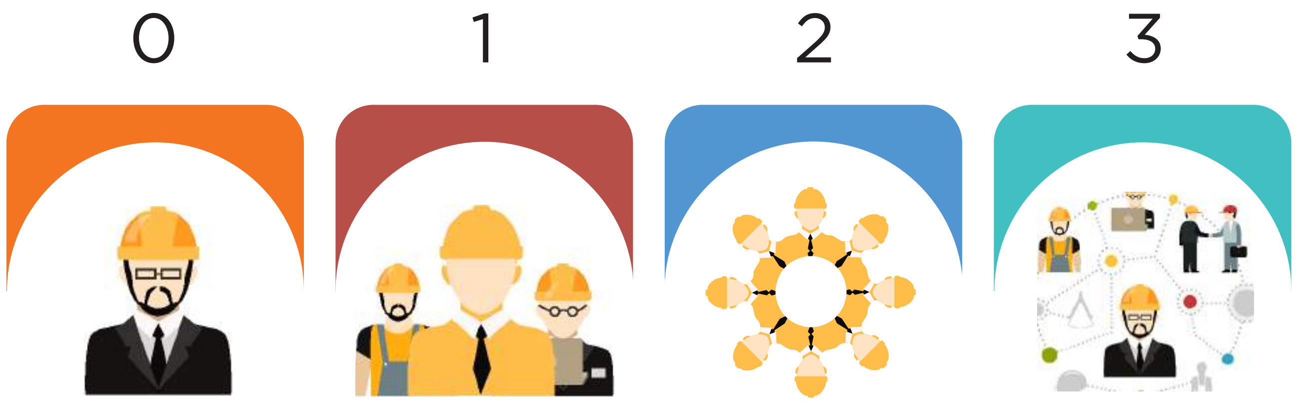
2.1.1 Overview of BIM

BIM is a comprehensive and collaboratimve process that allows architects, engineers, real estate developers, contractors, manufacturers, and other construction professionals to create and manage information about a built asset. It involves making an intelligent 3D model and using a cloud platform to integrate structured, multi-disciplinary data. This results in a digital asset representation spanning its entire life cycle, from initial planning and design to construction, operation, and maintenance.

In addition to BIM, ISO 19650 plays a crucial role in the construction industry. ISO 19650 is an international standard for managing information over the whole life cycle of a built asset using building information modelling (BIM). It contains all the same principles and high-level requirements as BIM Level 2 and is closely aligned with the UK 1192 standards. This standard outlines the concepts and principles for information management using building information modelling (BIM) for any built asset. It provides recommendations for a framework to exchange, record and organise information for all involved in the whole life cycle of any built asset. This standard contributes to the following Sustainable Development Goal 9. The adoption of ISO 19650 helps to standardise processes, promote efficiency, and improve the quality of outcomes in the construction industry.

2.1.1.1 Understanding of BIM Maturity Levels

BIM maturity levels are characterised into stages, ranging from minimal collaboration to full integration of processes and data. The commonly recognised BIM maturity levels include Level 0, Level 1, Level 2, and Level 3. This document utilises BIM Levels to remain consistent with CIS 18: Manual for IBS Content Scoring System (IBS Score) terminology. Nevertheless, BIM Guide 5 and the Construction Industry Transformation Programme (CITP) employ BIM Stages. BIM Levels serve varied purposes across different project types. They are intended to integrate precise and pertinent information into the BIM model throughout the design-build process. **Figure 2.1** presents the BIM Levels and characteristics that are suitable for effective implementation in Malaysia. Notably, CIS 18 emphasises that the IBS project should attain at least Level 1 in BIM implementation to gain points involving modelling tools in IBS design.



MANUAL	MODELLING	COLLABORATIVE	INTEGRATION
2D CAD/Managed	Discipline-based 3D models.	Collaboration-based 3D Model with digital information.	Integrated 3D model and digital information through integrated network or cloud-based applications.
Both manual and computer-based documents are used, such as CAD drawings and spreadsheets.	The application of BIM tools (if applied) streamlines the design or constrcution activities. It is restricted internally.	The construction information will be managed in a structured manner in a 3D environment.	Use of a cloud-based BIM model to strengthen the collaborative progress coordination throughout the construction process.
Much of the project information (i.e, Drawings and written documents) is manually on paper.	No significant model-based interchanges among different disciplines.	The information can be shared and communicated using a specific and common platform.	Use of single sources of information on a cloud or common server.
Design information is not communicated effectively.	The implementation of BIM takes place in an isolated condition within the organisation.	Use of a multidisciplinary model that promotes collaborative processes.	
		Use of common standards for collaboration between different disciplines.	

Adapt from BIM Guide 1

Figure 2.1 BIM level and characteristics in Malaysia.

2.1.1.2 BIM Dimensions

BIM dimensions have evolved to extend the modelling approach, as illustrated in **Figure 2.2**. This helps various user groups understand the information and applications they can utilise from BIM. The commonly recognised dimensions are as follows:

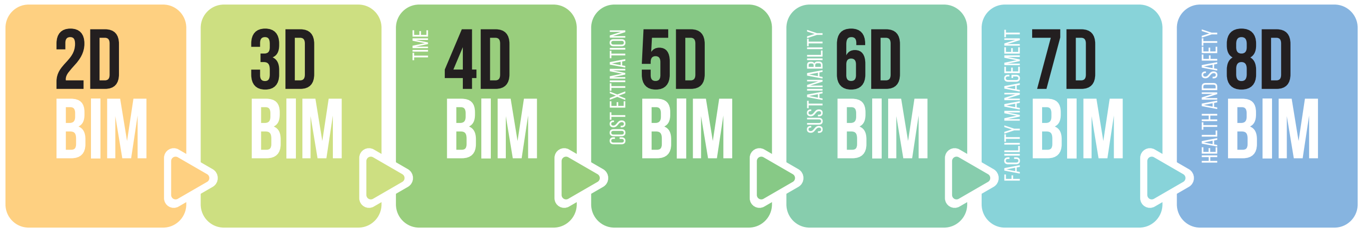


Figure 2.2 Evolution of BIM Dimensions.

(a) **2D BIM:**
2D BIM is a digital geometric model with an X and Y axis and associated information.

(b) **3D BIM:**
3D BIM involves a digital geometric model incorporating an X, Y, and Z axis and associated information.

(c) **4D BIM (Time):**
4D BIM involves adding scheduling information to the model to visualise construction sequences.

(d) **5D BIM (Cost estimation):**
5D BIM generally refers to adding cost information to a model for budget analysis and control during the planning, construction, and operating phases.

(e) **6D BIM (Sustainability):**
6D BIM occasionally includes a sustainability model for evaluating energy consumption, environmental impact, and pollution risk, among other factors.

(f) **7D BIM (Facility Management):**
7D BIM is associated with adding facility management information for the management and maintenance organisation throughout the facility's entire lifecycle.

(g) **8D BIM (Health and safety):**
8D BIM is occasionally connected to incorporating health and safety information to assess operators' risks and prevent critical hazardous scenarios.

2.1.1.3 BIM Model Development and Practice

BIM model development methodology is used to ensure that the model is reliable. This methodology allows the project team to specify the details and reliability of model elements at various stages of the project life-cycle. It is crucial to embed the model development methodology in the BIM Execution Plan (BEP) because it provides the foundation for reliable structured project information, collaboration, coordination, and data that the project team members will use.

(a) Level of Information Need (LOIN):

ISO 19650-1 introduces the term LOIN to define information services. LOIN is not a simple replacement for the LOD concept. The LOIN is intended for clients who define their information needs for project management. Within the LOIN concept, various metrics can be used to measure the information that is to be delivered, particularly geometry, alphanumeric data and documents, for example, unstructured information such as plans, reports, photographs and so on. At the very least, alphanumeric information should be as important as geometry.

(b) Level of Development (LOD):

LOD defines the content of a BIM project in different stages of its development. It grows as the project progresses and is enriched with details, evolving from a simple initial concept to a construction model. LOD also refers to the degree of completeness and accuracy of both the graphical and non-graphical information within a BIM element. It considers the visual representation, associated data, and attributes. LOD levels go from 100 to 500, shifting from conceptual to detailed representations.

The LOD consists of 2 elements:

a) the geometry or visual representation of a project – LOG (Level of Geometry).

b) the data attached to the objects of the BIM model – LOI (Level of Information).

(c) Level of Detail (LOd):

LOd describes the complexity of a 3D model representation, summarising the geometric (LOG, Level of Geometry), and meta information (LOI, Level of Information). It is used in the construction industry to describe the model elements' level of detail and maturity.

(d) Level of Geometry (LOG)

LOG focuses on the appearance of the objects in a model. It gives us an idea of their appearance, position, and orientation within the model space. It is part of the LOD concept, which describes the complexity of a 3D model representation.

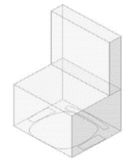
MODELLING AND SIMULATION

(e) Level of Information (LOI):

LOI is a framework that groups geometry, information, and documentation requirements in BIM projects. It provides a structured approach to define the level of detail, dimensionality, location, appearance, parametric behaviour, accuracy, and reliability of model elements.

Table 2.1 further explains the differences between LOD, LOd, LOG and LOI within the construction phase.

Table 2.1 BIM model development methodology.

Phase	Level of Development (LOD)	Level of Detail (LOd)	Level of Geometry (LOG)	Level of Information (LOI)
Planning	**LOD 100: Conceptual (presentation)** 	The model graphically represents the object (or structure) using symbols (e.g., a line or surface) or is generic (i.e., dimensions and quantities are not defined). This represents the overall geometric expression of the object.		Description : Office Chair Width : - Depth : - Height : - Manufacturer : - Model : -
Preliminary Design	**LOD 200: Approximate Geometry** 	An object (or structure) is geometrically represented as a generic object with approximate quantities, sizes, dimensions, location, and orientation. The function of the objects is described, and the model is further divided into several discipline models.		Description : Office Chair Width : 700mm Depth : 450mm Height : 1100mm Manufacturer : - Model : -
Detail Design	**LOD 300: Precise Geometry** 	An object (or structure) is graphically represented as a specific object exhibiting quantities, sizes, dimensions, location, and orientation. The object's overall function, performance, and material are described in detail.		Description : Office Chair Arms, Wheels Width : 685mm Depth : 430mm Height : 1085mm Manufacturer : - Model : -
Construction	**LOD 400: Fabrication/ Installation** 	Object (or structure) is graphically represented and possibly as a supplier-specific object with quantities, sizes, dimensions, location, and orientation. Objects are detailed for fabrication, assembly, and prefabrication and contain the installation information.		Description : Office Chair Arms, Wheels Width : 685mm Depth : 430mm Height : 1085mm Manufacturer : Herman Model : Mirra
Closeout/ Handover	**LOD 500: As-Built/ Facility Management** 	The quantities, sizes, dimensions, location, and object orientation are confirmed on-site (as built).		Description : Office Chair Arms, Wheels Width : 685mm Depth : 430mm Height : 1085mm Manufacturer : Herman Model : Mirra Serial Number : OCM03101 Purchase Date : 01/02/03

Adapt from CIDB Malaysia, 2019a; Al-Ashmori et al., 2020; BibLus, 2022

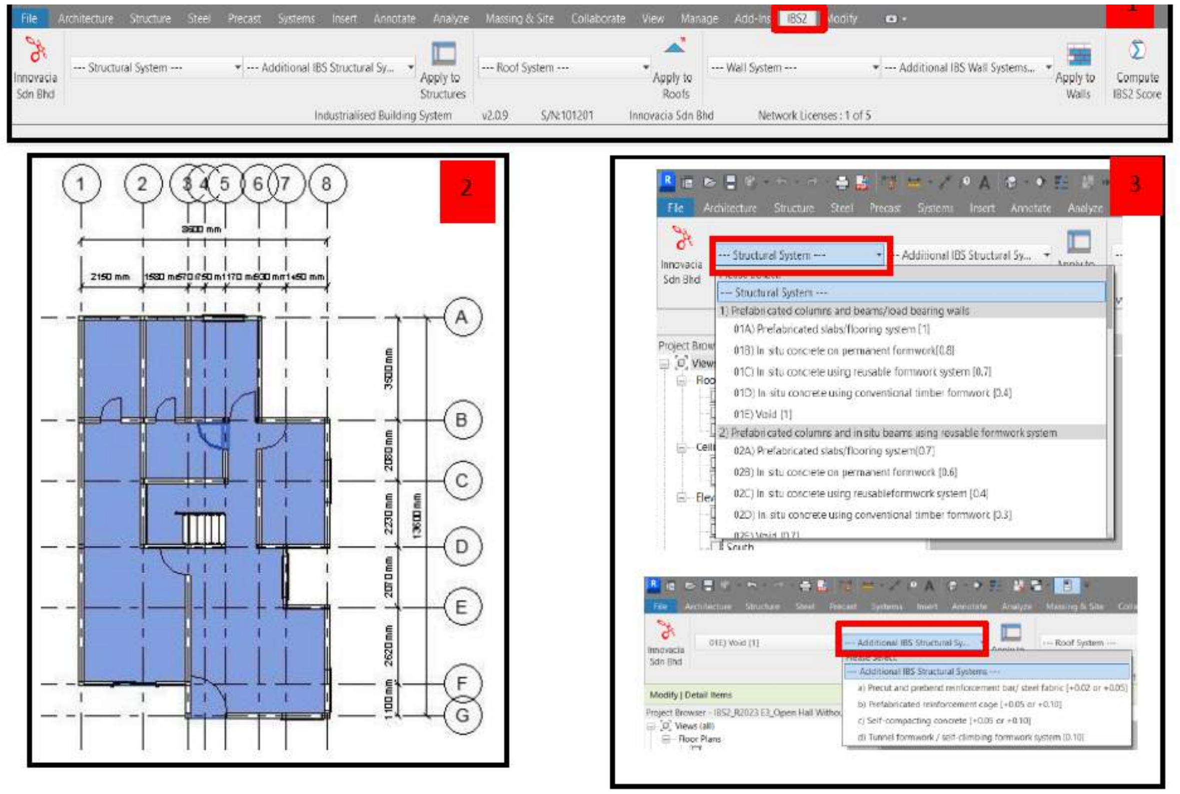
2.1.1.4 BIM Software for the Construction Industry

BIM software is essential for modern construction projects. It offers a range of solutions, from design to management, all aimed at optimising the building process. **Table 2.2** illustrates the key applications and BIM software solutions that are widely used in the construction industry. The software listed in the table represents just a portion of the available options and is not limited to these alone.

Table 2.2 Example of BIM software and application in the construction industry.

MODELLING AND VISUALISATION	ANALYSIS AND DESIGN	CLASH DETECTION	PROJECT COORDINATION	COST ESTIMATION	FACILITY MANAGEMENT
BIM software allows architects and designers to create accurate BIM models of buildings and infrastructures, enabling visualisation and exploring design alternatives such as design for safety.	BIM software allows engineers or architects to simulate, analyses, and run calculations to validate the design and meet project requirements.	During the design phase, BIM software can identify clashes between different building elements, such as structural components, electrical systems, and plumbing, saving time and reducing errors.	BIM platforms enable better collaboration among project stakeholders, facilitating efficient coordination between architects, engineers, contractors, subcontractors and manufacturers.	BIM software facilitates accurate cost estimation and material quantity calculations, enabling better project budgeting and procurement	BIM data can be used to manage and maintain buildings throughout their lifecycle, providing valuable information for maintenance, renovations, and future expansions.
WORLDWIDE BIM SOFTWARE					
a) Autodesk Revit b) Autodesk Civil 3D c) Graphisoft Archicad d) Tekla Structures e) Trimble SketchUp f) BlenderBIM	a) Tekla structure designer b) StaadPro c) Prota d) Cype	a) Acca usBIM. clash b) Autodesk Navisworks Manage c) Solibri	a) Autodesk Construction Cloud b) BIMcollab c) Trimble Connect d) AllPlan e) RIB CX	a) Cost-OS b) RIB CostX c) Vico Office d) Glodon Cubicost	a) Archibus by eptura b) IBM Maximo c) YouBIM
LOCAL DEVELOPED BIM SOFTWARE					
a) TiffinBIM	a) TiffinBIM b) MiLA Structure c) Esteem		a) BuildSpace b) Globe3 ERP c) Speedbrick		a) Cerev CMMS

Besides the listed software above, one of the applications of BIM in the Malaysian construction industry is the IBS Score analysis. The BIM-based IBS Score analysis simplifies the calculation of the IBS Score for buildings by providing automated calculations from BIM models. This technology is a great tool to execute the BIM-based IBS Score submission process to authorities and ease the authorities' checking process. It supports the C4.0 agenda through promotion and education that are related to IBS and BIM. **Figure 2.3** shows an example of a BIM-based IBS Score analysis that is developed by a local company.



Courtesy from Innovacia Sdn Bhd, 2024.

Figure 2.3 Example of BIM-based IBS Score analysis

2.1.2 Benefits of BIM Implementation in the Construction Industry

BIM is a transformative force in the construction industry. The benefits of implementing BIM are manifold and significant, fundamentally streamlining construction and design processes. This results in enhanced efficiency, reduced errors, and substantial time and cost savings. Here are some key benefits:

(a) Increased collaboration and coordination:
BIM fosters improved multi-party communication and maintains synchronised communication among all stakeholders on a shared digital workspace, ensuring everyone is on the same page.

(b) Reduced construction time and cost:
BIM allows for assessing time and costs for identifying potential problems before construction begins, facilitating better decision-making and budget management. It also enables off-site fabrication of building components, reducing construction time on-site, and resulting in significant cost savings overall.

(c) Improved quality of works:

The standardised BIM requirements and workflows lead to better quality assurance and control. Notably, BIM-enabled automatic compliance checks can further achieve accurate construction planning and coordination, resulting in a higher quality finished product, and thus it can be used for quality control to ensure that all building components and systems meet the required standards.

(d) Improved safety:

BIM allows for detailed visualisation and simulation of the construction process to identify potential safety hazards for managing risks. With a digital site model, a BIM-integrated site monitoring system can perform data analysis and alert generation, as well as facilitate follow-up actions with potential identification of hazards and abnormalities.

(e) Increased productivity and efficiency:

BIM helps to identify and resolve design clashes early on, preventing costly and time-consuming issues during construction. BIM boosts productivity and efficiency by enabling precise planning and coordination, reducing the likelihood of errors and rework. It also enables efficient project management through real-time monitoring and tracking of progress during construction, ensuring that the project stays on schedule and within budget.

(f) Enhanced sustainability:

BIM helps to identify opportunities for carbon footprint reduction and waste during construction and operation. BIM models can also be used for lifecycle assessment, which considers the environmental impact of a building over its entire lifespan.

(g) Improved facility management:

BIM models are an invaluable tool for evaluating the performance of building systems and enabling more efficient operation and maintenance as a result.

In essence, BIM's ability to improve project efficiency and reduce costs makes it an indispensable tool for any organisation involved in the construction industry.

2.1.3 The Future Advancements in BIM Development

The future of BIM is bright, with ongoing technological advancements and growing industry acceptance. BIM is expanding beyond its traditional roles in design and construction to encompass facility management, operations, and maintenance. Integrating BIM with emerging technologies such as cloud collaboration, IoT and GIS is set to revolutionise the industry further.

Here are some key advancements to look forward to:

(a) Generative design algorithms:

Modern BIM software incorporates generative design algorithms. These algorithms can explore many design options based on predefined parameters, aiding architects and designers in optimising building performance and aesthetics.

(b) Leveraging cloud collaboration:

BIM tools leverage cloud computing, enabling project teams to collaborate in real-time, regardless of geographical location. This not only enhances communication but also ensures seamless information exchange.

(c) IoT integration in building monitoring:

BIM software can now integrate data from the IoT, facilitating real-time building performance monitoring. This optimises energy consumption and promotes sustainability.

(d) GIS Integration:

GIS focuses on spatial location analysis and organises layers of information into visualisations using maps and 3D scenes. BIM-GIS integration enables comprehensive urban planning, infrastructure management, and optimising various city services and resources. The industry can ensure seamless data exchange and collaboration between GIS and BIM systems by adhering to standards.

In summary, BIM's future holds immense potential to transform how we design, construct, operate and maintain buildings and infrastructure, promoting sustainability, efficiency, and improved collaboration among the stakeholders.

2.1.4 Suggested Readings for Additional Information

To acquire comprehensive insights into the implementation of BIM in both organisational and project contexts, it is recommended that readers refer to the reference listed below:

a. ISO 19650-1:2018: Organization and digitisation of information about buildings and civil engineering works, including building information modelling (BIM) — Information management using building information modelling — Part 1: Concepts and principles. (2018). International Organization for Standardization (ISO).

b. ISO 19650-2:2018: Organization and digitisation of information about buildings and civil engineering works, including building information modelling (BIM) — Information management using building information modelling — Part 2: Delivery phase of the assets. (2018). International Organization for Standardization (ISO).

c. ISO 19650-3:2020: Organization and digitisation of information about buildings and civil engineering works, including building information modelling (BIM) — Information management using building information modelling — Part 3: Operational phase of the assets. (2020a). International Organization for Standardization (ISO).

d. ISO 19650-4:2022: Organization and digitisation of information about buildings and civil engineering works, including building information modelling (BIM) — Information management using building information modelling — Part 4: Information exchange. (2022). International Organization for Standardization (ISO).

e. ISO 19650-5:2020: Organization and digitisation of information about buildings and civil engineering works, including building information modelling (BIM) — Information management using building information modelling — Part 5: Security-minded approach to information management. (2020b). International Organization for Standardization (ISO).

f. BIM Handbook: A guide to Building Information Modelling for Owners, Designers, Engineers, Contractors, and Facility Managers. 3rd Edition, 2018, John Wiley & Sons, Inc.

g. Handbook for the Implementation of Building Information Modelling in Construction Industry Transformation Programme 2016-2020. 2018, CIDB Malaysia.

h. BIM Guide 1: Awareness. 2016, CIDB Malaysia.

i. BIM Guide 5: BIM Project Guide - A Guide to Enabling BIM in Projects. 2019, CIDB Malaysia.

j. Know the Power of BIM: Transforming Construction, Architecture, and MEP Industries. Augmintech. https://augmintech.com/what-is-bim/

k. Construction 4.0: An Innovation Platform for the Built Environment. 2020, Anil Sawhney, Michael Riley, Javier Irizarry.

l. What is BIM? An in-depth look at Building Information Modelling. BIMcollab. https://www.bimcollab.com/en/resources/blog/what-is-bim/

DIGITALISATION AND VIRTUALISATION

"This chapter, "Digitalisation and Virtualisation," discusses the transformative roles of these two technologies in the construction industry as part of the Construction 4.0 Strategic Plan (2021-2025). It explores how IoT, cloud and real-time collaboration, BDA, AI, blockchain, and AR and VR are reshaping project management and execution, enhancing safety, reducing costs, and improving visibility and control. The chapter differentiates between digitalisation, which involves using digital technologies to transform business models, and virtualisation, which consists of creating virtual versions of resources. By digitalising project information and creating virtual models, construction firms can enhance efficiency, safety, health, quality and customer satisfaction, contributing to a more efficient and improved construction industry."

3.0 Digitalisation and Virtualisation

Digitalisation and virtualisation are two pivotal technologies revolutionising the construction industry. They form the second cluster of the Construction 4.0 Strategic Plan (2021-2025). The technologies that are utilised in these clusters include the Internet of Things (IoT), cloud and real-time collaboration, Big Data Analytics (BDA), Artificial Intelligence (AI), blockchain, Augmented Reality (AR), and Virtual Reality (VR). These technologies are reshaping the management and execution of construction projects, enhancing safety, cutting costs, and providing greater project visibility and control.

DIGITALISATION uses digital technologies to change a business model to provide new revenue and value-producing opportunities. It is the process of moving to a digital business. The following technologies are categorised as follows:

1. **Internet of Things (IoT):**
   IoT refers to a network of physical devices, vehicles, appliances, and other objects embedded with sensors, software, and network connectivity, which allows them to collect and share data. IoT devices range from simple “smart home” devices, such as smart thermostats, to complex industrial machinery and transportation systems.

2. **Cloud and Real-Time Collaboration:**
   Cloud computing refers to providing computing resources, such as storage and infrastructure, on-demand and as services over the internet. This eliminates the need for individuals and businesses to self-manage physical resources, and they only pay for what they use. On the other hand, real-time collaboration is the act of people working together simultaneously, even if they are geographically dispersed. The available online collaboration tools are as diverse as the types of collaboration they enable.

3. **Big Data Analytics (BDA):**
   BDA examines and analyses large and complex data sets known as “big data” to uncover valuable insights, patterns, and trends to make more informed decisions. It uses several techniques, tools, and technologies to process, manage, and examine meaningful information from massive datasets.

4. **Artificial Intelligence (AI):**
   AI refers to computer systems that can perform tasks that historically required human intelligence, such as recognising speech, making decisions, and identifying patterns. AI is used in many technologies that power many daily services and goods.

5. **Blockchain:**
   A blockchain is a distributed database or ledger shared among a computer network’s nodes. They are best known for their crucial role in cryptocurrency systems for maintaining a secure and decentralised record of transactions.

VIRTUALISATION is creating a virtual (rather than actual) version of something, including virtual computer hardware platforms, storage devices, and computer network resources. The following technologies are categorised as follows:

1. **Augmented Reality (AR) and Virtual Reality (VR):**
   AR is an interactive experience that merges computer-generated content with the real world. This content can consist of multiple sensory modalities, including visual, auditory, haptic, somatosensory, and olfactory. On the other hand, VR is a computer-based system that uses software, interactive controls, and screens on each eye to enable users to enter a virtual, digital world. VR experiences are generated with computer technology and presented to the user through a VR headset or head-mounted display (HMD), which creates an immersive and interactive three-dimensional environment. Mixed Reality (MR) is a blend of AR and VR, overlaying and anchoring virtual objects to the real world and allowing users to interact with these objects as if they were real. This technology creates a hybrid environment where physical and digital objects coexist and interact in real time. MR not only overlays but also anchors virtual objects to the real world, creating new environments and visualisations where physical and digital objects interact in real time. It offers the most immersive experience, providing a seamless blend of the physical and digital worlds.

By digitising project information and creating virtual models of construction projects, construction firms can save time and cut costs while enhancing safety and visibility. Moreover, these technologies improve customer satisfaction by enabling more accurate and timely project delivery. Ultimately, these technologies contribute to a more efficient and improved construction industry.

3.1 Internet of Things (IoT)

3.1.1 Overview of IoT

The Internet of Things (IoT) comprises physical devices, vehicles, and other items. These objects have embedded electronics, software, sensors, actuators, and connectivity, enabling them to connect and exchange data. Each object has a unique identification system owing to its embedded computing system. Nevertheless, it can still function with the existing internet infrastructure. This technology is widely applicable and is used in many sectors, each with its specific usage and requirement.

The construction industry is undergoing significant adjustments to enhance efficiency, well-being, process improvement, and the incorporation of new tools. The IoT incorporates simple low-control sensors that can transmit data efficiently at a low cost. IoT solutions for the construction sector have revolutionised how the industry operates. It allows each partner to comprehend what occurs at every stage of the real-time development process, from planning to post-development, and how the structure functions during administration.

Since construction companies often face issues of low profitability, reduced margins, increased schedule overruns, and heightened challenges, embracing IoT technology and digitisation is a compelling need. Data and information have evolved into critical company assets, and only data-driven decisions should be considered.

3.1.1.1 IoT Applications and Devices for the Construction Industry

The IoT has revolutionised the construction industry by tracking and monitoring equipment, materials, and workforce. **Figure 3.1** illustrates some practical uses of IoT technology in construction sites. The example is just a portion of the available options and not limited to these alone.

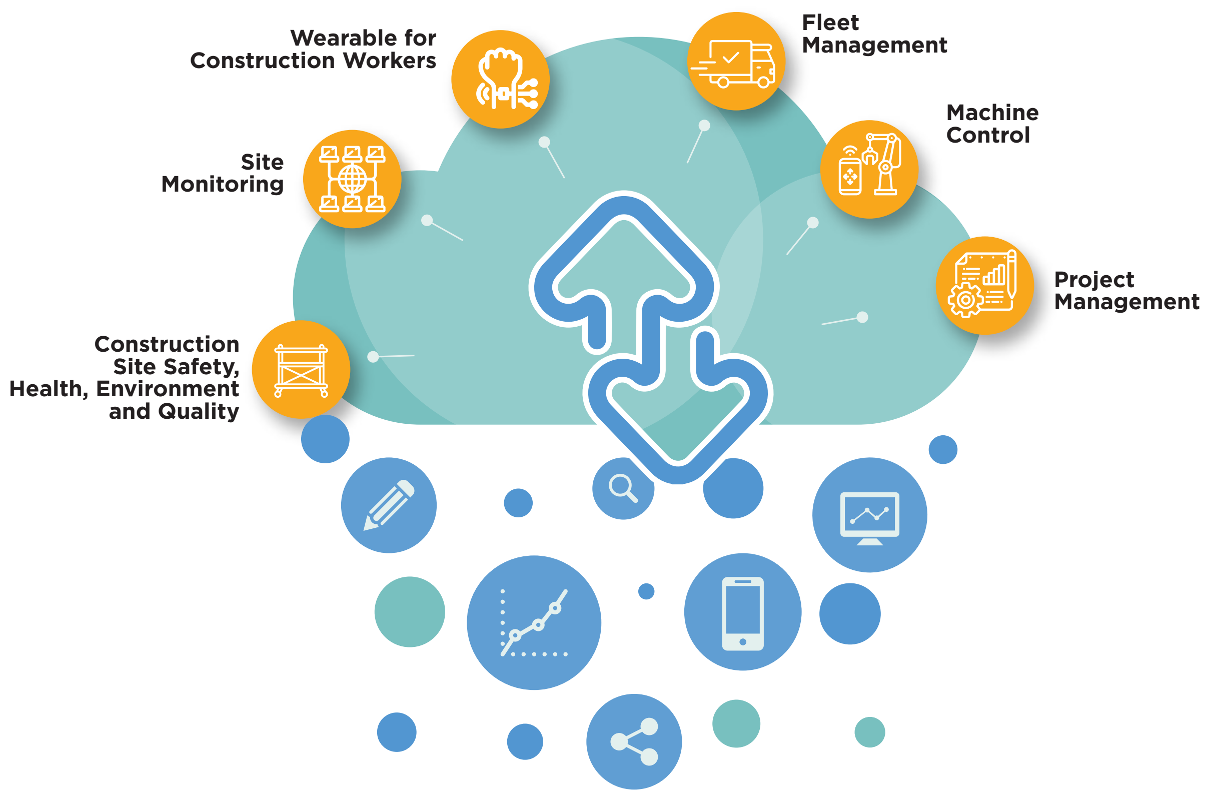


Figure 3.1 Practical uses of IoT can be offered in the construction industry.

(a) Wearables for construction workers:
Different wearables can warn workers when they are near a dangerous zone. For instance, an IoT-enabled helmet worker can receive real-time alerts if they approach a hazardous area, as illustrated in **Figure 3.2 (a)**. These wearables can also provide real-time instructions on how to complete tasks safely and efficiently. For example, in the event of an accident, they can assist in determining the real-time location of an injured worker.

(b) Site monitoring:
Construction managers can leverage IoT devices to obtain real-time information and insights on workers and machinery. For instance, IoT-enabled cameras and drones can provide a bird' s-eye view of the construction site, enabling managers to monitor progress and identify potential issues promptly, as illustrated in **Figure 3.2 (b).**

(c) Construction site safety, health, environment, and quality:
Combining AI and IoT enhances safety measures, helping ensure worker safety and the public. For example, IoT devices can monitor environmental conditions such as temperature, humidity, and air quality, alerting site managers to potential hazards and preventing accidents, as illustrated in **Figure 3.2 (b)** and **Figure 3.2 (c)**.

(d) Fleet management:

IoT technology can optimise fleet management by planning optimal transit routes and scheduling vehicle maintenance. For instance, GPS-enabled IoT devices can track the location and movement of vehicles, helping to plan efficient routes and reduce fuel consumption. This can be seen in **Figure 3.2 (d)**.

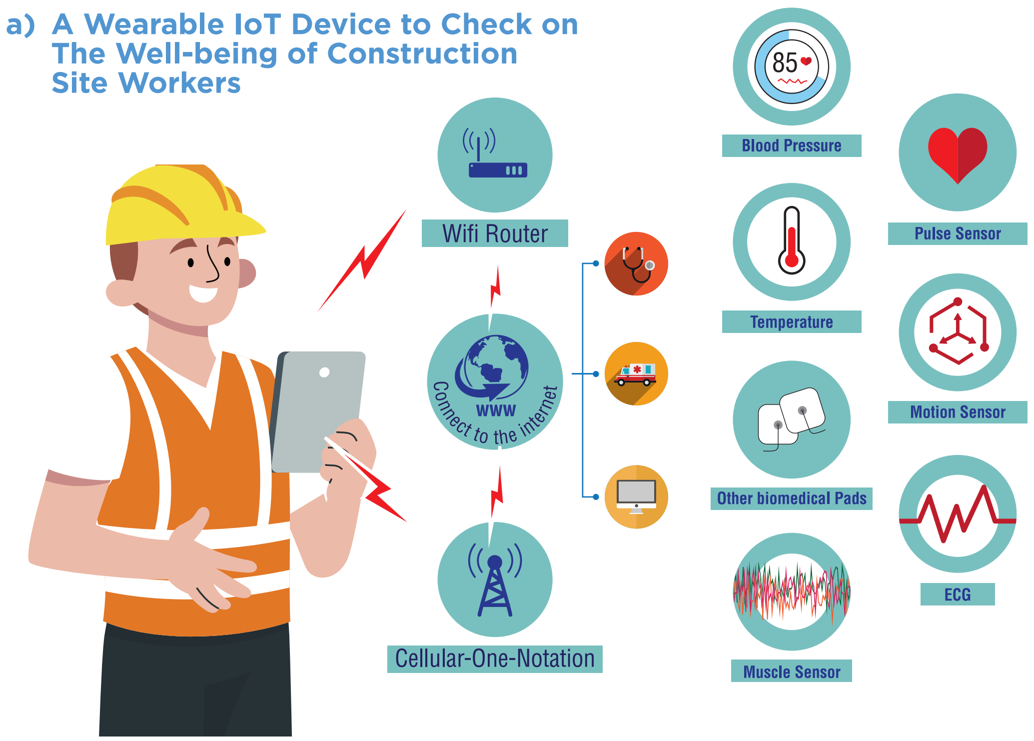
(e) Machine control:

As shown in **Figure 3.2 (c)**, IoT sensors embedded in machinery can guide their operation with greater precision, eliminating the need for human intervention. For example, an excavator that is equipped with IoT sensors can dig with exact depth and angle specifications, reducing errors and enhancing efficiency.

(f) Project management:

IoT devices can help reduce costs by minimising the need for extensive site monitoring, thereby helping to optimise budgets. For example, IoT-enabled smart meters can monitor and control energy usage on the construction site, leading to significant cost savings.

a) A Wearable IoT Device to Check on The Well-being of Construction Site Workers



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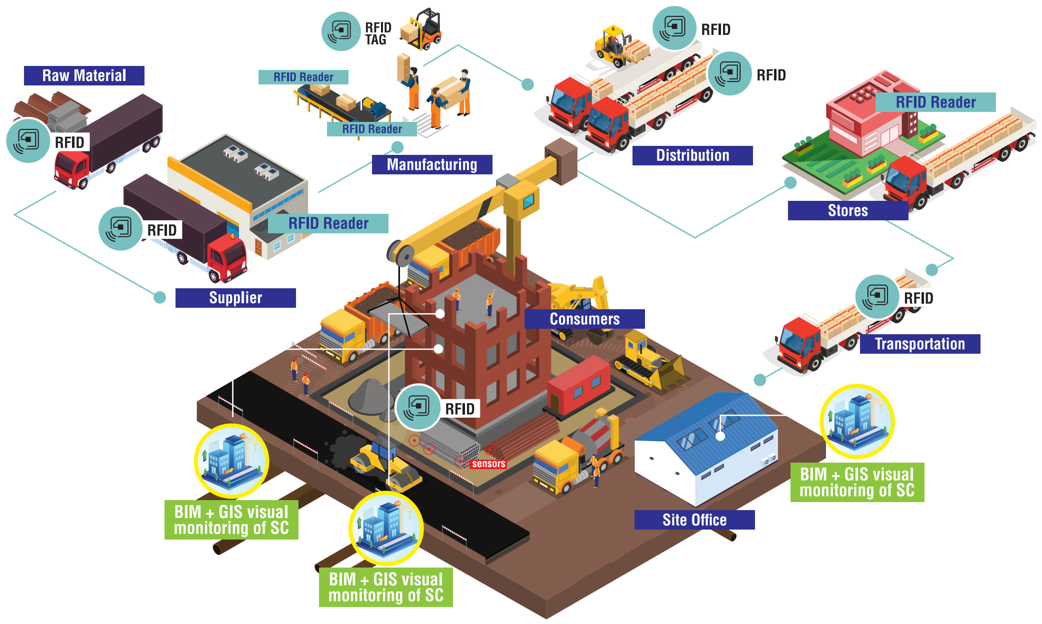
b) The IoT Sensor Device for Site Monitoring

c) The IoT Tagging Device for Construction Site Mobile Plant Operations and Mapping

d) The IoT Tracking device for Construction Procurement and Project Management



Adapt from Edirisinghe, 2019.

Figure 3.2 Example of IoT applications in the construction industry.

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In conclusion, incorporating IoT in the construction industry has revolutionised traditional practices, paving the way for enhanced efficiency, safety, quality, and cost-effectiveness. As technology continues to evolve, IoT's potential applications and benefits in construction are expected to expand further.

3.1.2 Benefits of IoT Applications in the Construction Industry

The IoT has shifted paradigms in various industries, including construction. The integration of IoT in the construction industry has led to significant advancements, enhancing efficiency, safety, and resource management.

Here are some key benefits:

(a) Real-time progress tracking:
IoT devices provide real-time data, enabling construction companies to monitor project progress and make data-driven decisions.

(b) Efficient resource management:
IoT assists with real-time tracking and generates a clear plan of advanced budgeting, maximising the value of available resources and reducing idle time.

(c) Predictive machinery maintenance:
IoT sensors guide machinery more precisely, optimising power and fuel usage and minimising waste.

(d) Improved health and safety measures:
IoT enhances safety measures through AI and IoT, ensuring workers' and public health and safety. Wearable sensors monitor workers' health and safety, detecting unsafe conditions and sending alerts.

(e) Hazard detection and emergency response:
IoT devices can warn when workers are near a dangerous zone, assist in determining the real-time location of an injured worker, and enhance emergency response.

(f) Energy efficiency and sustainability:
IoT devices can help optimise energy usage, contributing to sustainability goals.

In conclusion, the utilisation of IoT in the construction industry offers substantial benefits, transforming traditional practices and paving the way for a more efficient, safe, and sustainable future. As technology continues to evolve, the potential for further enhancements in the construction industry through IoT is vast and promising.

3.1.3 The Future Advancements of IoT in the Construction Industry

The construction industry is constantly evolving and integrating IoT technology with other Construction 4.0 technologies is expected to play a significant role in its development. The latest advancements in IoT for construction include integrating smart cities and infrastructure and the synergy with artificial intelligence (AI), machine learning (ML), and Big Data Analytics (BDA).

Here are some key advancements to look forward to:

(a) Integrating IoT for Smart Cities:
IoT technology can create smart cities by integrating various systems, such as traffic management, waste management and energy efficiency, into a unified whole. For example, IoT sensors can monitor traffic flow and adjust light timings to optimise traffic movement.

(b) Better prediction with AI and ML:
AI and ML can be used with IoT to analyse data from various sensors and make predictions or decisions. For instance, based on sensor data, AI can predict when a piece of machinery will likely fail, allowing for preventative maintenance and reducing downtime.

(c) Improve insight with BDA:
BDA can analyse vast amounts of data generated by IoT devices. This can provide insights into patterns and trends that can improve efficiency and productivity. For example, analysing data from IoT devices can help identify bottlenecks in the construction process and suggest ways to overcome them.

Adopting IoT solutions with other C4.0 technologies is pivotal for the future success of construction projects. It opens doors for a more innovative, efficient, and sustainable construction sector, positioning companies at the forefront of technological advancement and industry innovation. By embracing these technologies, construction companies can improve operations and stay ahead in the rapidly evolving construction landscape.

3.1.4 Suggested Readings for Additional Information

To acquire comprehensive insights into the application of IoT in construction, it is recommended that readers refer to the references listed below:

a. Construction 4.0: An Innovation Platform for the Built Environment. 2020, Anil Sawhney, Michael Riley, Javier Irizarry.
b. What is IoT in Construction? Definition, Applications and Steps. Haleh Khanzadeh. https://neuroject.com/iot-in-construction/
c. IoT in Construction: Top Benefits, Use-Cases & Application. ToolSense. https://toolsense.io/equipment-management/iot-in-construction-top-benefits-use-cases-application/
d. IoT in Construction: What Are the Applications and Benefits?. Trackunit. https://trackunit.com/articles/iot-in-construction/
e. What is the Internet of Things (IoT)?. IBM. https://www.ibm.com/topics/internet-of-things

3.2 Cloud and Real-Time Collaboration

3.2.1 Overview of Cloud and Real-time Collaboration

Cloud collaboration is a type of enterprise collaboration that allows employees to work together on documents and other data types which are stored off-premises and outside of the company firewall. A cloud collaboration project begins when one user creates a file or document and gives access to other individuals. Changes are saved and synced so all users see the exact version of the project. Cloud collaboration tools allow project participants to see who else is viewing the document and communicate with other team members while working, using comments or a chat function. Users can also implement integrations that let them set up email alerts, so they know when a file is changed. These and other functions increase worker efficiency and productivity.

The **Common Data Environment (CDE)** is an internationally recognised information collaboration solution for project, department and enterprise applications. An ISO-compliant CDE solution and workflow allow information to be accessed by those requiring it to perform their function in a standardised manner for quality assurance. Given the advancement in BIM and technology use, the adoption of CDEs helps ensure the quality of built assets information and serves as a single source of truth for collaboration throughout the whole building life cycle. The CDE solution should allow cloud options to suit the needs of the information security requirement of each stakeholder.

3.2.1.1 Cloud and Real-time Collaboration Applications and Software for the Construction Industry

In the dynamic construction industry, cloud-based and real-time collaboration tools have emerged as vital elements in enhancing productivity, reducing costs, and gaining a competitive edge. These tools integrate various project stages, streamline workflows, and foster effective stakeholder communication. This document presents an overview of six such prominent tools. The example is just a portion of the available options and is not limited to these alone.

(a) RIB 4.0:
A cloud-based construction enterprise platform integrating all project stages from planning to operations. It enhances collaboration, productivity, and return on investment by leveraging 6D BIM technology to link people, processes, and data, streamlining enterprise-wide workflows.

(b) Trimble Viewpoint:
A comprehensive suite of applications for managing construction projects. It offers tools for project management, field operations, and office administration, fostering seamless communication and collaboration among project stakeholders.

(c) Oracle Aconex:
A project delivery and control platform providing teams with secure and efficient means to collaborate and manage project information. It offers tools for document management, workflow automation and quality control.

(d) ASITE Adoddle:
A platform offering various cloud-based solutions for managing project information and facilitating collaboration among project teams. It provides tools for document management, project scheduling, and cost management.

(e) Autodesk Construction Cloud:
A cloud-based document management system providing teams with a centralised location for storing, viewing, and collaborating on project documents. It offers features such as version control, markups, and issue tracking.

(f) Bentley Systems (ProjectWise):
A project information management and collaboration platform that provides teams with the tools that are needed to manage and share project information effectively. It provides features such as document management, workflow automation and design collaboration.

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(g) Procore:
A construction management software that harnesses AI to enhance project efficiency. It streamlines workflows, improves collaboration, and provides real-time access to project information.

(h) AutoCDE:
AutoCDE is an ISO-compliant Common Data Environment which is a cloud-based online platform for project and asset management for the AECO industry, carbon neutrality and smart cities. It provides features such as requirement management, model and document management, workflow management, 2D and 3D online viewer, asset management, and AI BIM analysis.

In conclusion, these cloud-based and real-time collaboration tools facilitate effective collaboration and provide secure and efficient means to manage project information. By leveraging these tools, construction companies can significantly enhance their productivity, reduce costs, and gain a competitive advantage in the industry. The future of construction lies in effectively utilising such advanced tools and technologies.

3.2.2 Benefits of Cloud and Real-Time Collaboration Applications in the Construction Industry

The construction industry stands to reap substantial benefits from integrating cloud-based and real-time collaboration applications. These digital tools can streamline workflows and enhance project outcomes when they are effectively harnessed, significantly improving traditional collaboration methods. They provide several key advantages, including improved communication, efficient data sharing and effective project tracking.

(a) Cost efficiency:
Cloud computing allows construction entities to reduce hardware and software costs significantly. Substantial capital investments can be conserved by eliminating the need for extensive on-site infrastructure. Additionally, outsourcing the procurement and maintenance of costly software licenses to cloud service providers can alleviate financial strain. These providers are responsible for infrastructure and software updates, maintenance, and troubleshooting, reducing the burden on internal IT teams. Consequently, construction firms can potentially reap significant cost savings by outsourcing these tasks.

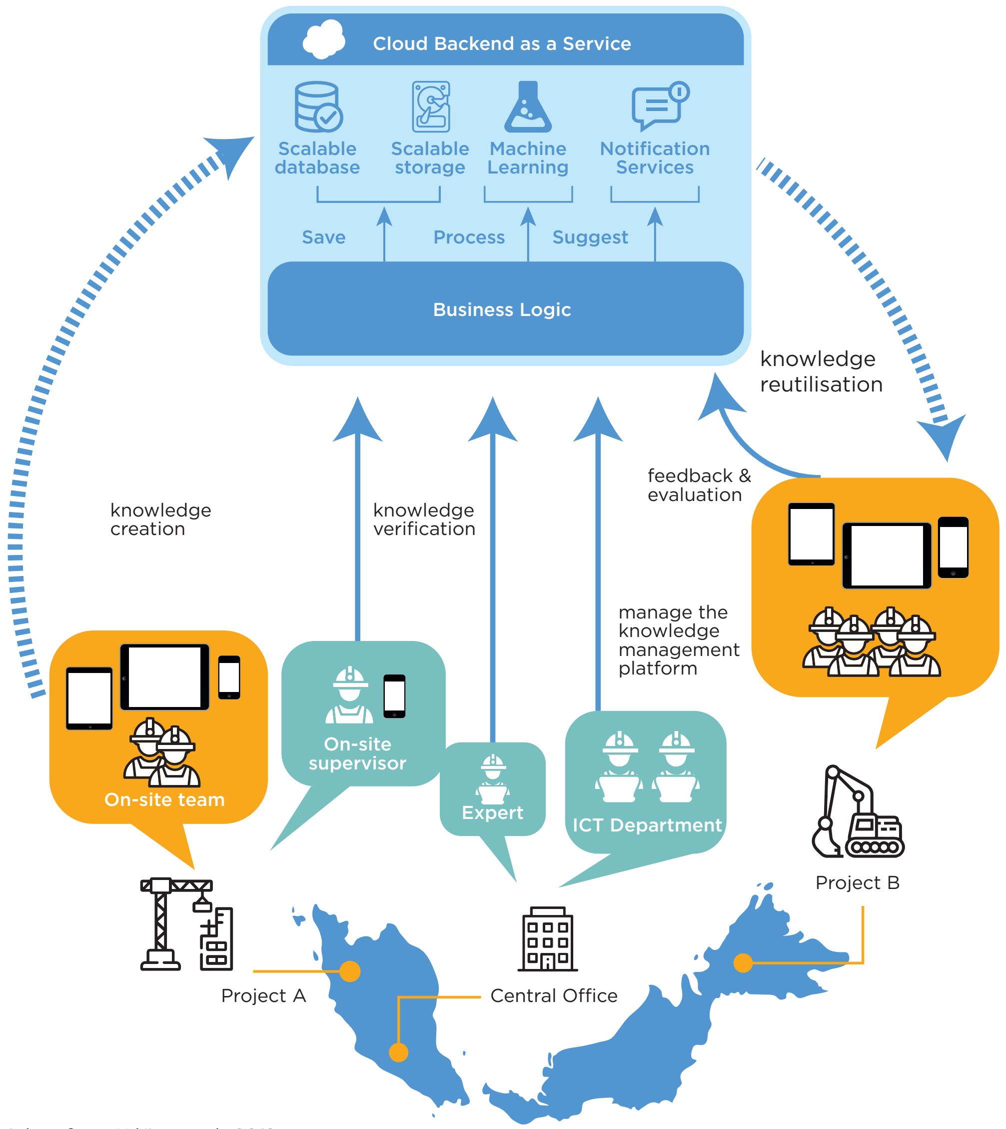
(b) Enhanced collaboration and communication:
Cloud-based platforms facilitate real-time sharing and project data access, fostering collaboration and enhancing decision-making processes. Multiple team members' ability to work concurrently on shared documents eliminates version control issues and delays. Furthermore, cloud-based communication tools, such as instant messaging and video conferencing, enable seamless and effective communication among project stakeholders, irrespective of their geographical location. This allows project stakeholders to exchange information, resolve issues, and monitor progress easily.

(c) Improved project management:
Cloud computing provides a centralised hub for storing and accessing project data, ensuring all stakeholders have access to the most up-to-date information. This secure repository protects project documents, plans, and specifications and allows convenient access from any location. This level of accessibility enhances efficiency and minimises delays. Cloud-based project management tools enable efficient scheduling and resource allocation, optimising labour, equipment, and materials use. Real-time updates and notifications allow project managers to make timely adjustments, reducing downtime and maximising productivity.

(d) Facilitate remote supervision:
Cloud and real-time collaboration allow the intervenable and auditable process of overseeing and managing on-site and off-site construction works from a distance, using purpose-built digital tools and technologies to ascertain the quality of works and conformity to project specifications. These monitoring and signing-off functions are crucial during construction's manufacturing and installation stages. Recording, storage, and reference of project documentation, including inspection forms, checklists, drawings, BIM models, photos, videos, and reports, are made possible and help facilitate decision-making, productivity, and a transparent audit trail as an example is shown in **Figure 3.3**.

Figure 3.3 Example of a cloud-based remote supervision app.

Integrating cloud-based and real-time collaboration applications in the construction industry offers many benefits, including cost efficiency, enhanced collaboration, and improved project management. As these digital tools evolve, they will undoubtedly play an essential role in shaping the construction industry's future, driving innovation, and fostering growth. **Figure 3.4**. illustrates an example of cloud and real-time collaboration workflow within an organisation in the construction industry. The organisation can improve process management, streamline business processes, and reduce errors through notification services to keep users updated about important changes, fostering quick response times.



Adapt from Núñez et al., 2019.

Figure 3.4 An example is a cloud and real-time collaboration workflow within an organisation.

3.2.3 The Future Advancements in Cloud and Real-Time Collaboration

The construction industry is progressively adopting cloud computing, integrating it with other technologies to open avenues for innovation and advancement. This integration with other technologies is a crucial aspect of the future of cloud computing in construction. It allows for the seamless exchange of data and information, enhancing efficiency and productivity.

Here are some significant trends anticipated in the future application of cloud computing in construction:

(a) Applications of AI and ML:

The fusion of AI/ML with cloud computing presents numerous opportunities for the construction industry. Construction projects leveraging AI/ML algorithms can gain from in-depth analysis of extensive data sets, facilitating resource allocation, task automation, and insightful predictions. This amalgamation enhances efficiency, productivity, and overall project performance.

(b) Integration of IoT:

Integrating IoT devices with cloud computing enables real-time monitoring and data collection from construction sites. Incorporating IoT sensors into equipment and structures allows valuable data to be collected for predictive maintenance, safety monitoring, and project optimisation. This integration empowers construction teams to make informed decisions, enhance safety protocols, and boost project efficiency.

(c) Application of AR and VR:

AR and VR technologies, when integrated with cloud computing, have the potential to transform design visualisation, virtual walkthroughs, and virtual training within the construction industry. These technologies enable stakeholders to immerse themselves in virtual models, facilitating informed decision-making processes.

In conclusion, the future of cloud computing in the construction industry is promising and brimming with potential. Integrating AI/ML, IoT, AR, and VR with cloud computing is set to revolutionise the industry, enhancing efficiency, productivity, and decision-making processes. These advancements will not only streamline operations but also open new avenues for innovation, setting the stage for a new era in construction. As we progress, witnessing how these technologies reshape the construction industry landscape will be intriguing.

3.2.4 Suggested Readings for Additional Information

To acquire comprehensive insights into the application of cloud and real-time collaboration in construction, it is recommended that readers refer to the references that are listed below:

a. Construction 4.0: An Innovation Platform for the Built Environment. 2020, Anil Sawhney, Michael Riley, Javier Irizarry.
b. Cloud computing and its application in the construction industry. PlanRadar. https://www.planradar.com/ae-en/cloud-computing-in-construction/
c. Cloud computing and construction: 7 ways tech helps you work smarter, not harder. Mauricio Prinzlau, 2023. https://buildertrend.com/blog/cloud-computing-construction-teams/
d. How Cloud Can Enable Collaboration in the Construction Industry. Julie Watson. https://www.acecloudhosting.com/blog/cloud-collaboration-in-construction-industry/
e. Real-time collaboration: what it is and how it helps your business. Microsoft 365 Team. https://www.microsoft.com/en-us/microsoft-365/business-insights-ideas/resources/real-time-collaboration-what-it-is-and-how-it-helps-your-business

3.3 Big Data Analytics (BDA)

3.3.1 Overview of BDA

BDA has emerged as a transformational force in numerous industries, including the construction sector. This data-processing approach involves scrutinising large and diverse data sets to uncover latent patterns, correlations, market trends, consumer preferences, and other valuable insights. In the construction industry, BDA has begun to gain traction. It is being adopted across all stages of the construction process to maximise productivity and efficiency.

The construction industry has historically been viewed as resistant to technological innovations but is now embracing BDA as it recognises the potential to unearth new possibilities. While construction is a primarily physical process that relies on human labour, integrating technology enhances certain aspects of construction.

To date, BDA has shown a significant impact on risk analysis, construction cost management, and health and safety management in the construction sector. Examining vast data pools allows potential risks to be identified and mitigated before they become problematic. This not only results in improved safety but also enhances efficiency and productivity.

Furthermore, data analytics tools have been designed to extract information from large data repositories and render it accessible to all stakeholders in the construction process. This democratisation of data has engendered better decision-making while promoting a more collaborative and transparent work environment. Consequently, the convergence of BDA in the construction industry is not merely a transitory trend but a necessity in the digital age. It is revolutionising the way the industry functions, facilitating the emergence of safer, more efficient, and more productive construction processes.

3.3.1.1 BDA Applications, Tools, and Software for the Construction Industry

The advent of BDA has revolutionised various industries, including the construction sector. Integrating data collection devices, analytics tools, and software has significantly enhanced the industry's efficiency, safety, and decision-making processes.

Several complementary technologies in support of the BDA ecosystem in the construction sector are as follows:

(a) Devices for data collection:

Construction work today involves the use of various tools for data collection, such as smartphones, drones, wearables, sensors, and GPS systems. These tools can all connect to the cloud and real-time collaboration platforms, as listed in **Section 3.2.1.1**. This makes managing and storing data easy, enabling quick responses to changes, ensuring worker safety, and efficiently using resources. More detailed information about these tools will be provided in the upcoming sections.

i. Smartphones:

These handheld devices capture and transmit real-time data, enabling immediate response to changing conditions on the construction site.

ii. Drones:

These unmanned aerial vehicles provide valuable data for site inspections, progress tracking, and topographical mapping, offering a bird's eye view of the construction site.

iii. Wearables:

These devices, which are worn by construction workers, monitor worker safety and productivity, providing real-time data on health metrics and work patterns.

iv. Jobsite Sensors:

Installing these sensors on the construction site enables data collection on environmental conditions and equipment usage, and aids in maintaining optimal working conditions and efficient use of resources.

v. Telematics and GPS Systems:

These systems track the location and performance of heavy equipment, ensuring efficient logistics and equipment management.

(b) Data analytics tools:

BDA is a constantly evolving field that uses tools such as Apache Hadoop, Apache Kafka, Apache Apex, Apache Spark, and Cloudera to manage, process, and analyse large amounts of data. These tools provide real-time analytics, and when combined with AI, they can efficiently extract valuable insights. In the following sections, we will discuss the role of each tool in BDA and their contribution to AI integration. The example is just a portion of the available options and is not limited to these alone.

i. Apache Hadoop:

As an open-source framework, Hadoop allows for the distributed processing of large data sets across clusters of computers. This is crucial in AI and BDA as it enables efficient handling of big data, which is the foundation of any AI model training and BDA.

ii. Apache Kafka:

Kafka is designed to handle real-time data feeds, an increasingly important feature in AI for real-time decision-making and predictive analytics. It can feed real-time data into AI models for immediate analysis and decision-making.

iii. Apache Apex:

Apex processes big data in motion, allowing for real-time analytics and insights. This is particularly useful in AI applications that require immediate response based on the incoming data, such as fraud detection or real-time recommendations.

iv. Apache Spark:

Spark is an analytics engine designed for big data processing and analytics. It can be used with AI to provide comprehensive insights from large data sets. For instance, the output from Spark can be used as input for AI models to generate predictions or classifications.

v. Cloudera:

Cloudera provides services for data engineering, data warehousing, machine learning, and analytics. It offers an all-in-one solution for big data management. Cloudera can be used to manage the data pipeline for AI applications, from data ingestion and processing to model training and deployment.

The integration of these applications is transforming the construction industry. They enable construction firms to harness the power of big data, leading to optimised costs, improved project management and enhanced decision-making processes. The construction industry's future lies in these technologies' continued adoption and advancement.

3.3.2 Benefits of BDA Applications in the Construction Industry

Using big data and predictive analytic applications in the construction industry can provide numerous benefits. For instance, companies can analyse vast amounts of data from multiple sources, such as project management systems, sensors, and mobile devices, to gain valuable insights into project performance, resource utilisation, and risk management. These insights can lead to a more informed decision-making process, better planning and scheduling, and better resource allocation.

Moreover, predictive analytics can help construction companies anticipate and mitigate potential risks and challenges. Companies can use historical data and statistical modelling techniques to identify patterns and trends that can suggest proactive risk management strategies. Predictive analytics can also enable more accurate forecasting of project timelines, budgets, and resource requirements, which can help companies avoid delays, cost overruns and other project disruptions. **Figure 3.5** outlines 12 examples illustrating how data analytics can impact and transform construction project management.

Adapt from Bilal et al., 2016; Darya Yatchenko, 2023.

Figure 3.5 Example of how data analytics can impact and transform construction project management.

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(a) Predictive analytics:

Access to historical and real-time data can help create predictive models that forecast outcomes and prevent project failures. Potential project delays can be anticipated by considering weather conditions, resource availability and past performance data. Moreover, predictive analytics can foretell equipment maintenance needs, optimise procurement processes, and minimise the likelihood of cost overruns. By utilising the power of predictive analytics, informed decisions can be made to remain on track and attain project objectives.

(b) Project planning and scheduling:

The construction industry faces the challenge of managing various factors such as personnel, equipment, and materials. It can be challenging to coordinate all these elements effectively. However, construction data analytics tools can help by analysing the activities of equipment and personnel along with their locations and generating reports. Using such tools, gaps or overlaps in schedules can be identified, work hours can be adjusted, tasks can be redistributed, and personnel assignments can be optimised. This not only improves project schedules but also minimises bottlenecks and downtimes.

(c) Warranty and risk analysis:

Construction data analytics is a tool commonly used to analyse risk by evaluating historical data, industry trends and external factors. It allows for assessing the probability and impact of potential dangers while creating effective mitigation strategies. Additionally, data analytics can also be used for warranty analysis, which includes evaluating warranty claims patterns, analysing equipment performance, and identifying potential weaknesses in materials or the construction process. By gaining insights through data analytics, proactive measures can be taken to address potential issues such as sourcing higher-quality materials or improving product design.

(d) Cost optimisation:

To optimise costs in the construction market, it is essential to consider every step of the process, from planning to development and implementation. Data analytics can be a helpful tool in achieving this goal. Real-time visibility into all project expenses can be obtained by integrating data from various sources, such as project management software, financial systems, and vendor invoices. This enables prompt addressing of budget deviations and maintaining budget accuracy. Construction analytics can also model "what-if" scenarios for effective budgeting. By simulating different scenarios and adjusting cost parameters, the feasibility of project plans can be determined, material costs can be optimised, and budget accuracy can be ensured.

(e) Subcontractor performance analytics:

When working with subcontractors challenges such as incomplete data or limited visibility of their activities can be expected Integrating data analytics software can help overcome these challenges by providing easy access to information on subcontractor activities and ensuring that quality work is delivered. With data insights, the contractor performance metrics such as adherence to schedule, budget compliance and quality of work can be evaluated to help make informed decisions when selecting contractors and managing contracts. Construction data analytics can also incentivise contractors by aligning payment structures, bonuses, and penalties with specific KPIs, thus motivating contractors to meet project objectives and deliver high-quality work consistently.

(f) Plant and machineries optimisation:

Equipment failures can result in significant setbacks in project timelines and increased expenses. However, companies can mitigate these challenges by utilising data analytics and asset management tools that enable real-time equipment data monitoring to prevent over or under utilisation. Data analytics solutions also facilitate comparing equipment performance against industry standards, allowing for timely identification of underperforming equipment and informed decisions regarding equipment upgrades or replacements. Other benefits include optimised equipment selection, reduced idle time, and streamlined procurement processes.

(g) Quality control and defect detection:

Quality control is critical in delivering high-quality construction projects. Construction analytics can analyse quality control data points such as inspection results, adherence to project specifications, and defect reports. This data can provide valuable insights into quality issues and defect causes, helping to identify areas for improvement. In other words, data analytics can enable proactive measures to reduce defects and enhance the overall quality of the project.

(h) Cost reduction:

Data analytics helps construction project managers monitor operational patterns and generate automated reports in real time. By accessing this data, managers can identify areas where their business may need improvement. Moreover, analysing historical cost data can help them develop more precise estimates for future projects, leading to better budget management and fewer cost overruns.

(i) Advanced safety measures:

Construction data analytics can detect risky patterns and behaviours, identify safety concerns, and take preventive measures to eliminate the possibility of accidents. Real-time reporting systems can be implemented to track and schedule necessary preventative maintenance for construction fleets, which can help reduce the risks that are associated with equipment breakdowns.

(j) Streamlined workflows:

Construction data analytics can help identify opportunities for automation and streamline various stages of the construction process, such as planning and payments. By automating repetitive tasks and routine activities, paper-based processes can be digitised, manual errors can be reduced, unnecessary steps can be eliminated, and the overall workflow can be accelerated.

(k) Human error reduction:

Manual documentation and management of important data such as timesheets, reports, and delivery receipts can lead to human error. However, automating data collection and reporting processes can ensure higher quality, accuracy, and accessibility, aiding in making well-informed decisions. Data analytics can also automate business processes, minimising the chance of human error and increasing workflow efficiency by saving time and resources.

3.3.3 The Future Advancements in BDA

BDA is a rapidly evolving field with unprecedented advancements. As we look towards the future, several key trends and technologies are set to shape the landscape of BDA, particularly within the context of Construction 4.0.

(a) Real-time analytics using IoT devices and sensors:

With the advent of IoT devices and sensors, real-time data collection and analysis will become increasingly prevalent. This will enable immediate insights and decision-making, enhancing the efficiency of construction processes and reducing downtime.

(b) Integrating AI and ML for precise data analytics:

By using AI and ML, we can automate data analysis, making processes more efficient and less reliant on human intervention. This can make construction work smoother, cheaper and more productive. It also allows us to predict future trends. With predictive analytics, we can foresee future patterns and behaviours that help us make proactive decisions. In construction, this could mean predicting equipment breakdowns or project delays, allowing us to take preventive actions ahead of time.

(c) Improve data visualisation with AR and VR:

Advanced data visualisation tools will make complex data more understandable and accessible, aiding in interpreting and communicating insights. This can facilitate better project management and stakeholder communication in construction projects.

(d) Enhance data privacy and security with blockchain technology:

As data becomes increasingly valuable, advancements in data privacy and security measures through blockchain technology will be crucial to protect sensitive information. This is particularly relevant in construction, where confidential project information and intellectual property must be safeguarded.

The future of BDA is promising, with numerous advancements on the horizon. These developments can revolutionise the construction industry, driving efficiency, innovation, and growth. As we progress, we must continue exploring and harnessing these advancements to unlock their full potential.

3.3.4 Suggested Readings for Additional Information

To acquire comprehensive insights into the application of BDA in construction, it is recommended that readers refer to the references listed below:

a. Construction 4.0: An Innovation Platform for the Built Environment. 2020, Anil Sawhney, Michael Riley, Javier Irizarry.
b. How Big Data and Analytics Are Transforming the Construction Industry. Matellio. https://www.matellio.com/blog/how-big-data-and-analytics-are-transforming-the-construction-industry/
c. What Is Big Data Analytics? Definition, Benefits, and More. Coursera. https://www.coursera.org/articles/big-data-analytics/
d. 12 Most Prominent Use Cases of Construction Data Analytics. Darya Yatchenko. https://pixelplex.io/blog/data-analytics-in-construction/
e. What is big data analytics?. IBM. https://www.ibm.com/topics/big-data-analytics

3.4 Artificial Intelligence (AI)

3.4.1 Overview of AI

The construction industry is slowly beginning to embrace advanced digital technologies, rendering it one of the least digitised industries. Manual calculations, reports, and practices are still pervasive, leading to project delays, cost inefficiencies, and decreased productivity, health, and safety performance. The integration of digital technology in the construction sector has the potential to enhance performance and productivity significantly. AI and machine learning (ML) mimic human intelligence and improve decision-making by processing vast data. While ML is a subset of AI that employs statistical techniques to enable computer systems to learn from data without explicit programming, AI refers to a machine that emulates human cognitive functions such as problem-solving, pattern recognition and learning. A machine becomes better at comprehending and providing insights as it is exposed to more data.

3.4.1.1 AI Applications, Tools, and Software for the Construction Industry

The domain of AI is advancing at an unprecedented pace, holding substantial potential for revolutionising many sectors. The most recent developments in AI are anticipated to shape this technology's trajectory significantly. Let us delve into these AI categories in detail:

(a) Multimodal AI:
Cutting-edge AI models like GPT-4 and Gemini can process text, images, and videos. The new capability is expected to unlock a plethora of innovative applications.

(b) Customised AI Chatbots:
Technology companies are developing user-friendly platforms that allow people to create mini chatbots using powerful language models. The chatbots can be customised to cater to specific needs, making them more effective.

(c) Generative AI:
Generative AI has expanded the possibilities and popularity of AI. It can potentially become helpful for regular, non-technical individuals, and more people are expected to experiment with various AI models.

AI has emerged as a revolutionary force, profoundly influencing many sectors. The construction industry has experienced substantial transformations.

Presented here are some of the principal AI-enabled tools and software applications. The example is just a portion of the available options and is not limited to these alone.

(a) Autodesk's Construction IQ:
Autodesk's Construction IQ is a tool that enhances project outcomes by leveraging machine learning and AI to manage and mitigate cost, schedule, quality, and safety risks. It provides predictive insights to identify potential issues before they become problems.

(b) EarthCam:
EarthCam is a leading provider of live camera technology, content, and services. It offers high-quality, high-resolution webcam content and services, enabling real-time visual monitoring of construction sites.

(c) OpenSpace.ai:
OpenSpace.ai is an AI tool that captures 360-degree photos of construction sites, aiding in progress tracking and quality control. It provides a comprehensive visual record of the site, facilitating improved project management.

(d) Kreo:
Kreo is an AI tool that is designed explicitly for pre-construction planning and estimating. It uses AI to automate and optimise the planning process, reducing errors and improving accuracy.

(e) AirWorks:
AirWorks is a tool that transforms aerial data into business intelligence using AI. It provides detailed, accurate site maps and models, enhancing project planning and execution.

(f) Versatile:

Versatile is a tool that provides real-time, actionable insights to construction teams through AI. It helps optimise resource allocation, improve productivity, and reduce project delays.

(g) Togal.AI:

Togal.AI is a tool that automates the process of creating 3D models from 2D drawings using AI. It accelerates the design process, improves accuracy, and facilitates better project visualisation.

(h) Buildots:

Buildots is a tool that leverages computer vision algorithms to track and analyse construction projects. It provides real-time updates on project status, helping to keep the project on track and within budget.

(i) ClickUp:

ClickUp is a project management tool that employs AI to streamline workflows, improve decision-making processes, and enhance communication. It helps teams to stay organised, collaborate effectively, and deliver projects on time.

In conclusion, AI plays a vital role in transforming the construction industry. By harnessing the power of AI, the industry is overcoming challenges, reducing cost overruns, increasing productivity, and creating safer and more efficient construction processes. The future of the construction industry undeniably depends on the further integration and advancement of AI technologies.

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3.4.2 Benefits of AI Applications in the Construction Industry

AI in the construction industry can bring numerous benefits throughout the project life-cycle, from design and bidding to financing, procurement, construction, operations, asset management, and business model transformation. ML can assist project engineers, supervisors, and all stakeholders in monitoring work progress, assessing risks, notifying managers of critical issues, improving design and planning activities, and making informed predictions for a more streamlined workflow. **Figure 3.6** illustrates the identified benefits that can be gained from AI Applications in the construction industry.

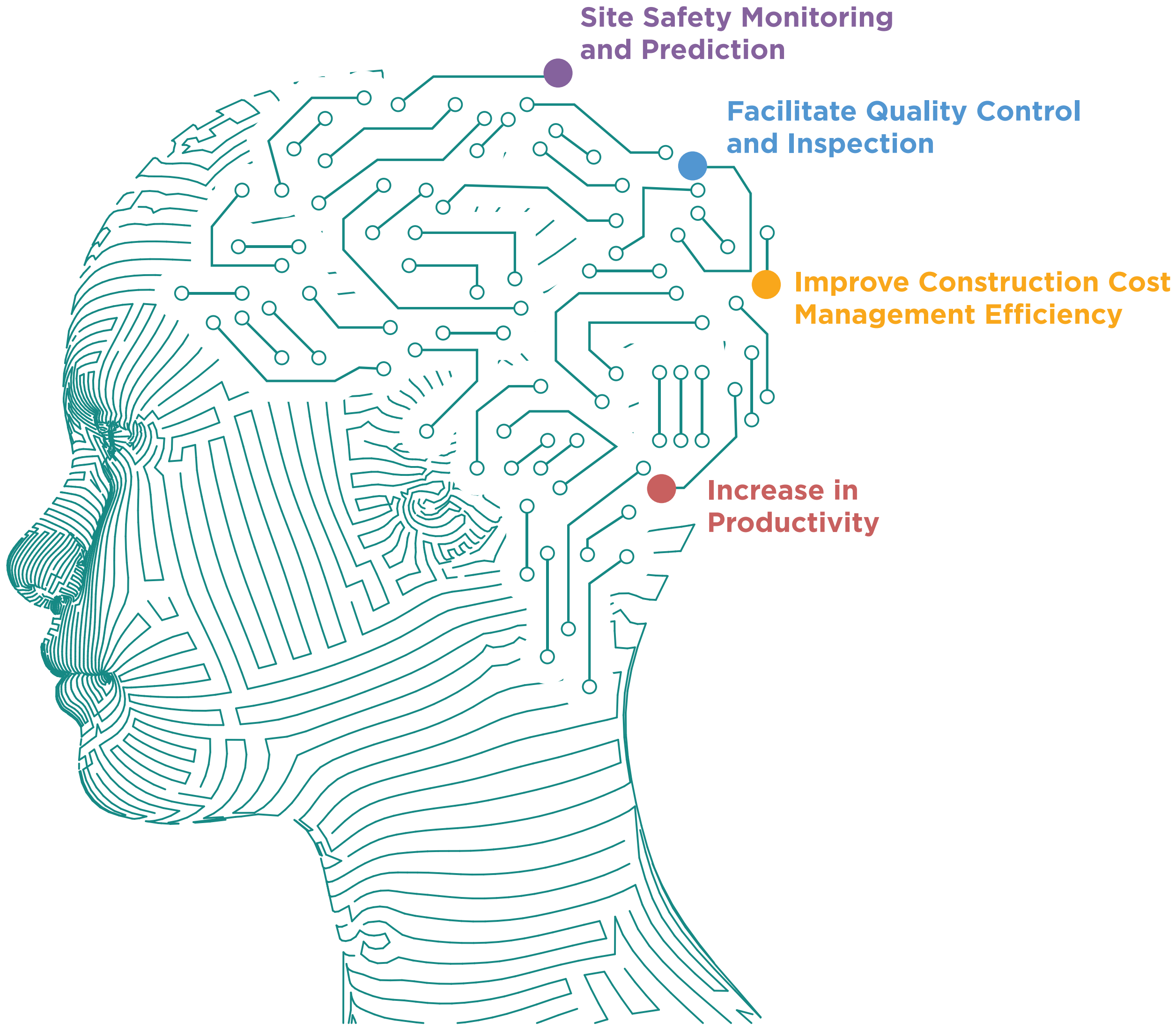

Figure 3.6 Identified benefits of AI applications.

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(a) Site safety monitoring and prediction:

Cloud-connected cameras can monitor a construction site worker's safety, allowing employers to gain insight into day-to-day activities. AI can assist in monitoring construction feeds without a human operator, enabling safety applications that were previously impossible **(Figure 3.7)**.

i. Personal protective equipment (PPE):

AI can analyse video footage and detect whether humans in the video are wearing PPE, returning an end-of-day report on how many workers violated PPE rules.

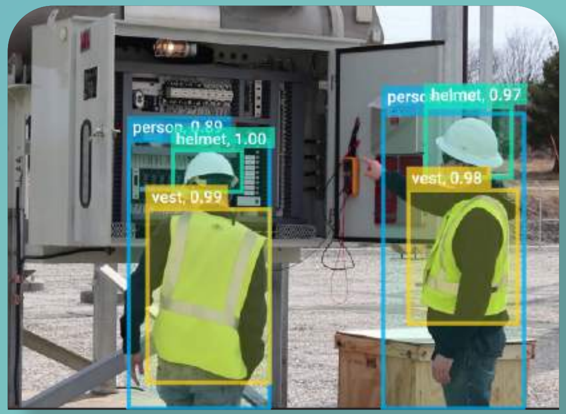
ii. Social distancing:

AI can analyse video footage to detect when workers are in frame and calculate the distance between them. When infractions occur, a push notification can be sent out to remind them to distance themselves.

iii. Danger zones:

AI can detect workers and fall hazards and generate alerts when they enter danger zones.

(a) Worker and object detection



(b) Personal protective equipment (PPE) detection

Adapt from SharpML, 2020; Gaudenz Boesch, 2023

Figure 3.7 Example of AI applications for site safety control.

(b) Facilitate quality control and inspection:

Implementing an AI-powered quality control and inspection system for construction sites can significantly advance the industry. This innovative technology is designed to enhance the accuracy and efficiency of construction projects, ensuring that they meet the highest standards of quality and safety, as seen in **Figure 3.8**.

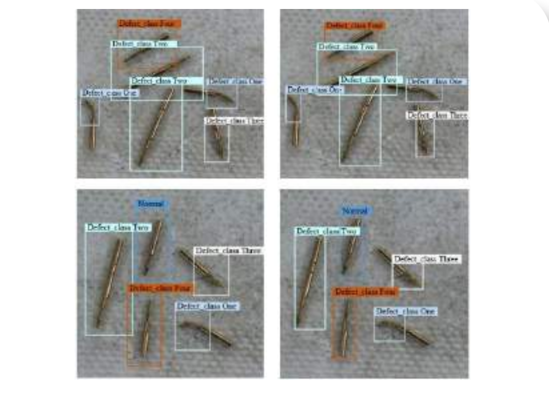
i. Quality control management:

Construction companies increasingly use mobile apps to track their jobs and attach photos to field reports. AI can make this process even more efficient by providing workers with real-time feedback on whether their work has been completed correctly. For instance, a painting company could use an AI image analyser to determine whether the surface has been painted with too much or too little paint, or the painting is inconsistent. This will help improve the quality of work while reducing the costs that are associated with rework.

ii. Defect detection:

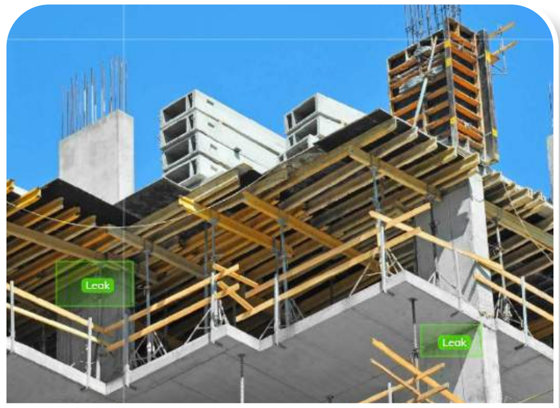
AI can be used to detect defects in materials or structures. Some examples of defects that can be detected using AI include cracks in the structure, misaligned or faulty joints, faulty construction materials, loose or missing bolts or screws, signs of corrosion or water damage, and movement or displacement in the structure.

(a) Job specification control



(b) Material quality control

(c) Asset inspection



(d) Structural defect detection

Adapt from SharpML, 2020; Alberto Rizzoli, 2021; Gaudenz Boesch, 2023.

Figure 3.8 Example of AI applications for quality control and inspection

(c) Improve construction cost management efficiency:

By ingesting disparate datasets such as job records, cost estimates, project plans, camera footage, and drone surveys, AI can assist construction companies in analysing and taking action to reduce costs and increase efficiency. However, many construction firms lack the in-house capability to organise their data.

i. Revenue projections:

AI can predict future revenues using historical accounting records, industry trends, and economic data points, allowing construction companies to make these predictions without hiring a data science team.

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ii. Cost estimates:

AI can analyse historical bids for projects and determine trends, which can clarify if a bid is above or below the norm. It can also identify line items within a bid that are above or below average and may require a second look from a human.

iii. Fraud detection:

AI can outperform traditional fraud detection algorithms by identifying outlier records, such as high cost, low cost, abnormalities for the business season, or anomalies based on the time of day. As a result, it can help companies understand when employees or vendors are manipulating financial data.

(d) Increase in productivity:

The utilisation of AI can significantly enhance productivity within the construction industry. By leveraging AI-powered tools and technologies, construction companies can streamline various processes, optimise resource allocation, and improve project management. Integrating AI can also reduce errors and delays, resulting in cost savings and increased efficiency. Adopting AI in the construction industry is a promising avenue for enhancing productivity and achieving better outcomes.

i. Improved designs:

The use of AI in design has the potential to enhance the quality of designs and make spaces more suitable for their intended users. It can help workers identify mistakes and errors in the design before proceeding with construction, saving teams valuable time that can be utilised for more productive tasks. AI technology allows testing of various environmental conditions and situations in the model, which can help determine if a particular design element is optimal or could cause future problems.

ii. Document search:

AI can speed up document searches within mobile apps and websites that construction companies use daily. It can analyse each image and video within a document repository and mark them with proper “tags”, making them more searchable. As a result, it can increase productivity on work sites by allowing people to find the documents and files they need faster. For example, imagine a field report titled “Motor needs repair”. A month later, a worker opens their project management mobile app and searches for “Forklift”. The mobile app will return empty results for traditional document searches because it searches across document titles rather than contents within an image. However, with AI, a forklift photo will be automatically tagged as “forklift”, making it searchable.

iii. Resource tracking:

With enough cloud-connected surveillance cameras on a job site, workers, equipment, and large tools can be tracked. AI can power cameras to count workers, identify vehicles and work activities, and report rough locations to project management software. AI can also count the number of vehicles entering and exiting the site, the number of workers at each sub-section, and the number of backhoes and cranes. These data points give construction companies a better real-time picture of their site.

3.4.3 The Future Advancements in AI

AI can help construction companies in many ways, such as making things faster, cheaper, and safer. It can do things such as entering and analysing data, which frees up workers to do more critical tasks. It can also watch construction sites in real time and warn workers about any dangers. As AI improves, it can perform even more complex functions, such as managing projects and designing things. This will make construction more efficient and help companies make better decisions. It will be interesting to see how it integrates with other technologies in the future.

(a) Enhance project design and management with AI, BIM, AR, VR, and MR:

BIM is a digital framework that has become essential in the construction industry. When combined with AI, BIM can enhance the management of complex construction projects. AI can streamline and automate BIM procedures such as design and rule checking, 3D as-built reconstruction, event log mining, building performance analysis, virtual, augmented and mixed reality, and digital twinning.

(b) Improve site safety and risk management with AI, IoT and big data:

AI can also detect and assess construction project risks, predict incidents, and issue early warnings. Smart wearables can collect valuable data that can be analysed to develop AI algorithms that are aimed at enhancing overall efficiency and risk management.

(c) Effective project and site planning with AI, big data and predictive analysis:

Construction companies increasingly use data-driven methods that utilise advanced analytics and AI to reduce waste. AI can convert raw data into practical insights, and these strategies include optimising offsite construction, selecting suitable materials, implementing waste-efficient procurement practices, facilitating reuse and recovery efforts, deconstruction, and promoting flexibility in construction processes. AI can also improve the accuracy of time and cost forecasting in construction projects.

(d) Enhance security and efficiency with the integration of AI and ML with cybersecurity and blockchain:

Integrating AI and ML with cybersecurity and blockchain technologies can significantly enhance the security and efficiency of the construction industry. Cybersecurity measures can be bolstered by incorporating AI, protecting sensitive project data from potential cyber threats. Additionally, leveraging blockchain technology establishes a transparent and immutable record of all transactions and data exchanges, ensuring accountability and trust among all stakeholders.

(e) Regulation and ethical AI concerns:

As AI continues to evolve, there is growing concern about regulation, copyright, and ethical considerations. The focus on these issues is expected to increase in the future.

3.4.4 Suggested Readings for Additional Information

To acquire comprehensive insights into the application of AI in construction, it is recommended that readers refer to the references listed below:

a. AI in Material Science: Revolutionizing Construction in the Age of Industry 4.0. 2024, Syed Saad, Syed Ammad, Kumeel Rasheed.
b. Construction 4.0: Advanced Technology, Tools and Materials for the Digital Transformation of the Construction Industry. 2021, Marco Casini.
c. Artificial Intelligence or AI in Construction Industry. Reza Dehghan. https://neuroject.com/ai-in-construction/#What_is_AI_or_Artificial_Intelligence/
d. How Does AI in Construction Industry Impact the Future?. Tarun Nagar. https://devtechnosys.com/insights/ai-in-construction-industry/
e. 6 Ways to Imagine AI Transforming the Construction Industry. Doug Dockery. https://www.constructconnect.com/blog/6-ways-to-imagine-a.i.-transforming-the-construction-industry/

3.5 Blockchain

3.5.1 Overview of Blockchain

Blockchain technology consists of a series of interconnected data blocks that form a distributed ledger. It is like a simple database with unique properties where each block contains a collection of accounts that automatically balances itself, like a chequebook. This ledger maintains a record of transactions or contracts that define a project and links each transaction to a separate block in the chain. For instance, when a supplier fulfils their contract by completing a delivery, the contract is finalised and added as a new block in the chain. This gives blockchains a natural order that is easy to follow when searching for information.

Blockchain technology is based on three principles: secure, decentralised, and scalable, as illustrated in **Figure 3.9**. It offers a multi-layered encryption system that uses mathematical functions to conceal data in a coded string of characters that is difficult to crack, thus ensuring security. It is decentralised, which means that connections called "nodes" automatically check transactions, leading to a digital paper trail of verified records. Finally, it is scalable, which means that because the information isn't stored on a central server, the blockchain can be expanded to fit large projects.

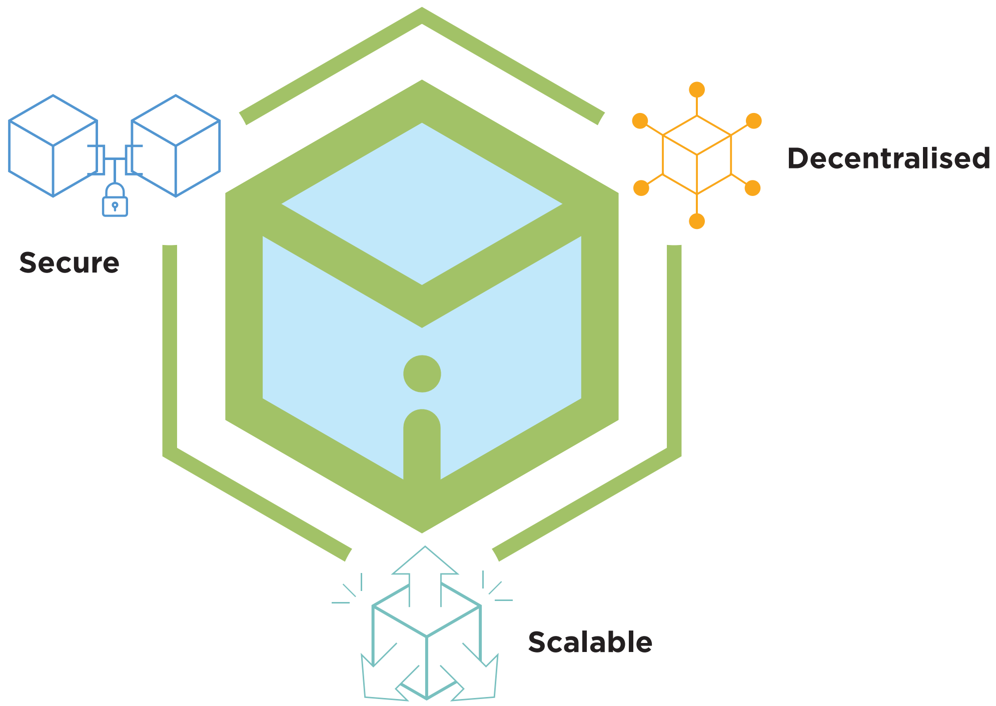

Figure 3.9 Principles Blockchain technology.

Blockchain technology can be classified into four major types: Public, Private, Consortium, and Hybrid blockchains, as shown in **Figure 3.10**. Public blockchains are decentralised and open to participation by anyone. Bitcoin and Ethereum are prime examples of public blockchains. On the other hand, private blockchains are centralised and controlled by a single organisation, making them ideal for internal business processes. Consortium blockchains, also known as federated blockchains, are controlled by a group of organisations, which makes them partially decentralised. They are often used for inter-organisational processes where transparency and collaboration are required. Lastly, Hybrid blockchains combine the features of public and private blockchains, offering a flexible approach where specific permissions may be controlled while others are open. This provides a balance between transparency and control. Each type of blockchain has its benefits and is chosen based on the specific needs of a use case.

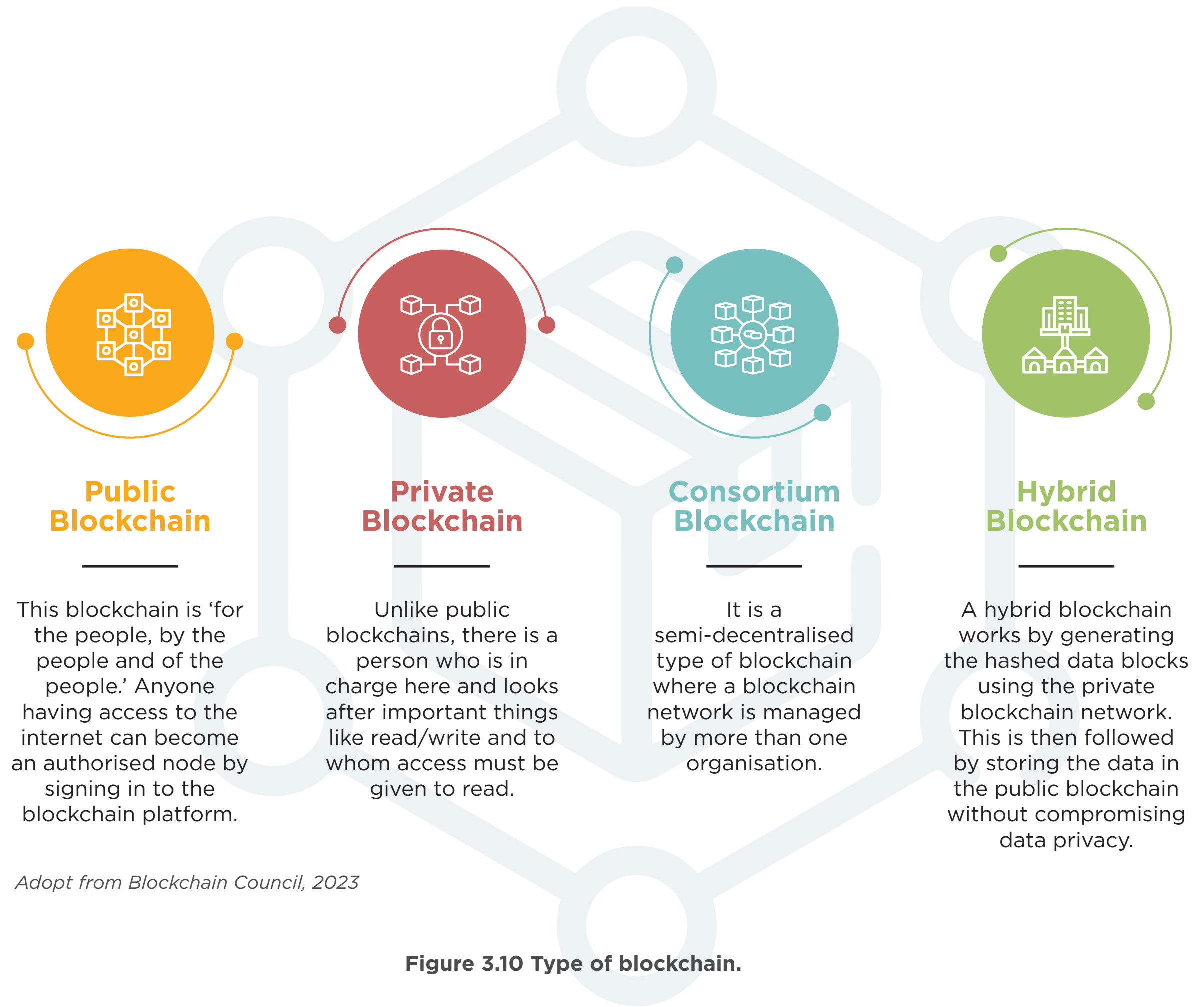

Figure 3.10 Type of blockchain.

3.5.1.1 Blockchain Technology Applications and Software for the Construction Industry

Blockchain technology has shifted paradigms in various sectors, including the construction industry. This revolutionary technology offers solutions that enhance efficiency, transparency, and collaboration. Here are some examples of blockchain technology software. The example is just a portion of the available options and is not limited to these alone.

(a) Provenance Blockchain:
Provenance Blockchain is a form of blockchain technology that can revolutionise the management of supply chains in construction. It offers a secure and transparent method for tracking goods, which is especially beneficial in large projects with multiple suppliers. For example, a construction company can utilise Provenance Blockchain to monitor the shipment of steel from the supplier to the construction site, ensuring transparency and accountability.

(b) Ethereum:
Ethereum is a decentralised blockchain with smart contract functionality. These automated contracts eliminate the need for intermediaries, saving both time and money. Smart contracts, powered by blockchain, automate the enforcement of contract terms, ensuring all parties adhere to their agreements. A construction company, for instance, could use Ethereum to automate payment upon delivery of materials, reducing the need for manual verification.

(c) BitPay:
BitPay is an application of blockchain technology that can streamline financial transactions, making them more secure and transparent. This can be particularly advantageous in large construction projects with numerous financial transactions. For example, BitPay can manage transactions, ensuring secure and transparent financial management.

(d) ConsenSys:
ConsenSys is a blockchain technology that can help establish a more efficient organisational structure by providing a transparent and secure platform for communication and collaboration. For instance, ConsenSys can facilitate communication and collaboration within a construction project team.

(e) RecycleGO:
RecycleGO is a blockchain technology that can promote sustainability and efficient waste management in the construction industry. For example, RecycleGO can track and manage waste, promoting sustainability.

(f) OpenBazaar:
OpenBazaar is a blockchain technology that can assist in creating new business models by providing a secure and transparent transaction platform. For instance, OpenBazaar can establish a decentralised marketplace for construction materials.

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(g) Storj:
Storj is a blockchain technology that can create a secure and transparent system for managing electronic documents. This can aid in reducing paperwork and improving efficiency. For example, Storj can be used to manage documents securely and transparently.

(h) VeChain:
VeChain is a blockchain technology that can be utilised to track and manage assets and schedule maintenance activities. For instance, VeChain can be used to track and manage construction equipment.

(i) Decentraland:
Decentraland is a blockchain technology that can securely store and manage design data and facilitate collaboration among the design team. For example, Decentraland can be used for collaborative design and visualisation.

(j) Civic:
Civic is a blockchain technology that can also be used to verify the identity of individuals and organisations, which can be particularly useful in large construction projects where multiple parties are involved. For example, Civic can be used for identity verification.

These blockchain technology applications can help make the construction industry more efficient, transparent, and collaborative. However, the adoption of blockchain in the construction industry is still in its early stages, and more research and development are needed to realise its full potential. As we move forward, it is anticipated that these blockchain-based tools and software will play an increasingly significant role in shaping the construction industry's future.

3.5.1.2 Steps to Implement Blockchain Technology in the Construction Industry

Integrating blockchain technology in the construction industry is a complex process that requires a systematic approach. The following guide outlines essential steps to incorporate blockchain technology seamlessly. By following these steps, construction companies can systematically integrate blockchain and leverage its benefits while minimising risks and disruptions.

(a) **STEP 1** is to identify use cases that leverage blockchain's transparency, traceability, and automation features. This entails identifying areas of inefficiency, pain points, and potential benefits. Supply chain management, payment processing, contract administration, and document verification are examples of use cases.

(b) **STEP 2** is to select the right blockchain platform for successful deployment. Scalability, security, consensus processes, interoperability, and community support are critical considerations for making the right choice. Public blockchains, such as Ethereum and Hyperledger Fabric, are attractive options for private or consortium blockchains, depending on the unique requirements of the construction project.

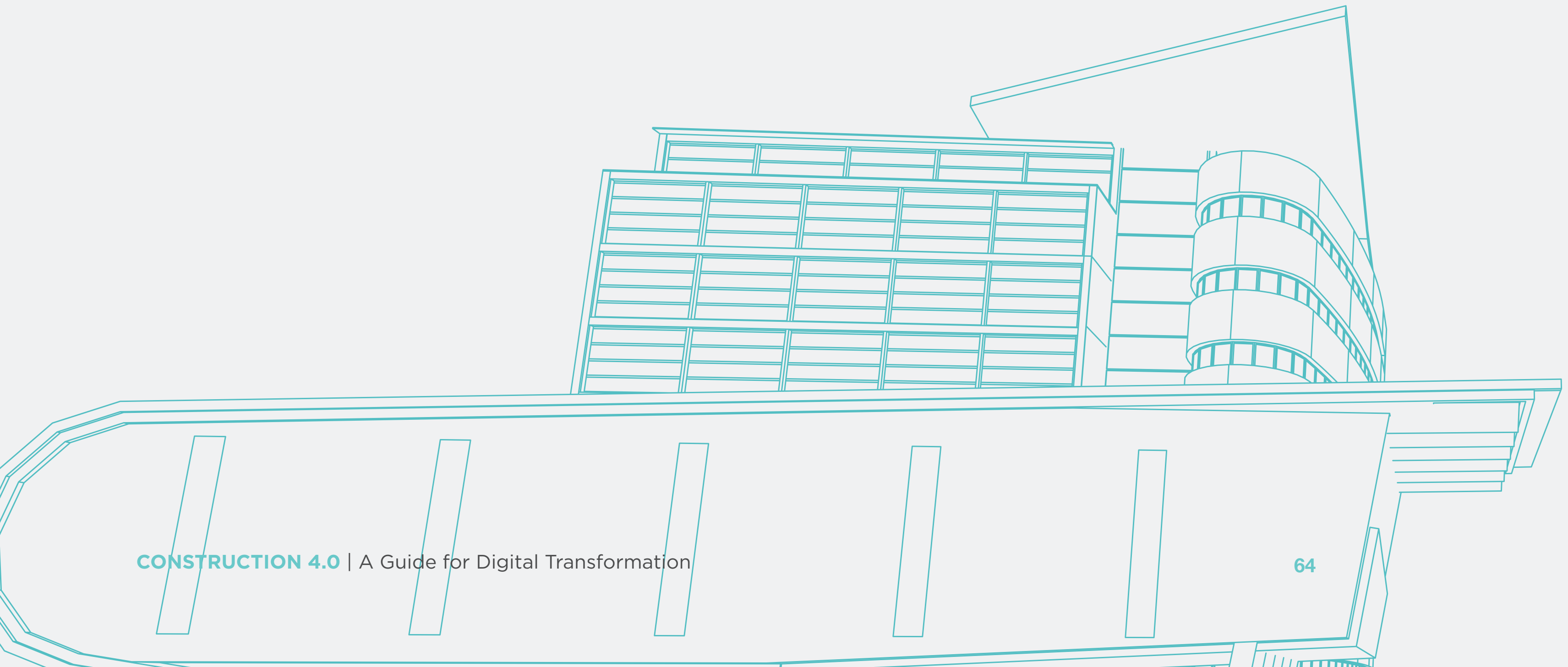
(c) **STEP 3** involves building a consortium or private blockchain. Companies must decide on the degree of collaboration they want, choosing between a consortium and a private blockchain. Private blockchains are limited to a single entity. In contrast, consortium blockchains involve multiple firms working together and sharing the blockchain infrastructure. Companies must also determine the intended degree of centralisation and control.

(d) **STEP 4** is to integrate blockchain with current systems and procedures for a smooth transition. Connecting the blockchain with legacy systems entails figuring out the interface points, implementing data exchange protocols, and creating APIs or middleware. Continuous integration ensures an adequate information flow and prevents delays in active construction projects.

3.5.2 Benefits of Blockchain Applications in the Construction Industry

The construction sector stands to gain substantially from the incorporation of blockchain technology. This technology offers a transparent and unalterable record of all transactions and interactions, streamlining project management and diminishing communication obstacles among the stakeholders. This can facilitate the avoidance of delays and disputes and simplify progress tracking.

Beyond project management, blockchain technology harbours the potential to bring about a revolution in supply chain management within the construction industry, as depicted in **Figure 3.11**. It facilitates a lucid cascade of work products and holds all parties accountable for completing crucial tasks. This degree of transparency and accountability was unattainable a decade ago.



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Adapt from Balint Penzes, 2018.

Figure 3.11 Example of collaborative project ecosystem in the blockchain.

Moreover, blockchain technology can enhance the efficiency of any project concerning crowdfunding and project financing. The decentralised and transparent characteristics of blockchain can facilitate secure peer-to-peer transactions and inaugurate new funding opportunities for construction projects. This enhances project transparency, reducing the necessity for extensive communication over straightforward objectives. There are four (4) categories of applications that can provide immediate benefits to the construction industry, as demonstrated in **Figure 3.12**.

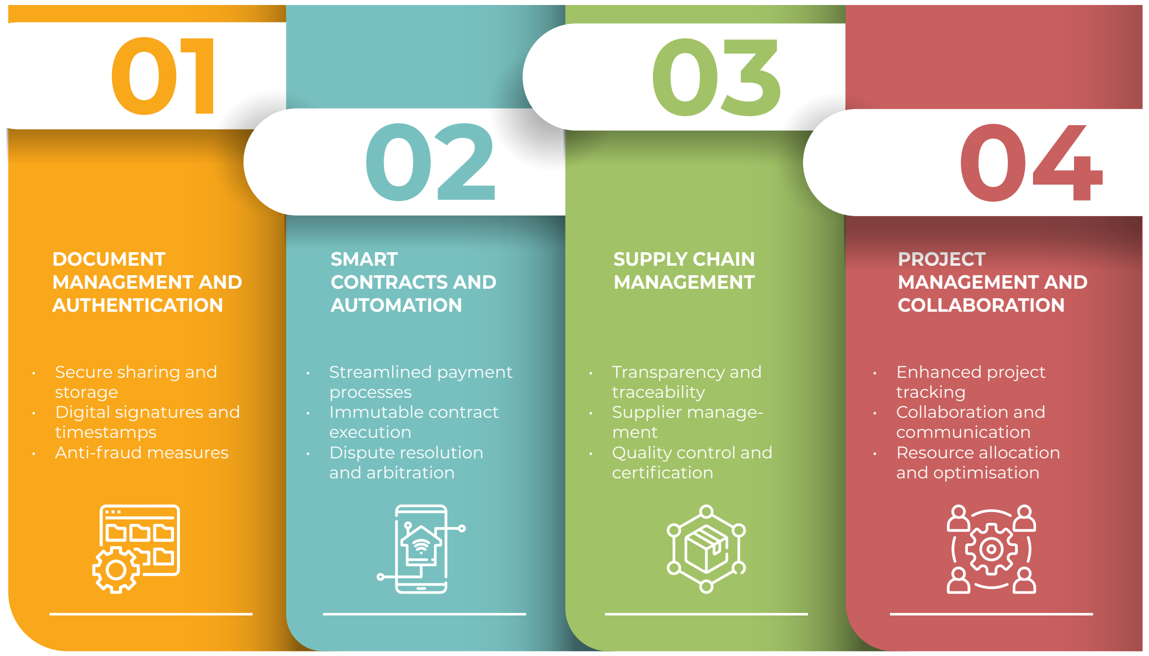


Figure 3.12 Immediate benefits in blockchain technology applications.

(a) Document management and authentication:

Blockchain technology offers a safe and decentralised platform for organising construction-related documents such as licenses, contracts, and drawings. Storing these documents on the blockchain allows construction companies to ensure the integrity of their papers, prevent unauthorised changes, and make information sharing and retrieval much more manageable. Moreover, the blockchain's authentication features allow for quick and easy verification of document validity.

i. Secure sharing and storage:

Blockchain technology provides secure sharing and storage solutions with high resistance against illegal access or manipulation. The data in a blockchain is dispersed among multiple nodes, making it much safer than centralised systems which are prone to hacking and data breaches. This enhances the privacy and security of critical construction data.

ii. Digital signatures and timestamps:

Digital signatures and timestamps, which provide unquestionable evidence of a document's integrity and authenticity, are made possible by blockchain technology. Timestamps offer a verifiable record of when a document was created or modified. At the same time, digital signatures ensure that papers cannot be altered without being noticed. These characteristics enhance the legitimacy and conformity of construction-related documents with the law.

iii. Anti-fraud measures:

The transparency and immutability of blockchain technology serve as practical barriers against fraud in the building sector. The blockchain keeps track of every transaction and modification, making it more difficult for bad actors to modify data or carry out fraudulent activities. This increases stakeholders' trust while lowering the financial and reputational risks related to fraud.

(b) Smart contracts and automation:

Smart contracts are self-governing agreements with pre-determined terms that can be implemented using blockchain technology. These contracts can automate construction processes such as project milestones, payment schedules and delivery confirmations. By eliminating the need for intermediaries and manual processing, smart contracts increase efficiency, reduce costs, and minimise delays associated with project execution.

i. Streamlined payment processes:

Blockchain-based payment systems can simplify financial transactions in the construction industry by enabling direct and secure peer-to-peer payments. By eliminating intermediaries, blockchain reduces transaction costs and promotes transparency, which helps both contractors and subcontractors.

ii. Immutable contract execution:

The immutability of blockchain technology ensures that a contract cannot be altered or tampered with once it is stored on the blockchain. This feature provides a trustworthy and transparent record of contractual agreements, reducing the likelihood of conflicts and providing parties who have disagreement with a verifiable source of truth. Immutable contract execution also makes effective contract management and auditing possible.

iii. Dispute resolution and arbitration:

In the construction industry, blockchain technology can facilitate arbitration and conflict resolution by providing an auditable and tamper-proof record of all relevant information. The blockchain can store evidence, contracts, and communication logs in case of disputes, making resolution procedures quicker and more accurate. This transparency fosters fairness and trust among all parties involved.

(c) Supply chain management:

Blockchain technology offers a transparent and secure platform for tracking the movement of resources and products in the construction industry supply chain. The blockchain records every transaction and product movement, allowing participants to track items' origin, status, and location in real time. This feature reduces supply chain delays and errors, lowers the risk of counterfeit products, ensures compliance with laws and standards, and increases efficiency.

i. Transparency and traceability:

Transparency and traceability are essential in the construction industry, and blockchain technology can provide both. By recording every transaction, update, and alteration on a distributed ledger accessible to authorised users, there is less room for fraud and manipulation. This openness increases stakeholder trust, settles disagreements, and makes decision-making more efficient.

ii. Supplier management:

Blockchain technology can simplify supplier management by building a decentralised database of suppliers' data, which includes credentials, certificates, and performance histories. This feature enables construction organisations to check the legitimacy of suppliers, assess their qualifications, and determine the best procurement course. Furthermore, blockchain can automate supplier payments, ensuring secure and timely transactions.

iii. Quality control and certification:

Quality control and certification procedures in the construction industry can be improved by blockchain technology. It can offer a visible and unchangeable record of inspections, testing, and certifications, including test results, compliance documentation, and materials utilised. This feature guarantees that quality requirements are met. It simplifies the auditing procedures and enhances the overall quality and safety of the project.

(d) Project management and collaboration:

Blockchain technology has the potential to revolutionise the construction industry by providing a decentralised platform for project information sharing, progress tracking and activity coordination. It enables real-time interaction, information exchange, and decision-making among project stakeholders, resulting in increased effectiveness and coordination throughout the project.

i. Enhanced project tracking:

With the transparency and audibility provided by blockchain, project milestones, tasks, and resources can be accurately tracked. Project managers can monitor progress, identify bottlenecks, and optimise resource allocation by storing this data on the blockchain. This improved project tracking leads to better project control, on-time delivery and increased overall performance.

ii. Collaboration and communication:

Blockchain-based collaboration tools make it easy for project stakeholders to communicate securely and effectively. This promotes cooperation, minimises communication gaps and enables effective decision-making by providing a shared workspace for discussing design changes, problem-solving and exchanging information.

iii. Resource allocation and optimisation:

Construction organisations can use blockchain to optimise resource allocation by providing a transparent and decentralised platform for tracking and managing resources such as machinery, materials, and labour. Construction organisations can reduce waste, improve efficiency, and cut costs by properly monitoring resource usage and availability on the blockchain.

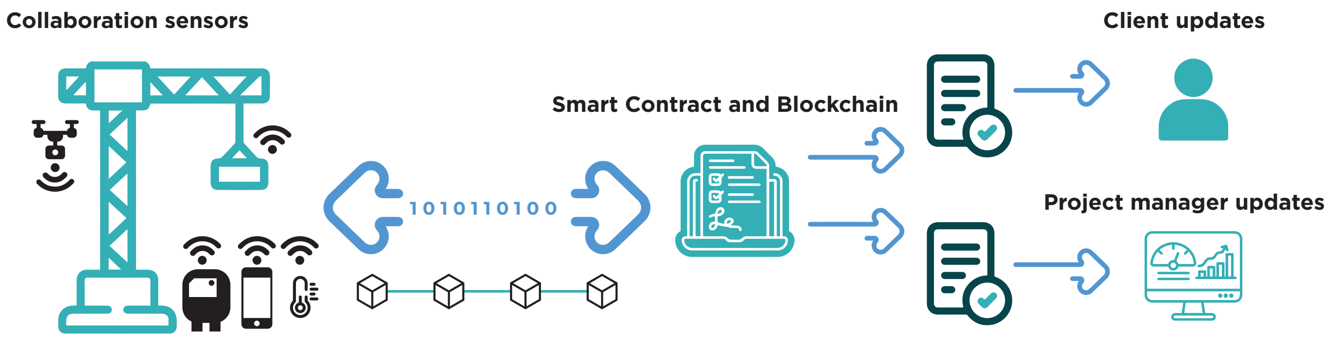
The decentralisation, transparency, and security features of blockchain technology have the potential to foster innovation, efficiency, and cooperation in the construction sector. By embracing blockchain, the construction industry can overcome long-standing obstacles, boost production, and complete projects more successfully in the digital era.

3.5.3 The Future Advancements of Blockchain in Construction

Blockchain technology is expected to bring about significant changes in the construction industry. The use of blockchain in the construction sector has a promising future, with new developments and trends leading the way for game-changing adjustments. Although there may be challenges, they can be overcome by using scalable solutions, working together, and addressing legal and regulatory issues. Collaboration and standardisation efforts are essential to establishing best practices across the sector and encouraging the broader adoption of this technology. Predictions for the upcoming years include increased use of blockchain in project financing, supply chain management, and interaction with other developing technologies. The construction sector has the potential to change several fields by adopting blockchain, enhancing efficiency, transparency, and collaboration and spurring innovation in the coming years. Here are potential advancements that could be realised in the future:

(a) Integrating with IoT:

The construction industry is witnessing several new trends and breakthroughs, indicating a promising future for blockchain technology. **Figure 3.13** illustrates the application of blockchain technology integrated with IoT sensors in construction project management. The use of IoT sensors on cranes, drones and other devices to collect real-time data from the construction site. This data is then stored and managed through a system represented by the “Smart Contract and Blockchain”, a secure and transparent method of recording transactions. The system allows for real-time updates on project progress to be communicated to clients and project managers. This integration of modern technologies enhances transparency, efficiency, and communication in construction project management, embodying the principles of C4.0.



Adapt from Balint Penzes, 2018.

Figure 3.13 Examples of IoT sensors and collaborators on site are informing smart contracts.

(b) Integrating with Cloud and Real-time Collaboration:

Emerging blockchain-based systems for project management, document sharing, and collaboration offer safe and open communication channels between project stakeholders. Collaboration and standardisation efforts are crucial for the widespread adoption of blockchain in construction. Coordination is required between construction businesses, technology providers, and regulatory organisations to create industry-wide standards, protocols, and governance models. These cooperative initiatives can develop best practices for blockchain adoption, ease interoperability, and increase stakeholder trust.

(c) Integration with AR and AI:

Several predictions indicate a bright future for blockchain in the construction industry. Blockchain is projected to be integrated with other cutting-edge technologies like AR and AI, which can facilitate better decision-making, boost project visualisation, and provide data-driven insights.

3.5.4 Suggested Readings for Additional Information

To acquire comprehensive insights into the application of blockchain in construction, it is recommended that readers refer to the references listed below:

a. Blockchain of Things and Deep Learning Applications in Construction. 2022, Faris Elghaish , Farzad Pour Rahimian , Tara Brooks , Nashwan Dawood , Sepehr Abrishami.
b. Blockchain for Construction. 2022, Theodoros Dounas, Davide Lombardi.
c. Blockchain in Construction. Forough Farhadi. https://neuroject.com/blockchain-in-construction/
d. Blockchain Technology in the Construction Industry: Digital Transformation for High Productivity. Balint Penzes, 2018. Institute of Civil Engineers (ice).
e. How Blockchain in Construction Will Change the Industry. Liam Stannard. https://www.bigrentz.com/blog/blockchain-in-construction

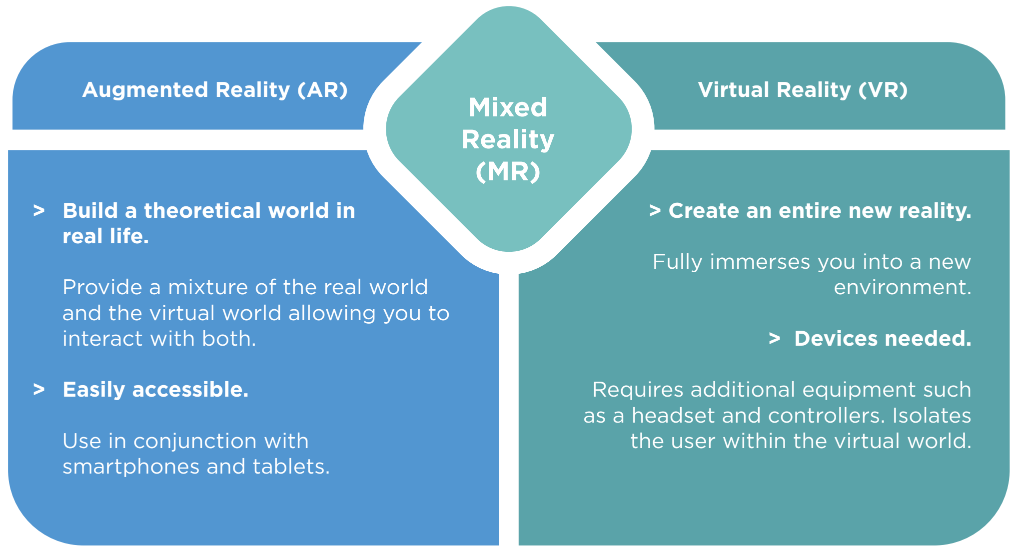
3.6 Augmented Reality (AR) and Virtual Reality (VR)

3.6.1 Overview of AR and VR

Augmented reality (AR) projects an image onto the user's line of sight, adding virtual elements to existing reality without completely replacing it. Virtual reality (VR) is an immersive view of a reality that does not exist, visualised to the user through a VR headset. VR completely replaces actual reality (both sight and sound) with a virtual one, allowing everyone from architects, engineers, project managers and end users involved in the building process to experience building designs and plans in 3D. This immersive experience will enable designers to "live the design" and identify potential flaws before the ground break, indirectly saving time and preventing rework. **Figure 3.14** illustrates the difference between AR and VR.

VR is typically used off-site during the design and pre-construction process, while AR is used on-site to apply a design to the real-world job site setting. Workers can visualise the completed design with the correct measurements to build directly from that AR-project image.

On the other hand, Mixed Reality (MR), is a blend of AR and VR. It anchors virtual objects to the real world, allowing users to interact with both physical and virtual items and environments, using next-generation sensing and imaging technology. MR can be used both on-site and off-site for tasks such as visualising the integration of new equipment into an existing facility or experiencing a walkthrough of a building before construction.



Adapt from Adrian Schley, 2019.

Figure 3.14 Differences between AR and VR.

3.6.1.1 AR, VR And MR Applications, Devices and Software for the Construction Industry

AR and VR have revolutionised various industries, including the construction sector. These technologies offer innovative tools and applications that enhance design visualisation, improve efficiency, and provide immersive training experiences. This document overviews several AR and VR applications, tools, and software in the construction industry. The example is just a portion of the available options and is not limited to these alone.

(a) AR applications and devices for the construction industry:

AR is revolutionising the construction industry by providing innovative solutions that enhance efficiency, reduce errors, and facilitate accurate construction. Here are three notable AR applications and devices:

i. Dalux:

Dalux offers three AR solutions for civil construction. These solutions can streamline the planning process and enhance the efficiency of construction teams. For example, a construction manager could use Dalux to visualise the placement of underground utilities, reducing the risk of costly errors.

ii. Fologram:

Fologram is another AR tool used in the construction industry. It provides a platform for architects and designers to bring their digital designs into the physical world. A designer could use a Fologram to project a digital blueprint onto a physical site, facilitating accurate construction.

iii. Novaby:

Nova is an AR tool that enhances the construction process by providing more information and better training. It aids in planning coordination and improves the efficiency of construction teams. For example, a construction worker could use Nova to access real-time information about a construction task, improving productivity.

(b) VR applications and devices for the construction industry:

VR significantly impacts the construction industry by offering immersive experiences that enhance project planning and execution. Here are two key VR applications and devices:

i. IrisVR:

IrisVR works with the 3D software already used by construction teams to provide a true-to-scale preview of a project before breaking ground. For example, a construction team could use IrisVR to resolve construction conflicts virtually, keeping projects on budget.

ii. Head-Mounted Displays (HMDs):

HMDs such as Meta Quest, Samsung Gear VR, HTC Vive, and Google Cardboard allow architects and project stakeholders a fully immersive 3D experience. These tools allow virtually crossing an entire building and accessing all the relevant information.

(c) MR applications and devices for the construction industry:

MR is a game-changer in the construction industry, offering immersive experiences that blend the physical and digital worlds. Here are two key MR applications and devices:

i. Head-Mounted Displays (HMDs):

HMDs such as Microsoft HoloLens allow users to engage with digital content and interact with holograms in the physical world. For example, the construction team uses Microsoft HoloLens to overlay BIM designs onto physical construction sites for better site planning and design visualisation. Stakeholders can "walk through" the full-scale design before construction begins, facilitating a deeper understanding of design plans and identifying potential issues early on.

ii. DAQRI Smart Helmet:

This device equipped with thermal vision and data visualisation capabilities, is a standout example of how MR can facilitate collaboration and remote assistance. This device enables architects and designers to visualise 3D models of their designs within a real-world environment. For instance, an architect could use this tool to visualise a proposed skyscraper within its intended urban context, improving design accuracy.

In conclusion, AR, VR and MR technologies offer an immense choice of applications that can significantly enhance the construction process. From design visualisation to immersive training, these tools provide innovative solutions to traditional challenges in the construction industry. As these technologies continue to evolve, they are expected to play an increasingly integral role in shaping the future of construction.

3.6.2 Benefits of AR and VR Applications in the Construction Industry

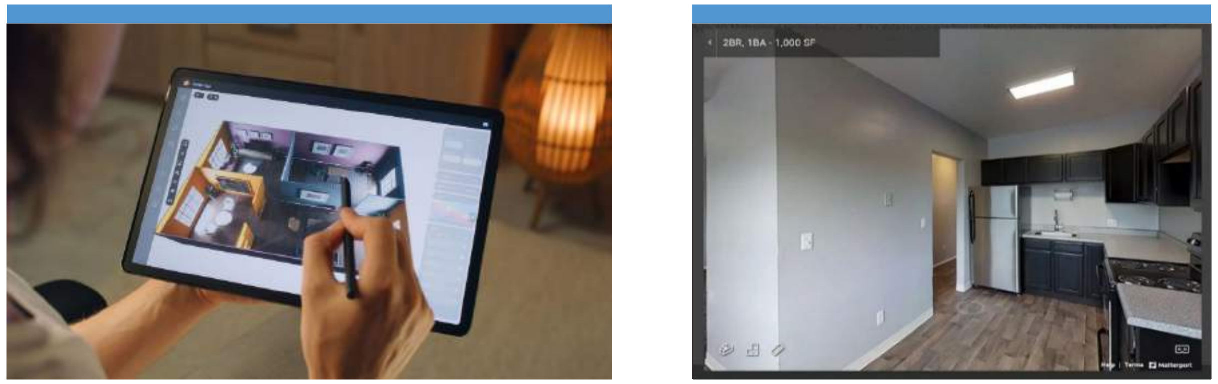
The implementation of AR and VR technologies has transformed the construction industry. The possibilities of these technologies are limitless, providing an innovative and immersive experience for all stakeholders involved in a project. From enhanced communication to better visualisation and collaboration, AR and VR applications can revolutionise the industry and create a better future for construction.

Here are the benefits of AR and VR for the construction industry:

(a) Better management of stakeholder expectations via virtual construction:

Advanced 3D modelling software and BIM have revolutionised the design and planning process. AR is an intelligent solution that allows stakeholders to take virtual walkthroughs of buildings in progress or see how changes will be incorporated into the design without throwing the job off track **(Figure 3.15 (a)**). AR can be used to showcase building designs to potential clients and investors, providing a more immersive and engaging experience. AR can also layer specific details and elements onto a building plan so stakeholders can better understand the project. In addition, AR can be used to showcase 3D models and even provide tours, giving stakeholders a solid idea of what a building would look like before it's built.

VR technology in construction allows people to visit the site virtually to see how the project is going. It also allows users to model buildings, rooms, and furniture virtually to ensure they suit them before investing. BIM involves creating 3D models to demonstrate future buildings, but VR takes BIM to the next level, making its models more immersive and interactive **(Figure 3.15 (b)**). VR technology like 3D interior designs, 3D visualisation, and virtual apartment tours showcase customers' buildings in an interactive, effective, and convenient way, boosting sales significantly. Users can try different designs and choose the most appropriate furniture.



a) Design walks through or view using an AR application

b) Interior designs and virtual apartment tours using VR application

Sources: Volodymyr Fedorychak, 2023; Onix, 2023.

Figure 3.15 Example of advanced visualisation

(b) Enhanced communication and collaboration:

AR/VR technology is revolutionising the way construction projects are conducted. It has taken the concept of 3D modelling to new heights and made it far more accessible. VR technology allows participants worldwide to meet virtually, coordinate projects, check for updates, spot issues, and make changes **(Figure 3.16)**. AR enables remote workers to inspect the job site as if they are present, enabling real-time collaboration to solve problems and fix errors without waiting for a particular contractor or decision-maker to be physically present. AR also allows designers and architects to walk through or view an offered project and select any structural or design features they want to change. AR can streamline collaboration in remote environments by letting teams share 3D images and videos with team members who are not on-site. Stakeholders can view images or videos in greater detail to identify errors or issues without being in the actual building/location.

Sources: Onix, 2023

Figure 3.16 Example of virtual collaboration

(c) Better construction management:

AR/MR technology can be used in construction management to help engineers spot opportunities for design improvements. AR/MR can observe the construction site, take photos or videos, and check how unbuilt structures align with a construction plan (**Figure 3.17**). VR technology can build 3D models containing information about the future building. It provides an immersive experience of walking around that building, allowing stakeholders to view a clear picture of their projects instead of uninformative drawings and spot problems before building. VR can also detect misconceptions in the initial stage and provide quick feedback, allowing users to avoid reworks and complete projects on time and within budget.

Sources: Turner Construction Company, 2023

Figure 3.17 Example of construction management using virtual technology.

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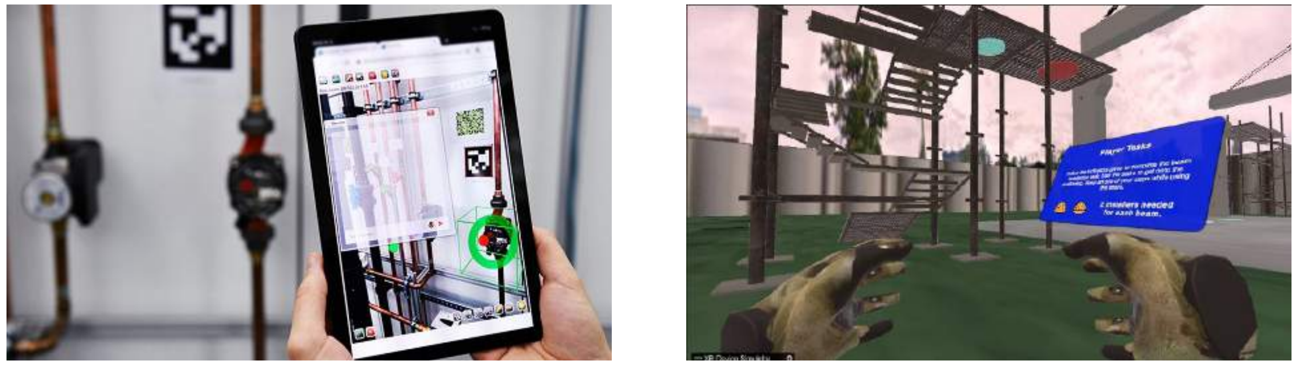
(d) Safe environment for training:

Safety is essential in construction, but safety training is costly, time-consuming, and potentially hazardous if it involves an inexperienced worker. In addition, human errors are a common cause of progress disruptions and money losses due to the low qualification of construction staff. This problem is challenging, as even construction personnel with degrees may lack practical skills.

AR can simulate tools, equipment, and other safety scenarios to provide a safe learning environment for trainees, allowing them to learn from their mistakes and transfer them to the real world **(Figure 3.18 (a)**). Meanwhile, VR-based training solutions allow trainees to simulate real-life situations in a risk-free environment, allowing construction workers to operate hazardous equipment without risks **(Figure 3.18 (b)**).



a) Design walks through or view using an AR application

b) Interior designs and virtual apartment tours using VR application

Sources: Volodymyr Fedorychak, 2023; Innovacia Sdn Bhd, 2024.

Figure 3.18 Example of training application AR/VR for construction workers

(e) Minimisation of errors and discrepancies:

AR/VR technology provides an exciting solution to put collaborative teams on-site without needing them to travel to the construction area. AR/VR technology allows remote workers to inspect the job site as if they are present and capture notes, images, or videos of problems, which distant teams can review later **(Figure 3.19)**. There is a software platform that combines AR with VR to enable collaboration between team members, allowing different teams to gain access to a virtual workspace that provides design reviews and creates markups. AR also allows field workers to walk a job site anytime and see what the finished project looks like, allowing them to compare what they see to the building plan to ensure everything is in order. AR/MR technology can quickly access 3D modelling, IT, and software compatibility to design, construct, and operate a building project.

AR/MR applications allow superimposing computer-generated images from CAD or BIM programs onto a user's real-world view, resulting in a composite or augmented image. For example, AR in construction reduces the need for paper-based plans and helps reduce the time spent on manual processes. It also helps to optimise the use of resources, reducing waste and saving money. AR technology can also improve safety on the job site. For example, some AR devices can scan tags or labels that are placed in specific areas or objects and bring up text or 3D models to communicate safety or hazard information.

Sources: Sarah Downey, 2016; Onix, 2023.

Figure 3.19 Example of application AR/VR to minimise errors and discrepancies.

3.6.3 The Future Advancements in AR and VR for the Construction Industry

In the realm of construction, a significant transformation is underway, driven by the integration of Augmented Reality (AR) and Virtual Reality (VR) with other advanced technologies. This fusion of technologies sets the stage for remarkable progress in the field. When these technologies are combined, they have the potential to enhance visual representation, boost efficiency, and aid in more effective decision-making processes. Let us go through some of these technologies and examine how they intertwine with AR and VR:

(a) Cloud and real-time collaboration integration:

Envision a future where AR and VR seamlessly integrate with cloud technology. This potent amalgamation has the potential to provide instantaneous updates to virtual models or simulations, akin to a real-time update feature for a virtual world. This ensures all participants can access the most recent and precise information, enhancing collaboration efficiency and accuracy.

(b) Advancements in data analytics and AI:

Data analytics, a powerful tool for processing vast quantities of data and extracting valuable insights, and AI, a sophisticated system capable of automating intricate tasks, are two transformative technologies. When integrated with AR/VR, they can provide predictive modelling and intelligent automation, revolutionising various sectors. For instance, in the construction industry, AI can scrutinise data from a construction site and employ AR/VR to generate a virtual model, thereby pre-emptively identifying potential issues. This integration signifies a leap towards a future where technology enables us to anticipate and mitigate problems before they materialise.

(c) Integration with IoT:

IoT devices can collect data from construction sites and render it using AR/VR technologies. This technological integration facilitates real-time surveillance and informed decision-making processes.

(d) Smart factory and automation:

The AR or VR interfaces can be seamlessly integrated into the smart factory setup by overlaying digital information onto the physical environment, providing real-time assistance and guidance in construction. This can include visualising complex construction blueprints, facilitating remote collaboration, and offering immersive training experiences for workers. Moreover, AR/VR can streamline project planning and coordination. For instance, AR can enable project managers to visualise the construction progress in real time and make informed decisions. At the same time, VR can simulate different construction scenarios and plan accordingly.

(e) Enhancing visualisation for 3D printing:

Integrating AR/VR technologies can significantly enhance the visualisation process in 3D printing. AR/VR technologies can be employed to visualise 3D models before their actual printing, providing a comprehensive understanding of the model and enabling the identification and rectification of potential design flaws. This leads to improved accuracy in the final product and a substantial reduction in material waste. Moreover, AR/VR can facilitate a more interactive and immersive design experience. Designers can manipulate 3D models in a virtual space, assess the model from various angles and make real-time modifications. This not only accelerates the design process but also fosters creativity and innovation.

(f) Enhance prefabrication & modular construction:

The integration of AR and VR technologies can significantly revolutionise the domain of prefabrication and modular construction. These technologies can provide a comprehensive visualisation of the assembly process of prefabricated components before their on-site installation. This not only facilitates seamless project visualisation but also enables efficient progress tracking. By creating an immersive, interactive 3D environment, AR or VR can aid in identifying potential issues, optimising assembly sequences, and improving overall construction efficiency. Thus, this integration represents a promising avenue for future advancements in the field.

The construction industry's future is poised for a significant transformation, with AR and VR at the helm. The integration of these technologies is set to enhance visual representation, streamline efficiency, and facilitate effective decision-making. This technological fusion will revolutionise various sectors, from real-time collaboration and predictive modelling to smart automation and prefabrication. As we continue to harness these advancements, we are paving the way for a future where the construction industry is more efficient, innovative, and forward-thinking. This progress signifies a promising avenue for future advancements in the field, setting the stage for a new era in construction.

3.6.4 Suggested Readings for Additional Information

To acquire comprehensive insights into the application of AR and VR in construction, it is recommended that readers refer to the references listed below:

a. Construction 4.0: An Innovation Platform for the Built Environment. 2020, Anil Sawhney, Michael Riley, Javier Irizarry.
b. 7 Applications for Augmented Reality (AR) in Construction. Volodymyr Fedorychak. https://smarttek.solutions/blog/augmented-reality-in-construction/
c. 4 Best Ways to Benefit from VR in Construction. Onix. https://onix-systems.com/blog/4-best-ways-to-benefit-from-vr-in-construction
d. Explore the Impact of Augmented Reality in Construction. Kamran Arabi. https://neuroject.com/augmented-reality-in-construction/
e. VR and AR Could Revolutionize Construction, But There Are Still Big Challenges. Sarah Downey. https://www.uploadvr.com/vr-and-ar-in-construction/

SMART CONSTRUCTION

“This chapter delves into Smart Construction, a vital component of the Construction 4.0 Strategic Plan (2021-2025), which leverages modern technologies to boost efficiency, accuracy, and safety in construction projects. It discusses advanced tools such as prefabrication and modular construction, photogrammetry and 3D scanning, AM, advanced building materials, and autonomous construction. Integrating these technologies can revolutionise the construction industry, leading to quicker, more precise, and more cost-effective project completion.

Additionally, these technologies can contribute to reduced labour costs, improved safety, enhanced productivity, better resource utilisation, and increased competitiveness, thus making the construction industry more efficient, sustainable, and resilient.”

4.0 Smart Construction

Smart construction refers to the application of modern technologies to enhance construction projects' efficiency, accuracy, and safety. This approach constitutes the third cluster in the Construction 4.0 Strategic Plan (2021-2025). It utilises various advanced tools, such as prefabrication and modular construction, photogrammetry and 3D scanning, additive manufacturing, advanced building materials, and autonomous construction.

Here is a brief explanation of each of these technologies:

1. **Prefabrication and Modular Construction:**
   Prefabrication and Modular Construction involve producing components in a factory setting, which are transported and assembled on-site. This method can significantly reduce construction time, improve quality control, and reduce waste.

2. **Photogrammetry and 3D Scanning:**
   Photogrammetry and 3D Scanning technologies allow for capturing high-resolution three-dimensional data from the real world, which can be used to create detailed 3D models for design and planning purposes, enhancing accuracy and efficiency.

3. **Additive Manufacturing (AM):**
   AM enables the creation of complex structures and components with high precision and speed, reducing the need for extensive inventories of standard parts. 3D printing is an advanced manufacturing technique that is a subset of AM.

4. **Advanced Building Materials:**
   Advanced Building Materials include self-healing concrete, smart glass, and energy-efficient insulation, which enhance buildings' durability, sustainability, and energy efficiency.

5. **Autonomous Construction:**
   Autonomous Construction involves using drones, robots, and other automated tools to perform excavation, site preparation, material delivery, and installation tasks. This can reduce the need for human labour, improve safety, increase efficiency and reduce carbon footprint.

By integrating these technologies, smart construction can revolutionise the construction industry, resulting in faster, more accurate, and cost-effective project completion. These technologies can also contribute to reducing labour costs, improving safety, enhancing productivity, better resource utilisation, and increased competitiveness. Consequently, the construction industry can become more efficient, sustainable, and resilient, thus, contributing to economic growth and development.

4.1 Prefabrication and Modular Construction

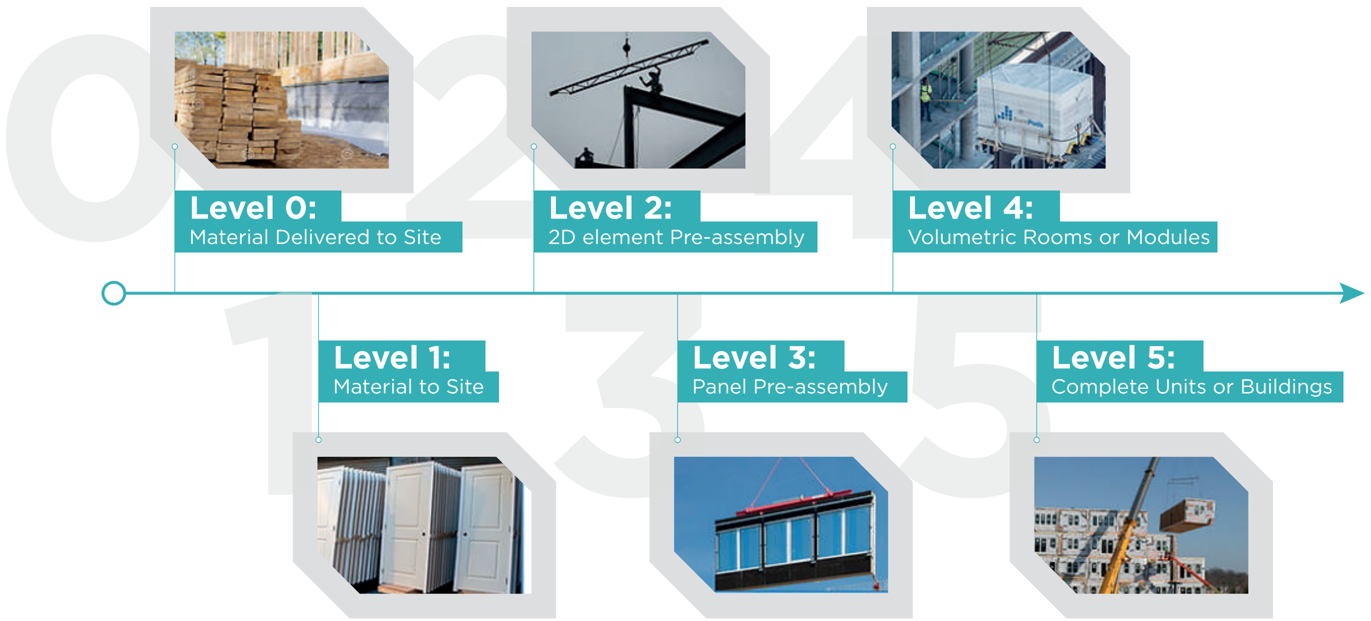
4.1.1 Overview of Prefabrication and Modular Construction

The construction industry often uses the terms prefabrication and modular construction interchangeably. However, the prefabrication process has gained popularity due to its numerous advantages and the ability to customise construction elements to meet specific project requirements. From the design of a façade to the manufacture of a factory-fitted bathroom, prefabrication offers endless possibilities. Similarly, modular construction involves various off-site construction techniques that the level of prefabrication can classify. The higher the level of prefabrication, the more pre-assembly or prefabrication is completed before the element arrives onsite, allowing for faster and more efficient construction. In short, both prefabrication and modular construction offer innovative solutions to traditional construction methods, paving the way for a brighter future in the construction industry.

4.1.1.1 Level of Prefabrication in Construction Industry

The level of prefabrication can vary greatly, ranging from the delivery of raw materials to the site to the construction of complete units off-site, as shown in **Figure 4.1**.

Here are six levels of prefabrication in the construction industry:



Adapt from BuildModular, 2023.

Figure 4.1 Level of Prefabrication.

(a) Level 0: Materials to site:

At Level 0, the construction materials are not pre-assembled before reaching the construction site. The timber, concrete mix, and reinforcement bar are delivered in bulk, while the masonry is delivered in shipments of individual blocks. All these materials are then assembled on-site to complete the building.

(b) Level 1: Minor components:

In Level 1, the minor components are assembled before being delivered to the site. This includes pre-assembled windows with glass in the required size from the window supplier. Pre-hung door assemblies, lighting fixtures, and mechanical equipment are considered minor components in Level 1.

(c) Level 2: 2D element pre-assembly:

At Level 2, several building elements are manufactured and shipped to the site. These elements are usually two-dimensional, skeletal, and linear. For instance, the contractor commonly orders roof trusses from a specific truss manufacturer. They are then delivered to the site for installation. The steel fabrication industry is a good example of Level 2, where steel assemblies are welded in fabrication shops and then lifted into place to be bolted or site-welded into the larger structure. All necessary components, such as clips, shear tabs, and base plates, are assembled in a controlled environment to make on-site assembly easier and safer. Level 2 mainly pertains to the structural discipline and does not include the integration of other disciplines such as electrical, mechanical, or building envelope. This is the primary difference between Level 2 and Level 3: Panel Preassembly.

(d) Level 3: Panel pre-assembly:

Level 2 and Level 3 in off-site construction differ in terms of integration. Level 3 involves the integration of various project disciplines into a single element. Integrating different project disciplines leads to increased efficiency, provided that the project is developed in a manner conducive to integration. Traditional project delivery models are not conducive to real integration. One example of Level 3 is manufacturing an off-site precast concrete wall element with integrated electrical components, windows, insulation, and a cladding system. However, Level 3 is still considered non-volumetric as it involves shipping multiple wall, floor, and roof panels to the site to be assembled to create the volumetric space. Levels 4 and 5 are considered volumetric prefabrication methods, and people often refer to them as 'modules' of Modular Construction.

(e) Level 4: Volumetric rooms or modules:

This level involves manufacturing enclosed boxes in a facility, which are then transported to the site and installed. The boxes require minimal plumbing and electrical connections before they are considered complete. All aspects of the volumetric module, including drywall, interior finishes, millwork, and flooring, are created in the manufacturing facility. Multiple volumetric rooms can be assembled, or an entire room can be combined with other construction methods. For instance, in building construction, bathrooms can be manufactured off-site, delivered, and installed into place finished with painted drywall, flooring, vanity, toilet, shower, electrical and lighting. This method is suitable for enclosed rooms that require multiple disciplines and can fit the shipping dimensions. Volumetric modules are also commonly used in commercial and industrial projects for complex mechanical rooms. The facility can efficiently assemble the central point for electrical and mechanical functions; once they are placed in the final position on-site, the necessary runs (electrical, ductwork, plumbing, gas, coolant, etcetera) can be connected.

(f) Level 5: Complete units or buildings:

Level 5 and Level 4 are volumetric modules that have most of their construction completed off-site, including interior finishes and final furniture. The difference between Level 4 and 5 is that the module of Level 5 is a whole living unit. In multi-unit residential, an entire apartment or condo is constructed off-site, and once lifted into place, it is essentially completed. In some cases, a whole apartment might consist of two modules connected, which is still considered Level 5 in the classification. Once lifted onto a foundation and connected to the services, these modules are ready to use, fully outfitted, and contain the main furniture.

As the industry continues to evolve, the adoption of higher levels of prefabrication is expected to increase, further transforming how buildings are constructed.

4.1.1.2 Type of Prefabrication in Modular Construction

Various types of prefabricated building units available in the market are made using different primary construction materials. These materials can include steel, concrete, timber, glass, and even recycled materials, as shown in **Figure 4.2**. The example is just a portion of the available options and is not limited to these alone. Prefabricated building units are manufactured off-site in a controlled environment and then transported to the construction site for assembly. They are designed to be quicker and easier to construct than traditional buildings while being more cost-effective and environmentally friendly. Additionally, prefabricated building units can be customised to fit specific requirements. They can be used for various purposes, such as residential homes, commercial buildings, schools, hospitals, etcetera.

a) Prefabricated precast concrete unit

b) Prefabricated metal framing unit

c) Prefabricated unit using shipping containers

d) Prefabricated timber unit

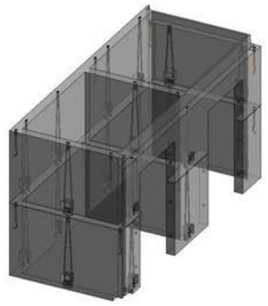
Sources: Aurelie Cleraux, 2018; Shift Modular, 2014; Bridgette Meinhold, 2010; Alter, 2014.

Figure 4.2 Prefabricated building units using different primary construction materials.

In the construction industry, prefabricated volumetric modules and building units are widely utilised. These modules, which include toilet pods, lift core modules, and prefabricated MEP (mechanical, electrical, and plumbing) modules, serve various functions, as shown in **Figure 4.3**. Toilet pods are fully equipped bathroom units, lift core modules are pre-built sections of a building that house elevators and stairwells, and prefabricated MEP modules contain all the necessary systems for a building, including heating, cooling, and electrical systems.

MEP modules typically require engineered overhead frame support for structural safety. Another manifestation of prefabrication in construction is the prefabricated modular support system. This system is essential for typical MEP applications, including pipe supports, cable trays, duct runs, electrical panel boxes, plumbing, data cable services, and many other overhead MEP services, as shown in **Figure 4.3 (d)**. This system improves efficiency and project productivity, reduces installation time and material wastage, and brings higher quality project standards than traditional methods.

a) Prefabricated toilet module/pod



a) Prefabricated lift core module

c) Prefabricated MEP module; horizontal module (left), vertical riser module (centre) and plant module (right)

d) Prefabricated modular support completed with MEP

Sources: K. Structures, 2015; PCE Ltd., 2017; BCA Singapore, 2018; Hilti Group, 2024.

Figure 4.3 Example of prefabricated volumetric module.

4.1.2 Benefits of Prefabrication and Modular Construction Applications in Construction Industry

Prefabrication is often seen as limiting the options for the final design in construction. However, if implemented effectively, it significantly benefits various parties involved in the project. For business initiatives, contractors and stakeholders can reap the rewards of this construction technique. There are numerous advantages to using prefabrication, including improved efficiency, reduced costs, enhanced quality control, and greater sustainability, as listed in **Figure 4.4.**

Figure 4.4 Benefits of using prefabrication in construction.

(a) Better security and safety:

The construction sector is widely recognised as a hazardous industry, necessitating trade contractors to prioritise adopting safer systems. One such technique is prefabrication, which entails employing sub-assembly workflows in factory-like, regulated environments, reducing environmental hazard risk. Modern engineering and prefab materials facilitate the construction of assemblies and structures that are just as durable as their older counterparts. Working in a controlled setting ensures that higher safety standards are adhered to on-the-job site, which is critical for trade contractors susceptible to health hazards, such as falls, associated with weather conditions on job sites. In addition, strict industrial protocols and processes contribute to fewer mishaps and injuries. The risks to employees continue to increase due to changes in job site conditions brought on by weather, terrain, excessive movement of people, etcetera. However, reducing the number of activities and working hours on the job site can help mitigate this risk.

(b) Cost-effective:

The construction industry has been encountering a persistent increase in costs annually, posing a significant challenge to trade contractors who strive to maintain their profit margins. The prices of materials and labour have not been decreasing, and delays from weather conditions and longer working hours can lead to a surge in demand for both labour and goods, resulting in higher prices. However, prefabrication in construction can assist in mitigating these escalating costs by streamlining the construction process.

(c) Advanced technology trends and industry impacts:

The construction industry has witnessed significant strides in technology and innovative thinking. Modularisation and prefabrication have been reimagined to achieve higher economic, environmental, and sustainability levels in construction projects. Building Information Modelling (BIM) has been pivotal in this achievement. The confluence of technology in the manufacturing factory and the embrace of lean construction practices have enabled leaders to visualise production, material, and labour costs on each project, resulting in cost optimisation and reduction for businesses.

(d) Offers flexible solutions:

Prefabrication and modular construction methods have become increasingly popular in the construction industry due to their flexibility and efficiency. These approaches allow for the utilisation of readily available materials and enable workers to disassemble and transport sub-assemblies to other job sites quickly. By providing more design freedom and flexibility, owners and general contractors consider prefabricated construction a viable option for their projects.

(e) Increased quality control and consistency:

Prefabrication has become a more popular method in construction due to its ability to enhance quality assurance and control. Prefabrication can ensure consistency throughout the build cycle by utilising a controlled environment that employs standardised, repeatable, and homogeneous manufacturing methods. In contrast, traditional on-site construction presents many obstacles, such as varying worker skill sets, weather conditions, overlapping trades, delivery errors, broken materials, and labour downtime. With prefabrication, these challenges can be minimised, and quality checks can be conducted at every stage of the build process, resulting in a more streamlined and efficient construction project.

(f) Offers substantial time savings:

Numerous studies and initiatives have shown that prefabrication in construction offers significant time savings compared to conventional on-site construction. This is primarily attributed to the ability to plan with greater precision, the parallel multi-trade assembling process, and the ability to mitigate the adverse impacts of weather conditions. Adopting manufacturing workflows can help produce deliverables and eliminate typical problems that lead to project delays. Prefabricated, offsite, or industrialised building methods can give construction companies greater confidence to complete projects on schedule.

(g) Environmental-friendly construction:

Prefabricated and modular construction techniques are considered more environmentally friendly than traditional construction in the short and long term. Conventional construction methods require more bulk materials, which leads to significant material waste on every construction site. However, prefabricated materials are often recycled, while waste is immediately dumped in landfills. Moreover, just-in-time material ordering becomes possible through prefabrication in construction, which reduces prices and waste. As a result, regular neighbourhood disruptions such as traffic and closures and busy construction sites with a lot of dust are minimised.

(h) Produces much more durable materials:

Prefabrication has been recognised as a method that leads to the production of more durable materials. Prefabricated materials, such as steel, concrete, timber, and PVC, are commonly used due to their efficiency in being transported and supplied to job sites. Compared to traditional components produced on the job site, prefabricated materials are less prone to problems such as rust. This is because they are manufactured in controlled environments and with higher quality standards. As a result, they provide a more reliable and consistent product that can withstand various environmental conditions.

(i) Optimises workforce:

Implementing preconstructed elements in construction can offer a streamlined approach to optimising the workforce by reducing the number of workers necessary for component assembly and minimising the need for supervisory personnel to oversee construction teams. This method also simplifies and improves accuracy during the preparation process for expedited timelines, leading to fewer delays and positively impacting labour scheduling. The reduction in communication problems only heightens the benefits of prefabrication in construction.

4.1.3 The Future Advancements of Prefabrication and Modular Construction

The construction industry has been significantly transformed by the implementation of prefabrication and modular construction, both of which seamlessly integrate with other advanced technologies. These innovative methodologies enable builders to erect structures with greater efficiency and speed than previously achievable. Prefabrication involves the off-site construction of building components, subsequently transported to the construction site for assembly, thereby reducing waste and enhancing quality control. Similarly, modular construction encompasses the off-site construction of entire building modules, which are then assembled on-site to form the final structure, resulting in expedited completion times and heightened safety measures. As technological advancements progress, these methodologies are poised further to enhance construction efficiency and accessibility for a wider demographic.

(a) 3D printing incorporation:

Integrating 3D printing and prefabrication has revolutionised manufacturing by developing intricate modular components. The combination of 3D printing's precision and speed with the efficiency of prefabrication has resulted in the creation of complex parts that fit together seamlessly. This integration has improved manufacturing techniques and enabled the production of sophisticated components that were once unattainable. Incorporating 3D printing and prefabrication has opened new avenues for innovation and creativity in the manufacturing industry.

(b) IoT integration:

The integration of IoT has transformed modular construction, elevating modules to the status of intelligent entities that can continuously monitor and maintain themselves in real time. Incorporating embedded sensors has enabled modules to detect when maintenance is required or a deviation from the expected function occurs. Notably, IoT is revolutionising the construction industry and is poised to deliver comprehensive and sustainable solutions that benefit many stakeholders.

The synergy between modular construction and emerging technologies has revolutionised the construction industry, increasing efficiency, intelligence, and innovation. As new technologies continue to emerge, their adoption is expected to continue to impact the industry positively.

4.1.4 Suggested Readings for Additional Information

To acquire comprehensive insights into the application of prefabrication and modular construction, it is recommended that readers refer to the reference books listed below:

a. Construction 4.0: An Innovation Platform for the Built Environment. 2020, Anil Sawhney, Michael Riley, Javier Irizarry.
b. Prefabrication in Construction. Nazanin Ghodsian. https://neuroject.com/prefabrication-in-construction/
c. A Guide to Design for Manufacturing and Assembly (DfMA) in Precast Concrete System. CIDB Malaysia, 2021.
d. Building the Future with Prefabrication Volumetric Module: Productivity and Jointing System. CIDB Malaysia, 2021.
e. Building the Future with Prefabrication Volumetric Module: Implementation & Business Model Framework. CIDB Malaysia, 2021.
f. Guideline for Volumetric Module House: Manufacturing Design and Construction for Malaysia. CIDB Malaysia, 2019.
g. Prefab Architecture: A Guide to Modular Design and Construction. Ryan E. Smith, 2010.

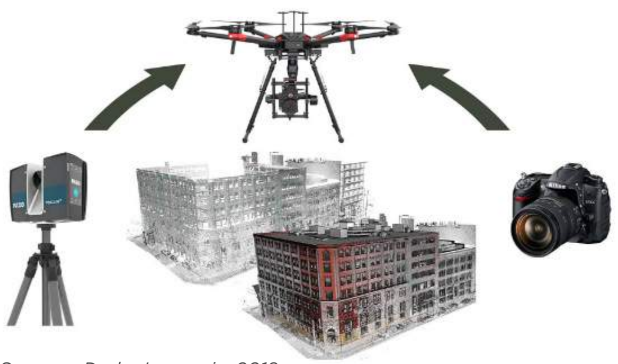
4.2 Photogrammetry and 3D Scanning

4.2.1 Overview of Photogrammetry and 3D Scanning

Photogrammetry and 3D Scanning technologies are sophisticated and advanced tools that are used to capture real-world objects and transform them into 3D models. These models have numerous applications, including e-commerce and the construction industry. Surveyors can use these technologies in the construction industry to collect accurate data from construction sites, which can help improve building planning, design, construction, management, and renovation processes.

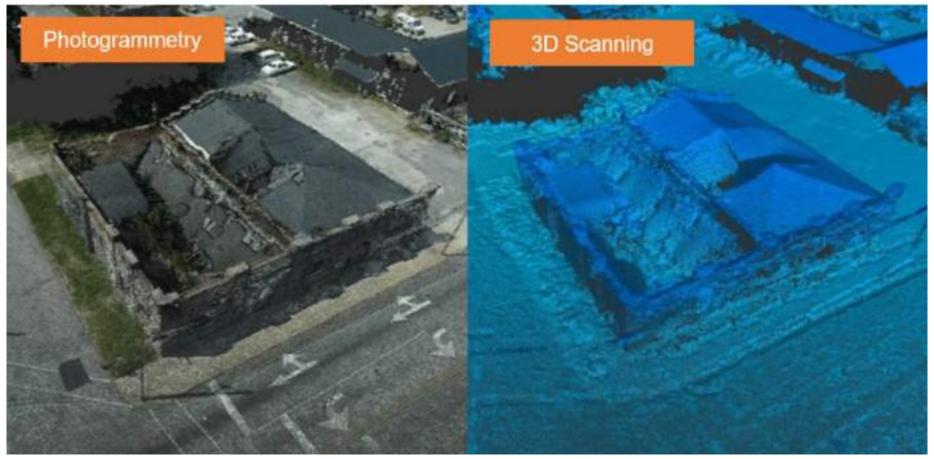
Photogrammetry captures data points from multiple images of an object at different angles, producing a dense point cloud. 3D scanning is an advanced method of photogrammetry that involves capturing an object's dimensions using a laser scanner, which then captures data points as a point cloud. The collected data is processed in both cases to create a 3D model.

When selecting between technologies for scanning, it is crucial to consider the characteristics of the objects to be scanned, their size and the intended use of the final output. The size and complexity of the object can affect the level of detail that can be captured. Additionally, it is essential to factor in the intended application of the final product, such as AR, VR, or web-based platforms, since these can impact the optimisation and conversion process to ensure that the final output is suitable for its intended use. **Figure 4.5** provides an example of the tools that are utilised for Photogrammetry and 3D Scanning, while **Figure 4.6** compares the images generated by photogrammetry and 3D scanning. The image shows that photogrammetry excels at capturing realistic textures and colours. Meanwhile, 3D scanning is more about precision in depicting an object's shape and volume. The choice between these two techniques depends on the specific requirements of your project. For instance, photogrammetry might be the better choice if you need a visually appealing model for a presentation or a virtual tour. On the other hand, if you need accurate measurements for construction or engineering purposes, 3D scanning would be more suitable.



Sources: Darko Izgarevic, 2019.

Figure 4.5 Examples of tools used for photogrammetry and 3D scanning.



Sources: heliguy™, 2022.

Figure 4.6 Comparison of the image generated between photogrammetry and 3D scanning.

4.2.1.1 Methods used in Photogrammetry and 3D Scanning to create 3D Models

Photogrammetry creates 3D models with the help of photographs. It uses specialised software to align the photos, plot data points, and calculate the distance along with the location of each point in 3D space. This results in a 3D point cloud that can create a polygonal mesh similar to 3D scanning. There are three methods of using photogrammetry, as illustrated in **Figure 4.7**.

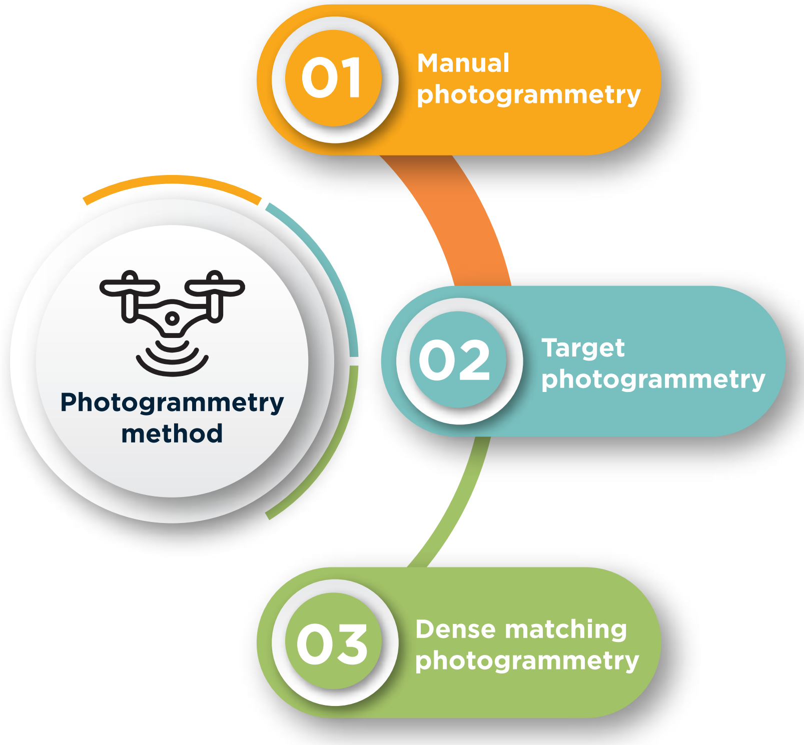


Figure 4.7 Methods in photogrammetry.

(a) Manual photogrammetry:

The manual method of photogrammetry is slow and generates a low point count. In the application of this method of photogrammetry, the user will manually take photographs of the physical object. The user of this method will identify like-points while taking the photographs to ensure that the entire object has been accurately recorded. This method can often take the longest time.

(b) Target photogrammetry:

The target method is automated and much faster, producing a higher point count. A bit more setup time is involved, but it is more accurate.

(c) Dense matching photogrammetry:

The dense matching method is most like 3D scanning. It generates dense point clouds that can be used in various applications.

3D scanning is a process that involves the analysis of a real-world object to capture its shape and appearance accurately. The data that is obtained from the 3D scan is then used to construct digital 3D models, also known as “digital twins,” of the physical object. There are several 3D scanners, each with advantages, limitations, and their respective costs. The two most used types are laser and structured light scanners. **Figure 4.8** illustrates three different 3D scanning methods.

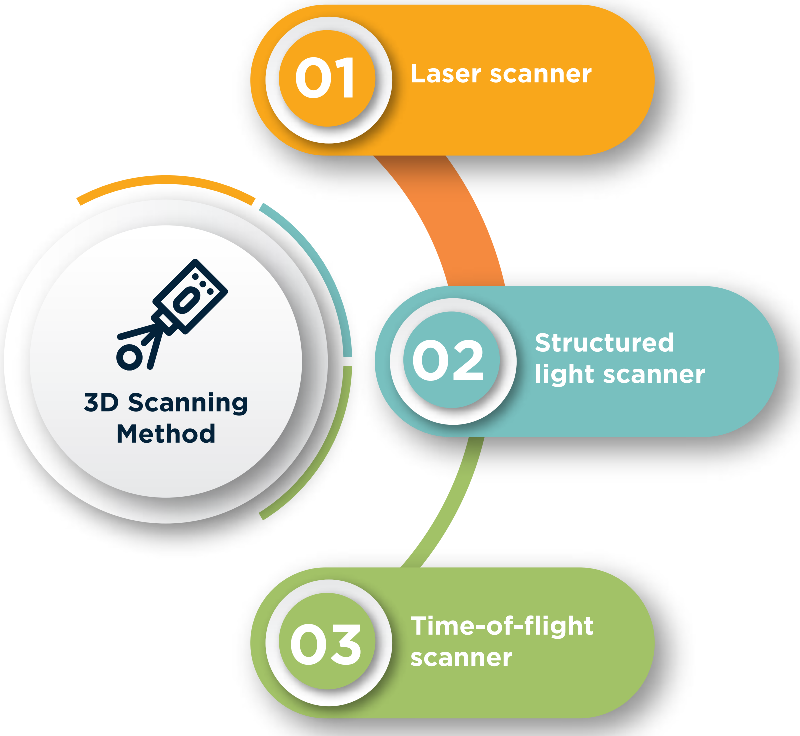


Figure 4.8 Methods in 3D scanning.

(a) Laser scanner:

Laser 3D scanning, as the name suggests, uses a laser to map the surface of an object’s geometry. The laser beams are reflected into a sensor that accurately calculates the distance between the sensor and the object, which is then used to create a digital 3D model. However, this technique depends on the surface type and does not work well with shiny or transparent surfaces. Additionally, it is better suited for close-range scanning and struggles at far distances.

(b) Structured light scanner:

Structured light 3D scanning, on the other hand, uses an LCD projector and multiple cameras to map the object’s geometry. The object must be rotated, or the scanners can be moved around it to capture all sides. Tracking stickers align the data to create the final 3D model. This technique is quick, accurate and helpful in scanning large areas. However, it is sensitive to light and unsuitable for outdoor scanning. It also struggles with far-range scanning.

(c) Time-of-flight scanner:

Time-of-flight technology (ToF) is another laser scanner that sends out laser beams and measures the time it takes to bounce back to approximate the distance between the laser and the object. This technique allows the software to create an essential 3D object representation. ToF scanners are good at far distances and are useful for scanning large objects such as buildings. However, they are not as accurate as laser or structured light scanners.

One of the main advantages of using photogrammetry over 3D scanning is that it is more accessible and cost-effective. It only requires a camera of choice with specialised software and is often less expensive than the machines needed for 3D scanning. Additionally, photogrammetry can reproduce an object in full colour and texture, making it the preferred method when realism is required. Furthermore, photogrammetry can work at many scales and sizes, allowing the modelling of objects ranging from the tip of a finger to a whole mountain range.

Meanwhile, 3D scanners are useful tools that offer high accuracy and resolution. They are particularly effective for scanning smaller parts. They can generate real-time data points, saving time during the design phase by identifying areas that must be rescanned or missed.

However, light interference can cause issues with 3D scans. Laser and white light scanners rely on reading light sources to collect data; too much ambient light can distort the resulting data. Therefore, 3D scanning is best used in controlled lighting environments. Additionally, shiny, or reflective surfaces can pose a challenge as they tend to reflect light away from the input sensors, making it difficult to obtain a good-quality scan.

4.2.1.2 Photogrammetry and 3D Scanning Applications Devices in Construction Industry

Photogrammetry and 3D scanning are two such technologies that have revolutionised the way we visualise and plan construction projects. These technologies allow us to capture detailed, three-dimensional data of a site or structure, which can then be used for a variety of purposes, from planning and design to inspection and maintenance. The following list provides a few examples of devices, tools or software that are used in the construction industry for photogrammetry and 3D scanning. The example is just a portion of the available options and is not limited to these alone.

(a) Drones:

Drones, also known as Unmanned Aerial Vehicles (UAVs), are commonly used in the construction industry for aerial photogrammetry. Equipped with high-resolution cameras, drones can capture detailed images of a construction site from various angles. These images can then be processed to create 3D models or maps. For instance, the DJI Phantom 4 RTK is a popular drone used for this purpose, known for its precise positioning system and high-quality camera.

(b) Software:

Software plays a crucial role in processing the data captured by drones or scanners. It can stitch together images, create 3D models, and perform measurements. Autodesk's ReCap Pro is an example of such software. It allows users to create 3D models from imported images and laser scans and integrates well with other design and construction software.

(c) 3D Laser Scanners:

These devices use laser technology to capture the shape and size of physical objects or environments, creating what is known as a "point cloud" of data. The Leica BLK360, for example, is a compact 3D laser scanner that captures full-colour panoramic images overlaid on a high-accuracy point cloud.

(d) 360 Cameras:

360 cameras capture images in all directions simultaneously, providing a comprehensive view of a site or space. The Ricoh Theta V, for example, captures high-resolution 360-degree images in a single shot, which can be useful for creating virtual tours or inspecting remote locations.

(e) Smartphones:

Modern smartphones, equipped with advanced cameras and sensors, can also be used for photogrammetry and 3D scanning. Apps such as Display.land allow users to capture, share, and transform reality into 3D models using just a smartphone.

The effectiveness of these devices, tools or software can vary based on factors such as the complexity of the project, the environment, and the specific requirements of the task at hand. It is always important to choose the right tool for the right task.

4.2.2 Benefits of Photogrammetry and 3D Scanning Applications in Construction Industry

Implementing Photogrammetry and 3D Scanning in the construction industry has recently gained significant attention. These technologies have proven to be valuable tools for capturing accurate spatial data and generating high-quality 3D models of physical structures. Photogrammetry and 3D Scanning applications in the construction industry are numerous, ranging from surveying and mapping to quality control and project management.

One of the primary benefits of Photogrammetry and 3D Scanning is the ability to create highly accurate as-built models of existing structures. These models can be used for renovation and refurbishment projects, as well as for maintenance and repairs.

Here are the benefits of Photogrammetry and 3D Scanning for the construction industry:

(a) Streamlined site survey and mapping:

Photogrammetry and 3D scanning can significantly streamline site survey and mapping processes. They allow for rapid data collection and the creation of detailed, accurate site maps, reducing the time and resources that are required for traditional survey methods. For instance, a construction company could use photogrammetry to quickly create a detailed 3D model of a large construction site, saving weeks of manual survey work.

(b) Precise as-built documentation:

These technologies provide precise as-built documentation, capturing the exact conditions of a site or structure after construction is completed. This can be invaluable for future renovations, expansions, or maintenance work. For example, after the completion of a building, 3D scanning can be used to create an exact digital replica of the structure, which can be invaluable for future renovations or expansions.

(c) Enhanced project coordination with BIM integration:

By integrating photogrammetry and 3D scanning data with BIM, project coordination can be enhanced. This allows for improved collaboration, better decision-making, and fewer errors and rework. For instance, a construction team could integrate 3D scan data with their BIM software to detect potential clashes between different building systems, such as HVAC and plumbing, before construction begins.

(d) Reliable quality control and inspections:

Photogrammetry and 3D scanning offer reliable quality control and inspections by providing accurate, detailed data that can be used to identify and rectify issues early in the construction process. For example, a construction company could use 3D scanning to monitor the quality of work and ensure it matches the design specifications, reducing the risk of costly rework.

(e) Accurate volume calculations (volumetrics):
These technologies enable accurate volume calculations, which are crucial for tasks such as material estimation and cut-and-fill analysis. This can lead to cost savings and improved project planning. For instance, a construction company could use photogrammetry to accurately calculate the volume of earth that needs to be moved during site preparation, helping to avoid costly overruns.

(f) Efficient construction planning and management:
Providing detailed, accurate data, photogrammetry, and 3D scanning can enhance construction planning and management, leading to more efficient workflows, better scheduling, and reduced project costs. For example, by using 3D scanning data, project managers can better plan construction activities, optimise resource allocation, and reduce project costs.

(g) Aiding in architectural documentation and historic preservation:
Photogrammetry and 3D scanning can aid in architectural documentation and historical preservation by capturing detailed data about existing structures, which can be used for restoration work, historical records, and virtual tours.

(h) Innovative Virtual Design and Construction (VDC):
These technologies support innovative VDC approaches, improving design visualisation, clash detection, and construction simulation. For example, a construction firm could use photogrammetry and 3D scanning to create a detailed 3D model of a proposed building, allowing stakeholders to visualise the design and identify potential issues before construction begins.

(i) Accurate facility coordination:
Photogrammetry and 3D scanning can enhance facility coordination by providing accurate data about existing conditions. This data can be used for space planning, facility management, and maintenance planning. For instance, facility managers could use 3D scanning data to plan space utilisation, coordinate maintenance activities, and manage assets more effectively.

(j) Improved geospatial data collection:
These technologies offer improved geospatial data collection, providing detailed, accurate topographic and feature data that can be used for site analysis, design, and planning. For example, a construction company could use photogrammetry to collect detailed topographic data for a large site, aiding in site analysis and design.

(k) Creating digital twin solutions:
Photogrammetry and 3D scanning can be used to create digital twin solutions, providing a virtual replica of a physical building or site that can be used for various purposes, including performance optimisation, remote monitoring, and predictive maintenance. For instance, a facility manager could use 3D scanning to create a digital twin of a building, allowing for remote monitoring, predictive maintenance, and optimisation of building performance.

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(l) Timely progress monitoring:
By providing regular, detailed data, photogrammetry and 3D scanning can support timely progress monitoring. This allows for real-time tracking of construction activities, early identification of issues, and improved project control.

4.2.3 The Future Advancements of Photogrammetry and 3D Scanning.

C4.0 has revolutionised the construction industry, with technologies such as photogrammetry and 3D scanning playing significant roles. These technologies have enhanced efficiency and accuracy and opened new possibilities for future advancements.

(a) Real-time monitoring through IoT devices:
Integrating advanced photogrammetry and 3D scanning with IoT devices will enable real-time monitoring of construction sites. This technology will instantly detect deviations from the planned design and immediate corrective actions. This application will significantly reduce the time and cost associated with manual inspections and corrections.

(b) Automated equipment calibration with AI:
Combining AI with advanced photogrammetry and 3D scanning technologies will enable the automated calibration of construction equipment. This application will ensure optimal performance and accuracy of equipment, leading to improved efficiency and quality of construction.

(c) Integration with AI and ML:
AI and ML algorithms will be increasingly used to analyse photogrammetry and 3D scanning data. This integration will enable predictive modelling and risk assessment, leading to better project management and execution. This application will enhance decision-making processes and improve project outcomes.

(d) Enhanced safety measures with AI:
Integrating AI with photogrammetry and 3D scanning will enable the identification of potential safety hazards in the construction site, such as unstable structures or dangerous equipment placement. This application will allow for proactive measures to ensure worker safety, reducing the likelihood of accidents and injuries on the construction site.

(e) Enhanced quality control with AI and BDA:
Photogrammetry and 3D scanning will play a crucial role in quality control. Integrating this technology with AI and BDA will enable the detection and rectification of errors in real time, thereby increasing efficiency and reducing costs. This application will ensure the delivery of high-quality construction projects that meet the required standards and specifications. This advancement will be closely tied to developing advanced data analysis tools in construction.

4.2.4 Suggested Readings for Additional Information

To acquire comprehensive insights into the application of Photogrammetry and 3D Scanning in construction, it is recommended that readers refer to the references listed below:

a. Construction 4.0: An Innovation Platform for the Built Environment. 2020, Anil Sawhney, Michael Riley, Javier Irizarry.
b. Laser Scanning in Construction: Everything You Need to Know. Grace Ellis. https://www.autodesk.com/blogs/construction/laser-scanning-in-construction/
c. Photogrammetry and 3D Scanning Explained. Ben Conway. https://www.vntana.com/blog/3d-scanning-and-photogrammetry-explained/
d. Photogrammetry in Construction. FlyGuys. https://flyguys.com/photogrammetry-in-construction/
e. Drone Surveying: A Guide to Point Clouds. heliguy™. https://www.heliguy.com/blogs/posts/drove-surveying-guide-to-point-clouds
f. Photogrammetry vs 3D scanning for creating a 3D model. Matthew McMillion and Paul Hanaphy. https://www.artec3d.com/learning-center/photogrammetry-vs-3d-scanning/

4.3 Additive Manufacturing (AM)

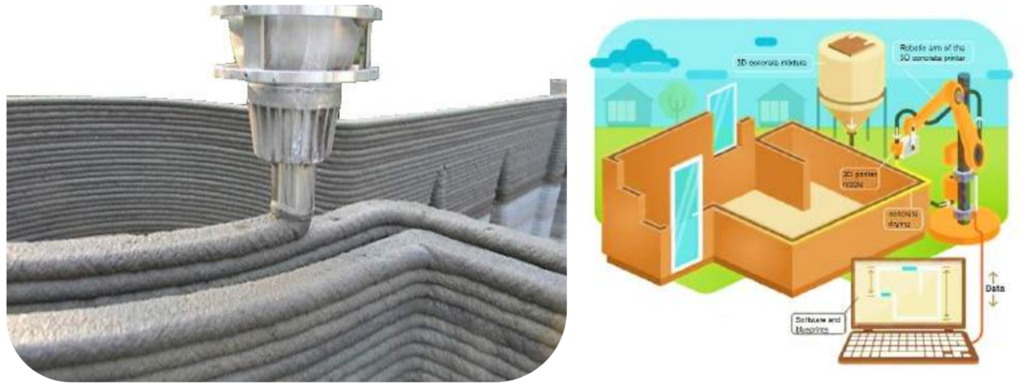
4.3.1 Overview of AM through 3D Printing

3D printing is an advanced manufacturing technique that uses software to direct the arrangement of materials to build 3D components (**Figure 4.9)** or entire building structures (**Figure 4.10**) without using traditional formwork. It is a subset of additive manufacturing (AM), a process that creates a physical project from a digital design. 3D printing involves depositing layer upon layer of a material, such as concrete, metal, polymer, or resin, using a printer head like the one inside an inkjet printer. The material fuses or binds with the previously deposited layers in a 3D model created on the computer using CAD software.

In the early days, 3D printing was only used to create 3D models such as landscaping bricks, prototypes, and small non-structural building parts. However, with further technological advancements, it is now possible to use 3D printing to create entire buildings. The construction industry uses 3D printing to create components or even print entire buildings. It is a computer-controlled process that can produce objects with accurate geometric shapes, unlike traditional manufacturing methods that often require machining or other techniques to remove surplus material.

Sources: The Construction Index, 2014.

Figure 4.9 A 3D-printed component (left) and a conventionally produced component (right) have the same structural loads and forces.



Sources: Tencom Ltd., 2022.

Figure 4.10 The building was produced using 3D printing technology.

4.3.1.1 3D Printing Devices and Software for the Construction Industry

The advent of 3D printing has revolutionised various industries, including the construction industry. This technology has introduced innovative devices and software that have significantly enhanced the efficiency and precision of construction processes. This document overviews these advancements, focusing on the devices and software applications that facilitate these processes. The example is just a portion of the available options and is not limited to these alone.

(a) Devices used in 3D printing for the construction industry:

i. Extrusion devices:

These devices operate by depositing material layer by layer through a nozzle attached to a gantry system, robotic arm, or crane. The most common application involves a robotic arm dispensing polymers or concrete material. An example is using extrusion devices to construct concrete walls in buildings.

ii. Powder bonding devices:

These devices utilise powdered raw materials to create prints through powder bed fusion or binder jetting. Powder bed fusion involves using a laser to melt powder particles onto a selected object, one layer at a time. Binder jetting, on the other hand, employs a print head to deposit a liquid bonding agent onto the powder printing bed. This can be seen in the production of complex architectural models.

(b) Software used in 3D Printing for the construction industry:

i. CAD Programs:

These programs supply design information to 3D printers to manufacture specific components or entire structures. For example, CAD programs design and print custom-made parts for building construction.

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vii. BIM Programs:

Like CAD, BIM programs also provide design information to 3D printers. However, BIM programs offer more comprehensive information about a building, enabling improved project management. An example of this is the use of BIM programs in planning and visualising the entire lifecycle of a construction project.

In conclusion, the application of 3D Printing in the construction industry has brought significant advancements in innovative devices and software. These technologies have improved the efficiency and precision of construction processes and opened new possibilities for architectural design and project management. As the industry continues to evolve, these technologies will undoubtedly play a crucial role in shaping the future of construction. **Figure 4.11** and **Figure 4.12** showcase examples of current AM technology using 3D printing.

Sources: Voxeljet, 2020.

Figure 4.11 3D printed formwork for smart slab (left) and 3D printing for architectural models (right).

Sources: COBOD, 2023.

Figure 4.12 **The tallest 3D-printed building in the world was built in Saudi Arabia** (left) and **the world's first 3D-printed school in Malawi** (right)

4.3.2 Benefits of AM Applications using 3D Printing in the Construction Industry

The construction industry has been utilising 3D Printing technology for various purposes, such as creating prototypes, building architectural models, fabricating parts, and constructing affordable housing. These technologies also enable the production of large building components and prefabricated building modules and customisation of building components. Additionally, they can be used for renovating and restoring structures. All these applications are illustrated in **Figure 4.13** using 3D printing. With 3D printing, users can create prototypes at a lower cost and in a shorter timeframe than traditional building methods.

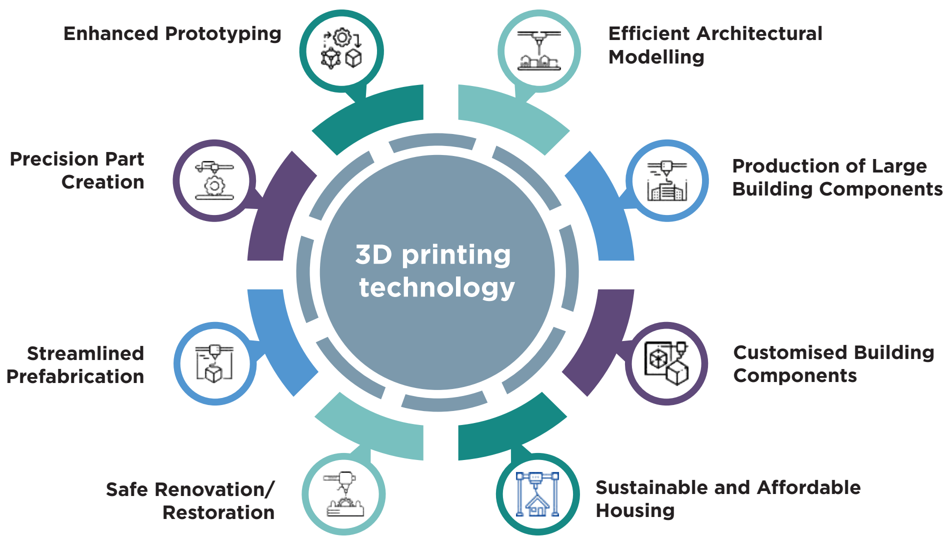

Figure 4.13 Benefits of 3D printing technology applications in the construction industry.

(a) Enhanced prototyping:
Prototypes are models created to represent structures in their preliminary stages. They serve as examples of what the final product might look like. For instance, when a company intends to construct a new office, a 3D printer can be used to create a prototype, which is much easier and less expensive than traditional building methods. Although costs are still involved, 3D printing enables clients to produce prototypes more quickly and at a lower cost than conventional building methods.

(b) Precision part creation:
Construction companies can use 3D printing to create complex project materials. By producing materials with exact measurements, 3D printing can help reduce costs and minimise waste. This approach can also ensure that construction labour remains in demand and allows for the creation of necessary components from raw materials.

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(c) Streamlined prefabrication:
Prefabrication of building modules is a construction method that involves manufacturing building components at an off-site location and then transporting them to the actual construction site for assembly. 3D printing technology can further speed up the process, making it a viable option for prefab construction.

(d) Safe renovation or restoration:
The use of 3D printing in the AEC industry has made it possible to undertake restoration of structures more safely without causing additional damage to the structure. This applies to both regular buildings and cultural heritage sites.

(e) Sustainable and affordable housing:
3D printing is a potential solution for building sustainable and affordable housing. According to experts, 3D printing technology can produce energy-efficient houses with reduced material waste and accelerate construction. This approach can potentially assist construction firms in reducing their carbon footprint and achieving the goal of net-zero emissions.

(f) Customised building components:
3D printing has created customised building components to meet clients' requirements. Architects and design professionals can create digital models of complex structures, which can be printed using 3D printers.

(g) Production of large building components:
Large-scale 3D printing technology has the potential to produce significant building components such as walls, roofs, and floors. The technology can create entire components in single pieces, resulting in a faster and more cost-effective construction process.

(h) Efficient architectural modelling:
Architectural modelling is scaling proposed projects to a size that can be viewed in a smaller space. This allows clients to inspect a structure's design, layout, and other elements. Traditionally, construction companies or architects design structures using software and build models manually. However, with the advent of 3D printing, it has become possible to quickly build models once the structure is created in the computer program and the printer has the required materials. This enables architects to create more architectural models in a shorter time.

4.3.3 The Future Advancements of AM using 3D Printing in the Construction Industry

The application of AM using 3D printing in construction has already achieved significant milestones. Still, its potential has yet to be fully realised. The future of 3D printing in construction presents exciting possibilities worth exploring. Here are potential advancements that could be realised in the future:

(a) Remote construction through digital twins:

The advancements in digital twin technology have opened the possibility of remotely deploying 3D printers. This breakthrough holds the potential to revolutionise the construction of buildings in challenging or remote locations. The implications of this technology are far-reaching, with significant impacts anticipated in areas such as disaster relief efforts and space exploration, particularly where traditional construction methods prove to be impractical. This technological leap promises to redefine the boundaries of construction and exploration, opening doors for unprecedented advancements in these fields.

(b) Integration of IoT and smart technology:

Integrating IoT devices and smart technology within 3D printed structures could revolutionise efficiency, monitoring, and maintenance capabilities. Incorporating sensors and energy management systems within these intelligent buildings could lay the groundwork for the evolution of smart cities. This fusion of technology and infrastructure promises to redefine urban living, ushering in a new era of efficiency and connectivity.

(c) Collaborative construction through cloud and real-time collaboration:

Fusing 3D Printing with cloud-based technologies and real-time collaboration could revolutionise the construction industry, potentially transforming the supply chain. Digital platforms could significantly streamline design and construction processes, fostering a more efficient collaboration among architects, engineers, and contractors. This innovative approach promises to redefine the industry, thus welcoming a new era of efficiency and integrated teamwork.

(d) Continuous advancements in building material:

Continuous advancements in building material research have created innovative construction materials meticulously engineered for 3D Printing. These cutting-edge materials are anticipated to exhibit superior structural integrity, enhanced durability, and improved thermal properties. Such progress is set to bolster the dependability of 3D-printed structures, further cementing their place in the future of construction. This evolution in material science promises to redefine the landscape of the construction industry, offering unprecedented possibilities for architectural design and structural resilience.

Imagine a future where construction is faster, more efficient, and environmentally friendly. This exciting possibility is now within reach with the advent of 3D Printing. By leveraging the benefits of speed, cost-effectiveness, design freedom, and sustainability, this technology has the power to reshape the industry.

4.3.4 Suggested Readings for Additional Information

To acquire comprehensive insights into the application of 3D printing, it is recommended that readers refer to the references listed below:

a. Construction 4.0: An Innovation Platform for the Built Environment. 2020, Anil Sawhney, Michael Riley, Javier Irizarry.

b. The Business of Additive Manufacturing 3D Printing and the 4th Industrial Revolution. 2023, Harm-Jan Steenhuis.

c. Large-Scale Additive Manufacturing: Future of 3D Printing in Construction?. Indovance, 2023. https://www.indovance.com/knowledge-center/3d-printing-in-construction-large-scale-additive-manufacturing/

d. 3D Construction Printing Vs Additive Manufacturing: Is There a Difference?. COBOD, 2023. https://cobod.com/3d-construction-printing-vs-additive-manufacturing-is-there-a-difference/

4.4 Advanced Building Materials

4.4.1 Overview of Advanced Building Materials

Building materials refer to substances or products that are used for construction, such as buildings, bridges, roads, and other structures. These materials can be natural, such as timber and stone, or synthetic, i.e., concrete and steel. These traditional building materials have been used for centuries and are well-established in the construction industry.

"Advanced building materials" typically refer to newer, more innovative materials that are developed to improve construction performance, efficiency, and sustainability. These materials often incorporate advanced technology, engineering, or scientific principles to enhance strength, durability, insulation, and environmental impact.

It is important to note that categorising materials as "advanced" or "traditional" is relative to the period and technological context. Materials considered advanced in the 18th century might be regarded as traditional by today's standards, as technological advancements have led to the development of new and more sophisticated building materials. For example, Portland cement was patented in 1824 and was considered an advanced material during that era. Though this material was one of the materials that represented significant advancements in the 1800s, this material may not align with our contemporary understanding of cutting-edge or high-tech materials. Therefore, it is essential to understand that certain building materials that are considered advanced for a specific era may have become more traditional over the centuries.

4.4.1.1 Categories of Advanced Building Materials

Several categories of advanced building materials are classified based on their material composition, as shown in **Figure 4.14**. Understanding these categories can be helpful when selecting suitable materials for construction projects.

Figure 4.14 Categories of advanced building materials.

(a) Composites:
Materials combine two or more different materials to achieve specific properties—for example, fibre-reinforced composites or concrete with embedded fibres.

(b) Nanomaterials:
Materials are engineered at the nanoscale, often to enhance strength, durability, or other properties.

(c) Smart materials:
Materials that can respond to external stimuli, such as temperature, stress, or moisture—for example, shape memory alloys and self-healing materials.

4.4.1.2 Identifying Characteristics Advanced Building Materials

Whether a building material is advanced depends on various factors, including the time, technological context, and the material's specific characteristics. **Figure 4.15** shows some considerations that are needed in identifying advanced building materials. The example provided is just a portion of the available options and is not limited to that alone.

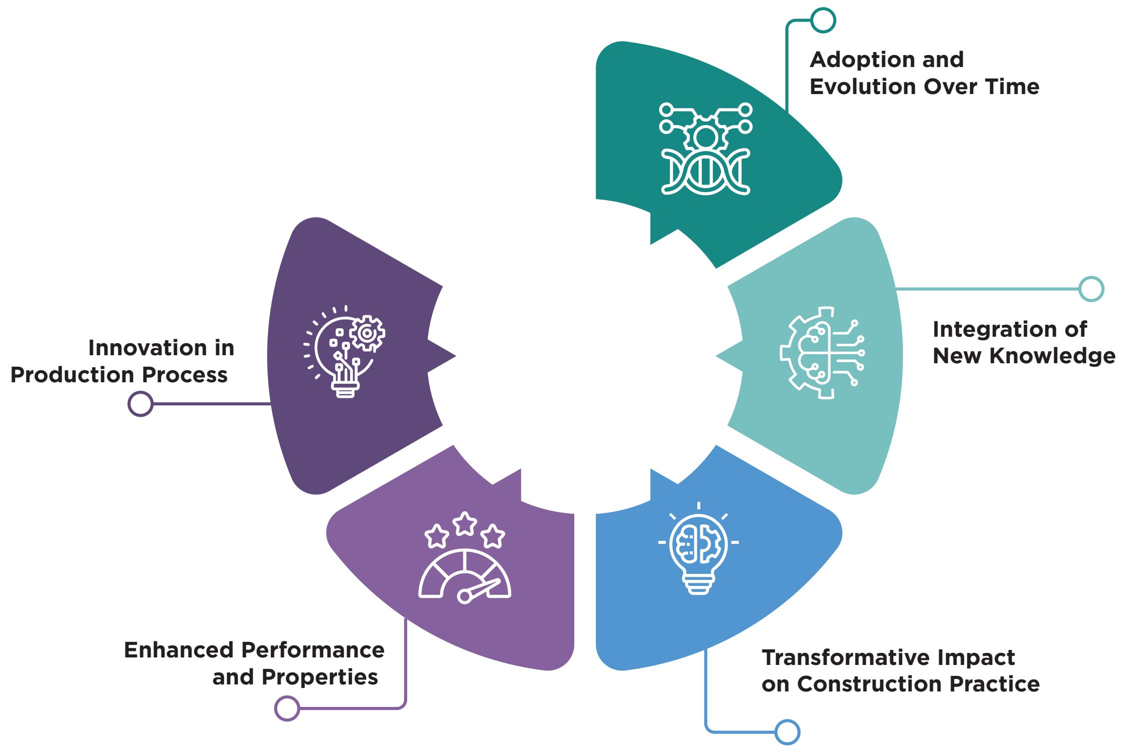

Figure 4.15 Considerations are needed to identify advanced building materials.

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(a) Innovation in the production process:

Identifying whether the material has introduced a novel or improved production process for its time involves new techniques, technologies, or methodologies that represent a departure from traditional methods.

Example:

Cross-laminated timber (CLT) can be considered an advanced building material as the production process aligns with contemporary technological standards, incorporating advanced manufacturing processes and modern technologies. The production process of CLT starts from lamella selection, grading, and classification, i.e., lamella finger-jointing, lamella cutting to length and planning, panel lay-up, adhesive application for every layer, assembly pressing, CLT online quality control-machining and cutting, and finally, product making, packing, and shipping (MTIB, 2022). The cutting precision of individual pieces of lumber is based on the exact specifications using Computer numerical control (CNC) technology, which is then cross-laminated and bonded using advanced adhesive technology. This production process requires efficiency and accuracy to produce high-quality, customised CLT panels, which can only be achieved through advanced CNC technology. Apart from that, the adhesive technology that has undergone innovation allows high-performance adhesives with specific properties, such as moisture resistance and durability, to ensure the panel's integrity, allowing it to meet stringent structural and safety standards. **Figure 4.16** shows blocks of CLT and an example of a CLT application in a building.

Picture courtesy: Malaysian Timber Industry Board (MTIB)

Figure 4.16 Block of CLT (left) and example of CLT application(right) from Malaysian tropical timber species.

(b) Enhanced performance and properties:

This test aims to evaluate the material's performance characteristics in terms of superior strength, durability, insulation, resistance to environmental factors, or other desirable properties compared to materials that are widely available in the market.

***Example*:**

Fibre-reinforced concrete (FRC) is an advanced building material that exhibits enhanced properties compared to traditional concrete. FRC incorporates discrete fibres, such as steel, glass, synthetic, or natural, to improve its structural and durability characteristics. Other enhanced properties of FRC include increased tensile strength and enhanced flexural strength, and it can even provide corrosion and fire resistance by integrating specific fibres. FRC's improved performance and properties make it a versatile and valuable building material, suitable for diverse construction needs requiring superior strength, durability, and resistance to various environmental and mechanical stresses. **Figure 4.17** shows the example of carbon fibre reinforced concrete (CFRC) and its application in construction.

Sources: The Constructor, 2023

Figure 4.17 Example of CFRP (left) and CFRP application in construction (right).

(c) Transformative impact on construction practice:

To examine whether the material has a transformative effect on construction practices new architectural possibilities are allowed, such as enabling the construction of larger or more complex structures.

Example:

Transparent Aluminium (Aluminium Oxynitride or ALON) is a ceramic material that is transparent and highly resistant to impacts, including bullets, which has opened new possibilities for architects to explore innovative designs that balance aesthetics with performance and security, as shown in **Figure 4.18**. It allows architects to create large, clear windows and facades without sacrificing safety or structural integrity. It also allows a more innovative and visually striking building facade. Its unique properties enable architects to explore creative and futuristic designs previously limited by traditional glass constraints.

Sources: The Constructor, 2023

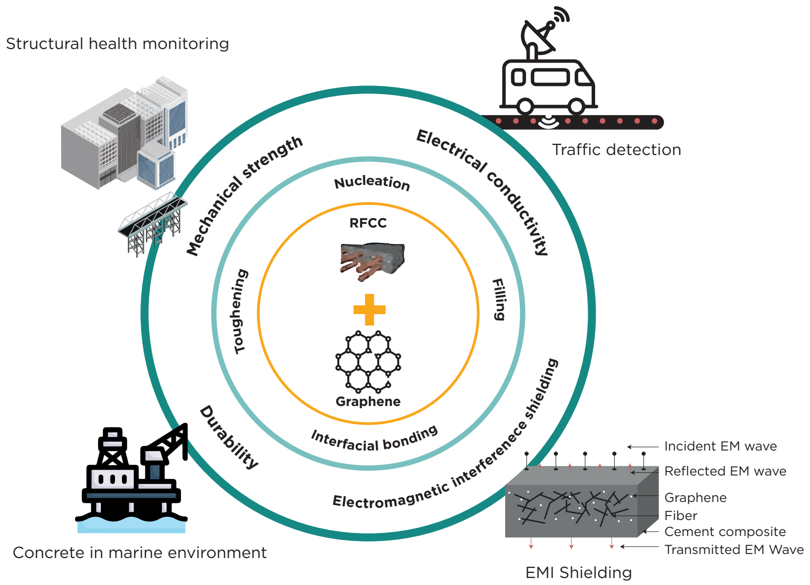
Figure 4.18 Transparent aluminium blocks.

(d) Integration of new knowledge:

To inspect whether the material was developed based on new scientific or engineering knowledge, the technological and innovative aspects of materials are expanded and the construction is through discoveries and insights.

Example:

Graphene is made from a single layer of carbon atoms arranged in a hexagonal lattice known for its exceptional mechanical strength, electrical conductivity, and thermal properties. It has been developed through the integration of cutting-edge material science research. Extensive research has been conducted on graphene, including the potential of integration with concrete, which creates graphene-reinforced concrete that exhibits improved compressive and flexural strength and enhanced durability. Ongoing research involving the optimisation of concentration and dispersion of graphene in concrete, understanding graphene interaction with cementitious materials, and exploring the full range of potential applications are continuously conducted to discover new possibilities and enhance this material's properties. **Figure 4.19** shows an example of graphene-reinforced polymer composite applications.



Adapt from Lynsey Hart, 2023.

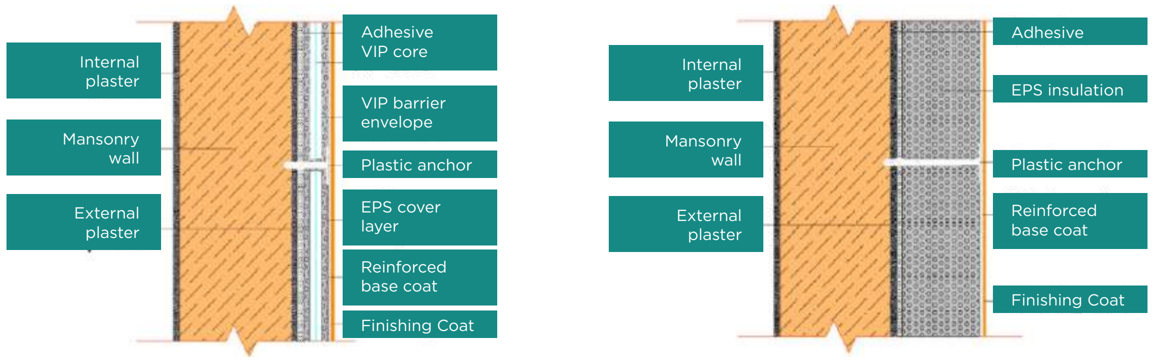
Figure 4.19 Applications of graphene-reinforced polymer composites.

(e) Adoption and evolution over time:

To study the adoption rate of the material and clarify whether the material has become a standard and whether innovations and more advanced alternatives have been made available.

Example:

Structural Insulated Panels (SIPs) are a widely used construction method that has gained popularity in the mid-20th century as an innovative building material. SIPs consist of a foam core (usually expanded polystyrene (EPS) or polyurethane) that is sandwiched between two structural-facing materials. New advanced insulating materials, such as aerogel-based insulation or vacuum insulation panels (VIPs), have been developed, offering high thermal performance with reduced thickness compared to SIP. This example (**Figure 4.20**) demonstrates how the construction industry evolves, with materials that have once been considered groundbreaking making way for newer solutions that address limitations and enhance performance.



Sources: Simões et al., 2021.

Figure 4.20 Comparison between SIPs (left) and VIPs (right) application in wall construction.

4.4.2 Benefits of Advanced Building Materials Applications in Construction Industry

In the construction world, advanced building materials are crucial in improving construction practices, promoting sustainable development, and enhancing building performance. As outlined in **Figure 4.21**, applying these materials offers significant benefits that can positively impact the construction process.

Figure 4.21 Benefits of advanced building materials applications.

(a) Strength and durability:
Advanced building materials often exhibit superior strength and durability, resulting in structures that can withstand greater loads and environmental stressors. Increased longevity and reduced maintenance needs contribute to the overall cost savings.

(b) Sustainability:
Many advanced materials are designed sustainably, incorporating recycled content, eco-friendly production processes, and reduced environmental impact. Sustainable building materials contribute to green construction practices and environmental conservation.

(c) Energy efficiency:
Advanced insulation materials improve building energy efficiency by minimising heat transfer and reducing heating and cooling demands. Energy-efficient materials contribute to lower utility costs and a smaller carbon footprint.

(d) Innovative design:
Advanced materials enable architects and designers to explore innovative and creative design possibilities that may not be achievable with traditional materials. This foster unique and aesthetically pleasing architectural solutions.

(e) Rapid construction:
Prefabricated and modular components that are made from advanced materials can accelerate construction timelines, leading to faster project completion. Speedier construction processes can result in cost savings and reduced on-site labour requirements.

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(f) Smart and responsive materials:
Integration with technology allows for the development of smart materials that respond to environmental conditions or provide real-time monitoring. Responsive materials contribute to the creation of dynamic and adaptive building systems.

(g) Safety enhancement:
Some advanced building materials offer improved safety features, such as enhanced fire resistance, seismic resistance, or resistance to other hazards. Enhanced safety contributes to better overall building performance and occupant well-being.

(h) Cost savings over time:
While initial costs for advanced materials may be higher, the long-term benefits, including reduced maintenance, energy savings, and extended service life can result in cost savings over the building's life cycle.

(i) Adaptability and flexibility:
Advanced materials often provide more outstanding design and construction flexibility, allowing building modifications or additions. Modular components and systems enhance adaptability to changing needs.

(j) Reduced weight:
Lightweight advanced materials, such as composite materials, contribute to reduced structural load and can benefit transportation, handling, and seismic considerations.

(k) Incorporation of nanotechnology:
Nanomaterials offer unique properties that can improve building materials' strength, durability, and performance. Nanotechnology enables precise material design and modification at the molecular level.

(l) Improved comfort and well-being:
Some advanced materials contribute to improved indoor environmental quality, providing better thermal comfort, acoustics, and air quality for building occupants.

(m) Resistance to environmental factors:
Advanced materials may resist environmental factors such as moisture, mould, and UV radiation, thus improving long-term performance.

(n) Reduced waste:
Sustainable and advanced materials often generate less construction waste and contribute to a more efficient use of resources.

4.4.3 The Future Advancements of Advanced Building Materials

The future integration of smart construction materials and advanced technology holds great potential for transforming the construction industry. Advancements in building materials continue to be a driving force in the construction industry, leading to improvements in sustainability, durability, energy efficiency, and overall performance. Here are some key trends in building materials:

(a) Self-healing materials:

Advances in material science have led to the development of self-healing construction materials. These materials could automatically repair cracks and damage, improving the durability and longevity of structures.

(b) Nano and advanced composite materials:

Integrating nanotechnology and advanced composite materials can result in stronger, lighter, and more resilient construction materials. These materials can enhance structural integrity and reduce the structure's overall weight.

(c) Sustainable and eco-friendly materials:

The future will likely see an increased emphasis on sustainable and eco-friendly construction materials. These include materials with a low carbon footprint, recycled content, and designs for easy deconstruction and recycling.

(d) Energy-generating materials:

Integrating materials that can generate and store energy, for example, solar-active materials embedded in facades or windows could contribute to more sustainable and energy-efficient buildings.

4.4.4 Suggested Readings for Additional Information

To acquire comprehensive insights into the application of advanced building materials, it is recommended that readers refer to the reference books listed below:

a. Construction 4.0: Advanced Technology, Tools and Materials for the Digital Transformation of the Construction Industry. 2020, Marco Casini.
b. Construction 4.0: An Innovation Platform for the Built Environment. 2020, Anil Sawhney, Michael Riley, Javier Irizarry.
c. Advances in Smart Materials and Innovative Buildings Construction Systems. 2023, Ayman S. Mosallam, Brahim El Bhiri, Vistasp M. Karbhari, Shadi Saadeh.
d. Green and Advanced Building Materials and Structural Engineering. 2023, Nuno Dinis Costa Areias Cortiços, Prof. Zongjin Li, Prof. Paulo Mendonca, Prof. Soon Hyung Hong, Prof. Hideaki Tsukamoto and Prof. Yuyuan Zhao.
e. 17 Innovative Construction Materials Changing How We Build. PlanRadar. https://www.planradar.com/gb/top-15-innovative-construction-materials/#1
f. 11 Most Advanced Construction Material Used Today. Giovanni Valle. https://www.builderspace.com/11-most-advanced-construction-materials-used-today

4.5 Autonomous Construction

4.5.1 Overview of Autonomous Construction

Autonomous construction is a fast-growing field that leverages advanced technologies such as AI, ML, and robotics to automate various processes that are involved in the construction industry. The main goal of autonomous construction is to increase efficiency, productivity and safety on construction sites while reducing the time and costs that are associated with traditional construction methods. The use of AI and ML in autonomous construction allows machines to learn from the data, identify patterns, and make predictions, which can help optimise construction processes. For example, AI-powered sensors can monitor construction sites in real time, detect potential hazards and alert workers to take necessary precautions. Additionally, autonomous vehicles, drones, and robots can perform dangerous or difficult tasks for human workers, such as inspecting structures, excavating sites, and delivering materials.

Moreover, integrating autonomous systems in construction can lead to more sustainable infrastructure development. Self-driving construction vehicles, for instance, can reduce fuel consumption and carbon emissions. At the same time, AI-powered energy management systems can optimise energy usage and minimise waste. Overall, autonomous construction has the potential to revolutionise the construction industry by improving safety, efficiency, and sustainability. As technology advances, we will likely see more and more applications of autonomous systems in construction, leading to a safer, more productive, and more sustainable future.

4.5.1.1 Autonomous Machine Used in the Construction Industry

Autonomous machinery is rapidly transforming the construction industry and is employed in various aspects of the construction process. **Figure 4.22** illustrates a fine example of autonomous construction equipment and machinery.

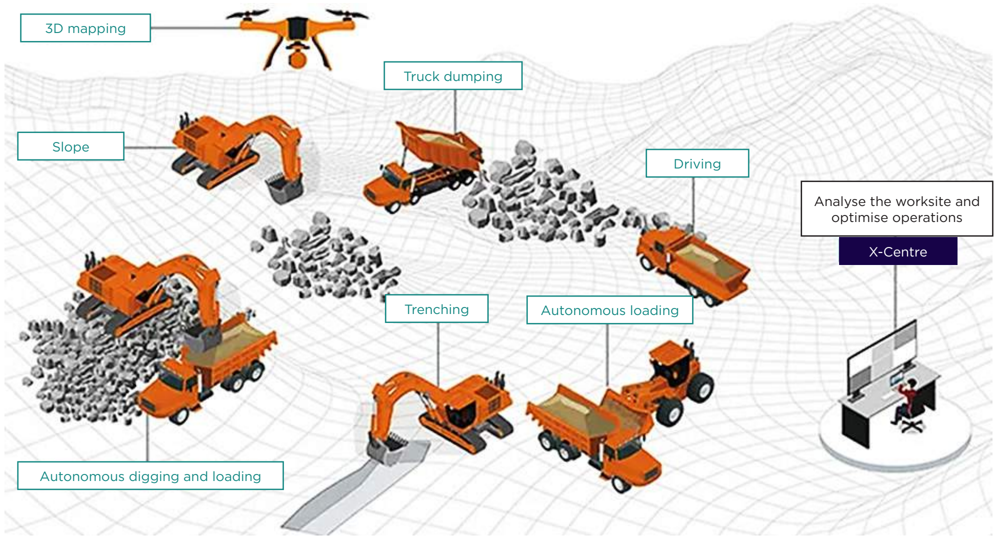


Figure 4.22 Example of autonomous construction equipment and machinery.

From excavation and grading to material handling and transportation, the applications of autonomous machines are vast and diverse, as shown in **Figure 4.23**. Let's explore the key areas where autonomous machinery significantly changes and revolutionises the construction industry.

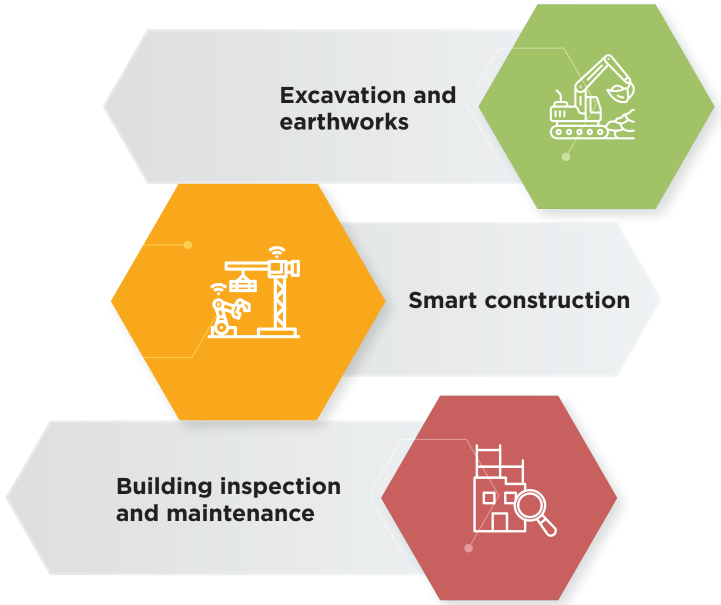


Figure 4.23 Autonomous machinery utilisation in the construction industry.

(a) Excavation and earthwork:
Autonomous excavators and bulldozers can efficiently perform tasks such as digging trenches, excavating foundations, and moving large amounts of earth. They can operate in complex terrains with minimal human intervention, saving time and resources. With advanced sensors, they can detect and avoid underground utilities, minimising the risk of accidental damage during excavation.

(b) Smart construction:
Autonomous machinery that is integrated with artificial intelligence can perform repetitive construction tasks such as bricklaying, concrete pouring, and assembling prefabricated components without human intervention. Robots with computer vision can accurately position and weld structural elements, ensuring precise assembly. This automated construction process can reduce labour hours, increase productivity, and enhance the overall quality of the constructed elements.

(c) Building inspection and maintenance:
Drones equipped with high-resolution cameras and thermal imaging sensors can carry out detailed inspections of buildings, bridges, and other structures. Aerial inspections can help detect defects, corrosion, or damage in the early stages, which can help with timely maintenance and prevent potential accidents. Autonomous machinery can also perform routine maintenance tasks, such as cleaning and painting, which are usually difficult to reach at certain heights.

The advent of autonomous machines has revolutionised various industries, with the construction sector not wanting to be left behind. Advancements in artificial intelligence, robotics, and connectivity primarily drive this transformation. Here, we will explore some key players leveraging this technology to enhance efficiency and productivity in the construction industry. The example is just a portion of the available options and is not limited to these alone.

(a) Autonomous equipment:
Prominent industry leaders are investing in autonomous construction equipment, such as bulldozers and excavators. Companies such as Volvo, Sany, and Topcon have specifically allocated resources to the development of autonomous dozers capable of operating without human intervention. These machines make real-time decisions based on data from various sensors and cameras.

(b) Built Robotics:
This startup is deploying autonomous machines on construction sites. Their semi-autonomous machines, such as the autonomous track loader, equipped with GPS and sensors, can follow predefined paths or maintain grade levels independently.

(c) Canvas:
Canvas is another startup working on autonomous construction technology. Their autonomous robots, integrated with technologies such as GNSS positioning or 3D scanning, can move through a job site and streamline the process of tracking the status of the construction project on an ongoing basis. For example, their drywall finishing robot can autonomously navigate and perform tasks on a construction site.

(d) SafeAI:
SafeAI sees value in using autonomous machines to accelerate construction projects. They retrofit heavy equipment such as dump trucks and dozers with AI to make them autonomous, enhancing safety and productivity on construction sites.

In conclusion, integrating autonomous machines in the construction industry is a game-changer, offering increased efficiency, productivity, and safety. As technology continues to evolve, it is anticipated that autonomous machines will become more prevalent, shaping the construction industry's future.

4.5.2 Benefits of Autonomous Construction Applications in Construction Industry

The utilisation of autonomous machinery in construction has gained significant traction in recent times, owing to its manifold advantages. Such machinery is equipped with cutting-edge technology, including sensors, GPS, and cameras, enabling smooth operation with minimal human intervention. Here are some key benefits:

(a) Increased efficiency:
Autonomous machinery has been shown to significantly reduce project timelines by eliminating human factors such as fatigue or human error. With the help of these machines, tasks that would typically take weeks to complete can now be done in a matter of days. These machines can work round the clock, ensuring uninterrupted progress and reducing overall project duration. The advanced algorithms and sensors allow autonomous machinery to optimise routes, reduce fuel consumption, and minimise wastage.

(b) Improved safety:
Autonomous machinery has been found to significantly enhance the safety of construction workers by taking charge of physically demanding and risky tasks. Robots can handle tasks in hazardous environments, such as working at extreme heights or in toxic conditions, reducing the potential for accidents and injuries. With the help of autonomous machines, human involvement in dangerous operations is minimised, which in turn helps to safeguard the well-being of the workers.

(c) Enhanced accuracy:

Autonomous machinery uses sensors, GPS, and laser technology to ensure precise measurements, cutting, and grading. These machines eliminate the possibility of human errors and inconsistencies, resulting in improved project quality and reduced rework. These machines' high-accuracy mapping and modelling capabilities allow for better planning and execution of construction projects. **Figure 4.24** shows an example of a machine that is used as a mobile drilling robot for anchoring holes, executing tasks based on digitally planned data.

Figure 4.24 Hilti Jaibot used to mark and drill holes, relieving construction workers from the strenuous task of overhead drilling.

4.5.3 The Future Advancements of Autonomous Construction

The construction industry is set to witness a remarkable transformation with the rapid advancements in autonomous machinery. The future looks promising, with an abundance of trends that are likely to shape the industry. Let's look at some of these trends that are expected to revolutionise the way construction projects are executed, as illustrated in **Figure 4.25**.

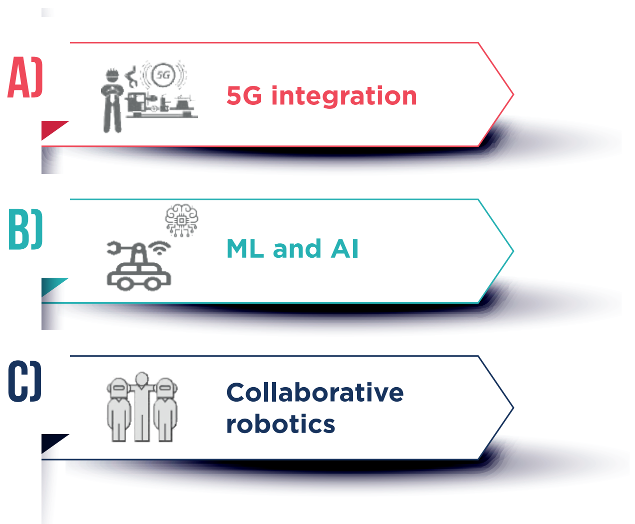


Figure 4.25 Advancements of autonomous construction for the construction industry.

(a) 5G integration:

As the world progresses towards digitisation, 5G technology is expected to revolutionise the construction industry by enabling real-time data transmission between autonomous machines and project management systems. This advancement will enhance coordination, monitoring, and control of construction operations, improving efficiency, safety, and cost-effectiveness. With the integration of 5G technology, construction companies can manage their projects more efficiently and make informed decisions in real time.

(b) Continuous learning and adapting to ML and AI:

Advances in machine learning algorithms have enabled the development of autonomous machinery that can learn from past experiences and improve its performance over time. This technology will revolutionise the construction industry by optimising processes and enabling predictive maintenance strategies. As these machines continue to learn and adapt, we can expect a significant increase in efficiency and productivity in the construction sector.

(c) Collaborative robotics:

As we move towards the future, we expect increased collaboration between autonomous machines and human workers. The rise of advanced robots that can assist and work alongside humans will improve productivity and create a harmonious human-machine ecosystem where both parties can contribute their unique strengths and skills to achieve common goals. This development holds great promise for industries seeking to streamline their operations and maximise efficiency while ensuring the safety and well-being of their workforce.

4.5.4 Suggested Readings for Additional Information

To acquire comprehensive insights into the application of autonomous construction, it is recommended that readers refer to the references listed below:

a. Construction 4.0: An Innovation Platform for the Built Environment. 2020, Anil Sawhney, Michael Riley, Javier Irizarry.
b. Lean Construction 4.0 Driving a Digital Revolution of Production Management in the AEC Industry. 2023, Vicente A. González, Farook Hamzeh, Luis Fernando Alarcón.
c. Revolutionising construction: The power of robotics in construction. Evan Beard. https://standardbots.com/blog/revolutionizing-construction-the-power-of-robotics
d. Autonomous construction. Mike Hayes. https://www.constructiontechnology.media/news/autonomous-construction/8011035.article
e. The rise of autonomous construction equipment. Rose Morrison, 2021. https://www.geospatialworld.net/blogs/the-rise-of-autonomous-construction-equipment/

BEST PRACTICES

"This chapter presents various case studies highlighting innovative practices in the construction industry. It is divided into two sections: building projects and infrastructure projects. The building projects section includes case studies on the TNB Platinum, the TRX Residences Plot 1C, and the Pembinaan Bangunan Tambahan Di SK Taman Scientex, showcasing how these projects revolutionised, innovated, and transformed their respective areas. The infrastructure projects section delves into the MRT Putrajaya Line, the Pan Borneo Highway Sarawak, and the Projek Penswastaan Lebuh Raya Bertingkat Sungai Besi - Ulu Kelang (SUKE), demonstrating how these projects innovated and revolutionised infrastructure development. These case studies collectively illustrate the application of the best practices in the construction industry."

5.0 Best Practices

This chapter investigates the modern strategies and methodologies that are currently transforming the construction industry. It provides an in-depth analysis of significant building and infrastructure projects, emphasising the innovative practices and technologies that bolster efficiency, sustainability, and collaboration. The chapter demonstrates how adopting BIM, cloud-based collaboration tools, prefabrication techniques, and advanced construction technologies are establishing new benchmarks and steering the industry towards a digitally enhanced future.

This document presents a comprehensive analysis of successful construction endeavours in the sphere of building projects, with a distinct emphasis on the integration of modern technologies and practices to surmount challenges and achieve extraordinary results. It comprises thorough examinations of a diverse range of building projects, including commercial, residential, and educational structures. Following this, it introduces three specific building projects that have adeptly utilised these technological advancements.

BEST PRACTICES

1

TNB Platinum, Bangsar, Kuala Lumpur:
TNB Platinum is a corporate building that houses TNB head office functions and equipped with state-of-the-art office facilities. Construction of the TNB Platinum began in March 2019 with a gross floor area of 135,644 square metres. This RM 781 million project sought to redefine contemporary architecture with a robust focus on sustainability. The project extensively used BIM throughout its lifecycle, from design to operation and maintenance, ensuring improved collaboration, reduced rework, and efficient asset management. Cloud-based tools and 3D scanning technologies further bolstered real-time collaboration and progress tracking, setting a new standard for office building projects in Malaysia.

2

TRX Residences Plot 1C:
The TRX Residences Plot 1C project signifies a milestone in residential construction, with a constructed area of 145,238 square metres. Spearheaded by a joint venture between TRX and Lendlease, the project incorporated BIM to streamline construction processes, identify clashes early, and enhance coordination. Cloud collaboration tools and prefabrication techniques were crucial in ensuring efficiency and safety. The application of modular construction methods, such as prefabricated steel staircases, expedited the construction timeline and reduced waste, exemplifying modern residential building practices.

3

Pembinaan Bangunan Tambahan Di SK Taman Scientex, Pasir Gudang, Johor:
The expansion project at SK Taman Scientex, Pasir Gudang, Johor, aimed to enhance educational infrastructure with a project value of RM 14 million. Covering 5.1 acres, the project harnessed BIM for detailed planning and coordination, ensuring the efficient use of resources and timely project completion. The integration of cloud-based collaboration tools facilitated seamless communication among stakeholders, while advanced construction techniques ensured quality and safety standards were met, demonstrating the potential for innovation in educational building projects.

In addition to highlighting various building projects, this document emphasises the notable advancements in infrastructure projects, particularly emphasising the adoption of modern construction technologies and practices to drive substantial improvements in project execution. It encompasses a wide range of infrastructure projects showcasing the successful integration of digital tools, collaborative platforms, and advanced construction methodologies to overcome traditional challenges and elevate project outcomes. Here, we outline three specific infrastructure projects that have effectively harnessed technological advancements.

1

MRT Putrajaya Line Project:

The MRT Putrajaya Line project is a crucial infrastructure development to enhance public transportation in Malaysia's Klang Valley. Covering 57.7 km and costing RM30.53 billion, the project was completed in March 2023. Technological advancements played a vital role, with BIM extensively used during the planning, design, construction, and maintenance stages to enhance collaboration and efficiency. AR and VR were employed for construction verification and error identification, while 3D scanning and photogrammetry were utilised for verifying construction elements and monitoring site progress. The project faced challenges such as data management, lack of supply chain support, and technological adoption issues, which were addressed by selecting appropriate platforms, conducting training sessions, and leveraging technology to streamline processes. The project's success underscores the importance of modern technology in infrastructure development, showcasing Malaysia's commitment to advancing its public transportation system.

2

Pan Borneo Highway Sarawak Project:

The Pan Borneo Highway Sarawak project aims to improve transportation connectivity across Sarawak, Malaysia. Spanning 786 km and valued at RM16 billion, the project commenced in 2015 and is expected to be completed by 2024. Key technologies like BIM were crucial for coordinating efforts among multiple stakeholders and enhancing project efficiency. Photogrammetry and 3D scanning were applied for site monitoring, boundary setting, and mission planning, while cloud and real-time collaboration ensured efficient data management and real-time access to project information. The project encountered issues such as limited internet connectivity, lack of tech-savvy personnel, and large data management, which were mitigated by developing a web-based system, implementing offline features, and conducting thorough pre-flight planning. The Pan Borneo Highway Sarawak project represents a significant step in Malaysia's infrastructure development, leveraging advanced technologies to overcome challenges and achieve project milestones.

3

Projek Penswastaan Lebuh Raya Bertingkat Sungai Besi - Ulu Kelang (SUKE):

The Projek Penswastaan Lebuh Raya Bertingkat Sungai Besi - Ulu Kelang (SUKE) is designed to alleviate traffic congestion and improve connectivity in Kuala Lumpur. Technological adoption included using BIM for planning and design to enhance accuracy and reduce errors, along with advanced construction techniques to streamline the building process and ensure safety. The project faced logistical and technological challenges, such as coordinating multiple construction sites and integrating new technologies, addressed through comprehensive planning, stakeholder coordination, and adopting best practices in construction management. The Projek Penswastaan Lebuh Raya Bertingkat Sungai Besi - Ulu Kelang (SUKE) exemplifies the challenges and solutions of modern infrastructure development, showcasing the benefits of technological adoption in enhancing urban connectivity and reducing traffic congestion.

5.1 Case Study for Building Projects

5.1.1 Revolutionising Construction: The Story of TNB Platinum, Bangsar, Kuala Lumpur.

The TNB Platinum, a commercial building project spearheaded by Tenaga Nasional Berhad (TNB), commenced its journey in March 2019. With a total gross floor area (GFA) of 135,644 sqm, this ambitious endeavour aimed to redefine contemporary architecture while adhering to sustainable principles. Valued at RM 781 million, it promised to be a leading project setting new standards in the industry.

Figure 5.1 TNB Platinum, the new headquarters for Tenaga Nasional Berhad

5.1.1.1 Project Details and Technology Adoption

Table 5.1 Project information in TNB Platinum, Bangsar, Kuala Lumpur

TNB PLATINUM	
Project Category	Building - Office
Gross Floor Area	135,644 sqm
Project Value (RM)	RM781 mil
Project Duration	March 2019 – October 2022
Owner & Developer	Tenaga Nasional Berhad
Project Management Consultant	Sunway Construction Sdn Bhd
Design Architect	Woods Bagot
Principle Architect	Neuformation Architects Sdn Bhd
Quantity Surveyor	Baharuddin Ali & Low
C&S	Meinhardt C&S Engineering
MEP	Meinhardt M&E Engineering
Building Facade	Meinhardt Façade & BMU
Façade Lighting	Meinhardt Lighting Studio
AV/ICT	Arup Jururunding
Landscape Architect	Praxcis Design Studio
Interior Architect	SW1 Solutions Sdn Bhd
Signage	Wayfinding Consult

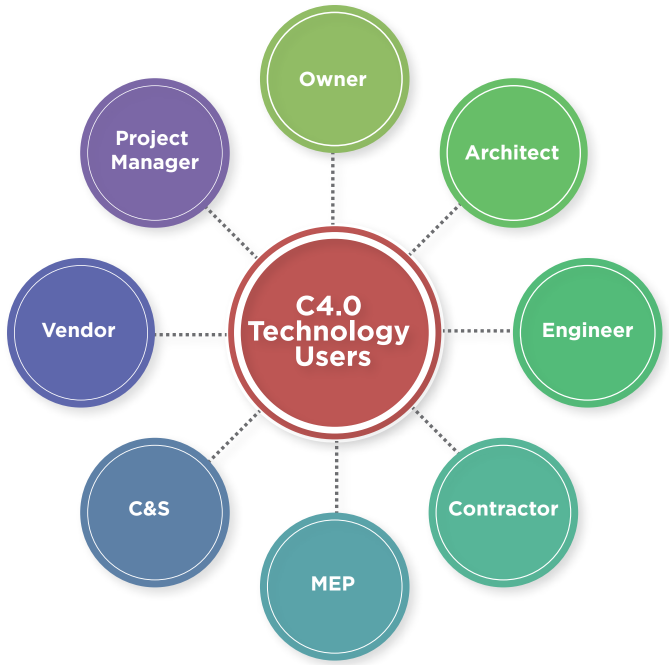


Figure 5.2 C4.0 technology user in TNB Platinum, Bangsar, Kuala Lumpur

Table 5.2 Technology used in TNB Platinum, Bangsar, Kuala Lumpur

CR4.0	Stage	Design	Construction	Operation & Maintenance
Building Information Modelling (BIM)	Type Of Software/ Tools/ Machinery Used	Autodesk Revit (3D Model Authoring, Drawing Production)	Autodesk Revit (3D Model Authoring, Drawing Production)	Autodesk Tandem (Digital Twin)
		Autodesk Naviswork (3D Coordination)	Autodesk Naviswork (3D Coordination, 4D Simulation)	Autodesk Naviswork (3D Coordination)
	Benefits of Implementation	Using the BIM model improves efficiency as it can be updated and upgraded, and is useful across the asset lifecycle.	Cost avoidance through less hacking/rework.	Enhanced Facility Management by having a comprehensive digital representation of the building, containing detailed information about its components, systems, and assets.
		Production of drawings, sections, details and schedules from the BIM Model improved productivity and minimise downtime through automation		Efficient asset tracking and inventory management.
		Enhanced and comprehensive 3D visualisation improved collaboration and coordination, thus enabling informed decision-making.		Accurate space management for future asset repurposing and upgrading works.
Cloud and Realtime Collaboration	Type Of Software/ Tools/ Machinery Used		Prolog	
			Procore	
		Autodesk Construction Cloud / Autodesk Tandem		
		Sharepoint		
	Benefits of Implementation	Allows for a single source of truth for versioning tracking of incoming/outgoing files		
		File mobility		
		Reduce software/hardware upgrades for stakeholders.		
Photogrammetry & 3D Scanning	Type Of Software/ Tools/ Machinery Used		Holobuilder (Construction site progress)	
			Matterport (As-built Reality Capture)	
			Drone (Construction site progress)	
			Project Timelapse (Construction site progress)	
	Benefits of Implementation	Immersive as-built reality capture used for asset repurposing and future space planning	Digital reality capture record for defect management	Immersive as-built reality capture used for asset repurposing and future space planning
			Digital reality captures records for publication/ reference/ record	

5.1.1.2 Building Information Modelling (BIM):

BIM Implementations span the entire asset lifecycle, encompassing the planning, design, construction, operation, maintenance, and asset repurposing.

(a) Design Stage:

BIM is used during the pre-construction stage to help in planning, design, analysis, and documentation production. Stakeholders benefit from the enhanced and comprehensive 3D visualisation that improves collaboration and coordination. thus, enabling informed decision-making. The main challenges during early implementation include high cost and the lack of BIM collaboration tools, which have been overcome by the integration with cloud platforms such as Procore and Autodesk Construction Cloud that help in seamless collaboration tools. Another challenge during the early implementation was that discrepancies occurred in 2D drawings and 3D BIM Models. This has been overcome by ensuring the BIM Model is used for construction documentation, i.e., drawings, schedules, sections, and detailing to ensure accuracy and to avoid discrepancies.

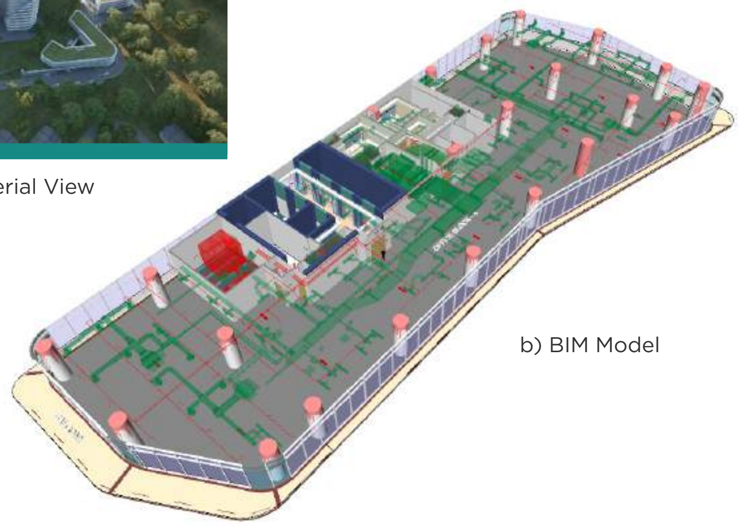
(b) Construction Stage:

BIM adoption during the construction stage brought benefits, which include cost avoidance through improved collaboration that results in better site coordination, less rework and less hacking. Having a BIM Model to produce site documentation, such as shop drawings, also benefits in reducing design discrepancies that always recur at the site. BIM model-site verification is the gap found during project closeout and has been overcome by ensuring BIM model-site verification is done using point cloud technology or equivalent during the closeout stage.

(c) Operation and Maintenance Stage:

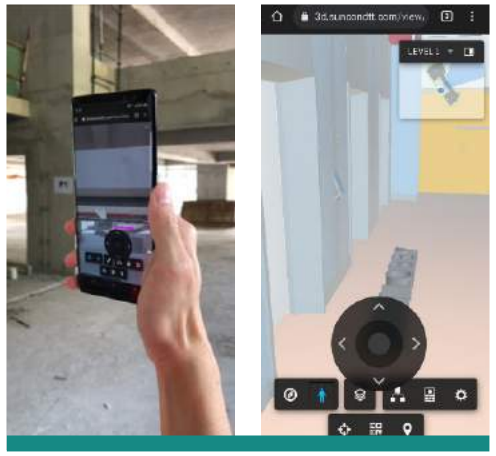
BIM implementation assists in facility and asset management (FM) by having a comprehensive digital twin of the building containing real-time building performance and asset data such as system and specification. This helps in efficient asset tracking and accurate space management for future asset repurposing and upgrading works. Integration of BIM software and FM software is a challenge during the operation and maintenance stage. Using API integration, real-time Building Management System (BMS) data has been developed to enabled data analytic and predictive actions.

a) TNB Platinum Aerial View



b) BIM Model

c) Clash Analysis Workshop



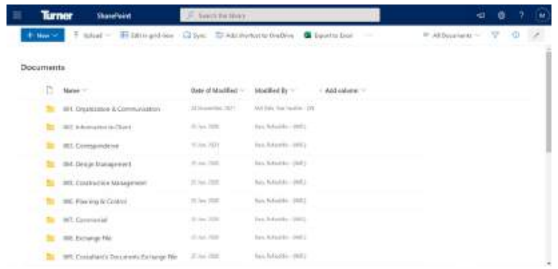
d) BIM VR for visualisation

e) Digital Twin for Operation Excellence

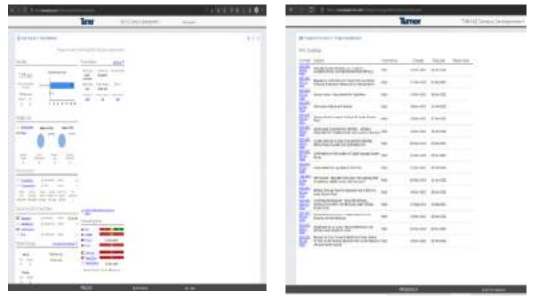
Figure 5.3 Building Information Modelling (BIM) Application for Design, Construction, Operation and Maintenance Stage

5.1.1.3 Cloud and Real-time Collaboration:

TNB leverages multiple cloud-based and real-time collaborations such as Procore, Autodesk Construction Cloud, Sharepoint and Prolog to address various challenges encountered during project management. The platform handles an abundance of BIM Models and documents requiring submission and approval by contractors and consultants with varying access levels.



a) Cloud: SharePoint



b) Prolog Converge

Figure 5.4 Cloud and Real-time Collaboration Application used for Design, Construction, Operation and Maintenance Stage

a) Sunway Project Management Dashboard (SPMD)

b) Turner-Safety Net

c) Power BI Dashboard

Figure 5.5 Other Technology Applications Used for Design, Construction, Operation and Maintenance Stage

5.1.1.4 Photogrammetry & 3D Scanning:

Photogrammetry and 3D scanning were implemented throughout the construction and post-construction to capture internal and external site progress and to record a digital as built. Various software tools and equipment were used to achieve this objective.

Holobuilder were used to capture internal digital site progress, drones for external site progress monitoring, and Project Timelapse for capturing external site progress over time. Matterport were used for digital as-built reality capture.

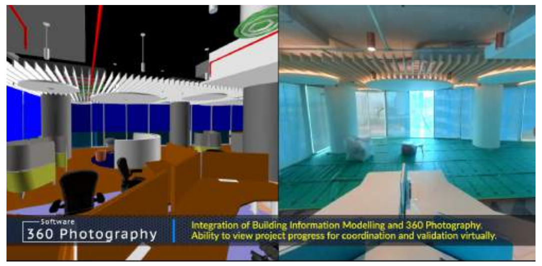
The adoption of these technologies was driven by the need to maintain project records in digital format, facilitating progress tracking, claim evaluation, dispute administration, and publication purposes.

To implement such tools and software, sufficient resources must be allocated to support these initiatives. Thus, TNB has invested to ensure the successful implementation of these technologies. As a result, the outcome yielded digital capture records that serve as valuable references for publication, record-keeping, and future project management endeavours.

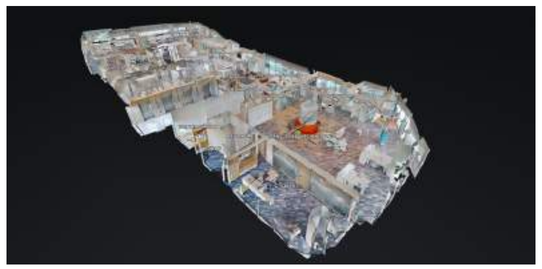
a) External and Internal Visual Documentation

b) 4D timelapse

c) Aerial Photography



d) Integration of BIM Modelling and 360 Photography



e) Matterport

Figure 5.6 Photogrammetry & 3D Scanning Application used for Design, Construction, Operation and Maintenance Stage

5.1.1.5 Conclusion

The TNB Platinum project is a beacon of innovation in Malaysia's construction landscape through the strategic adoption of BIM, cloud-based collaboration, 3D scanning, and photogrammetry. TNB delivered a groundbreaking project and laid the foundation for future industry standards. As the construction sector evolves, TNB's journey inspires, driving the industry towards a digitally empowered future.

5.1.2 Innovating Residential Construction: A Case Study of TRX Residences Plot 1C

The TRX Residences Plot 1c project represents a significant milestone in residential construction. With a constructed area of 145,238m^2, it exemplifies modern building practices and innovative approaches to construction. Lead by the joint venture of TRX and Lendlease, in collaboration with esteemed contractors and architects, it stands as a testament to groundbreaking construction methodologies.

Figure 5.7 TRX Residences

5.1.2.1 Project Details and Technology Adoption

Table 5.3 Project information in TRX Residences Plot 1C

TRX RESIDENCES PLOT 1C	
Project Category	Residential Building
Constructed Area	145,238m^2
Project Value (RM)	RM 530 million
Project Duration	17/8/2021 – 31/5/2024
Owner	LQ Residential 1 Sdn Bhd
Developer	JV - TRX and Lendlease
Contractor	IJM Construction Sdn Bhd
Architecture	GDP Architect Sdn Bhd
Civil and Structural	KTP Civil & Structural Sdn Bhd
MEP	PCR Sdn Bhd
Quantity Surveyor	JUBM Sdn Bhd

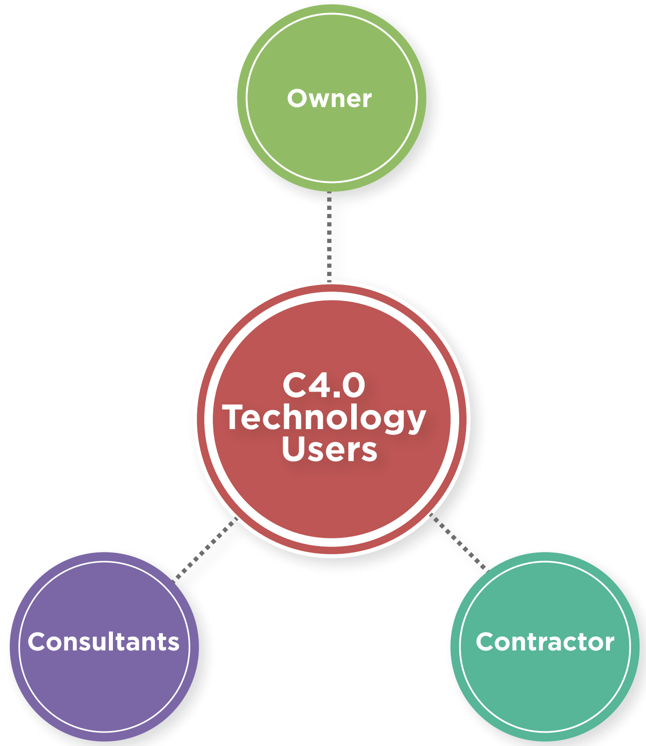


Figure 5.8 C4.0 technology users in TRX Residences Plot 1C

Table 5.4 Technology used in TRX Residences Plot 1C

CR4.0	Stage	Construction Stage
Building and Information Modelling	Type Of Software/Tools/Machinery Used	Autodesk Revit (Model Authoring)
		Autodesk Navisworks (3D Coordination, 4D Simulation)
	Benefits of Implementation	Managed to identify many issues before construction, thus avoiding rework or additional work.
Cloud and Realtime Collaboration	Type Of Software/Tools/Machinery Used	BIM 360
		Aconex, Novade
		Synology, Blokalert and BlokCam
	Benefits of Implementation	Enhances collaboration, efficiency, and transparency throughout the project lifecycle, ultimately leading to better project outcomes, and centralising all data management in a single platform.
Prefabrication and Modular Construction	Type Of Software/Tools/Machinery Used	BIM 360
		Aconex, Novade
	Benefits of Implementation	Synology, Blokalert and BlokCam

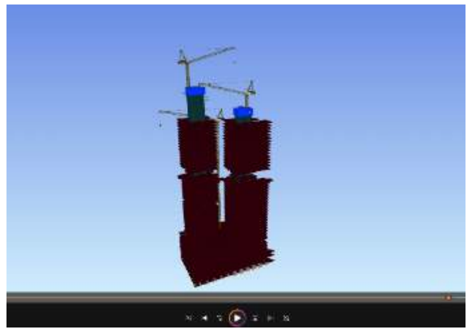
5.1.2.2 Building Information Modelling (BIM) Implementation:

The adoption of BIM played a crucial role in streamlining the construction process of TRX Residences Plot 1c. Utilising sophisticated software tools and methodologies, the project team achieved enhanced coordination and identified potential clashes and issues before they could impact construction progress.

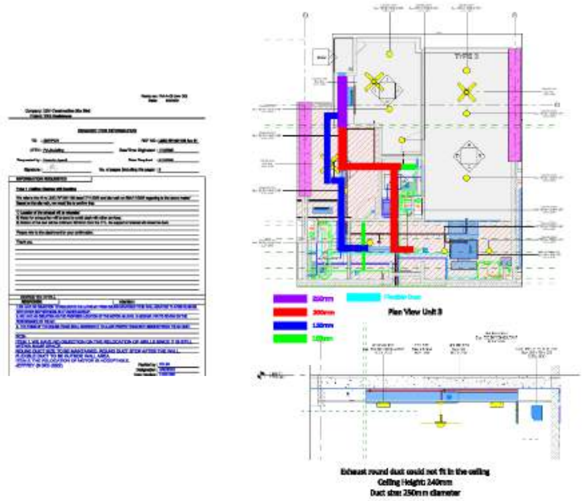
(a) Challenges and solutions implemented for BIM implementation:

The primary goal behind adopting BIM was to enhance coordination and identify clashes or issues early in the project lifecycle. The main challenge faced during BIM implementation was the extensive modelling work required. To overcome the challenges, a dedicated BIM unit and personnel were established, ensuring efficient management of the modelling process.

a) 3D BIM Model – using Autodesk Revit



b) 4D Timeliner – using Autodesk Navisworks



c) RFI based on BIM Field Verification

d) CSD Drawing Production – for coordination and construction purpose

Figure 5.9 Building Information Modelling (BIM) Application Used for Construction Stage

BEST PRACTICES

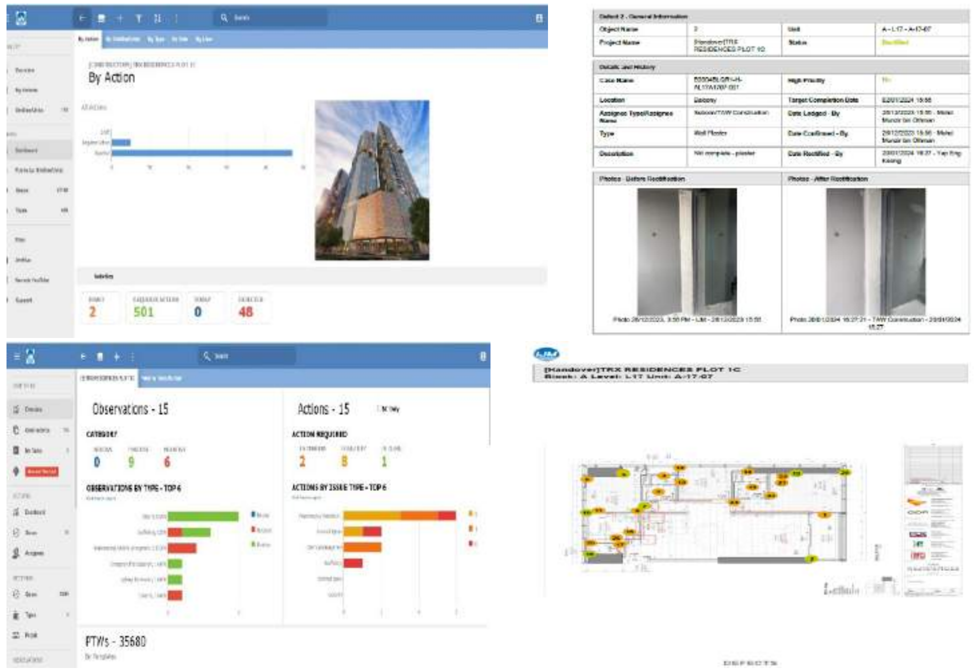
a) Aerial Photo – Perspective View

b) Aerial Photo – for Logistic Planning

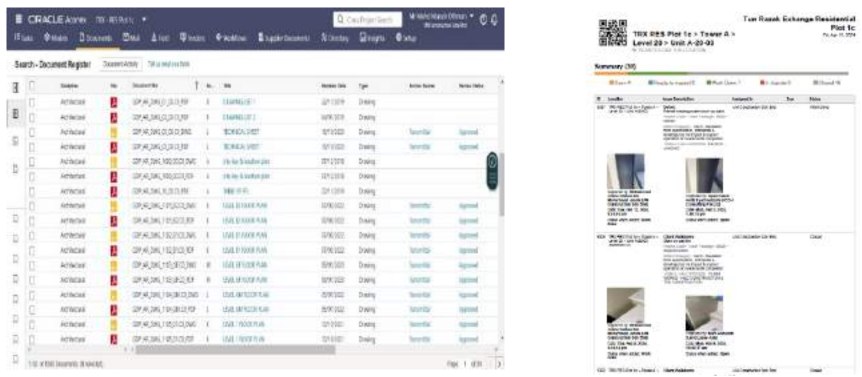
Figure 5.10 Aerial photo for viewing and planning.

5.1.2.3 Cloud and Real-time Collaboration

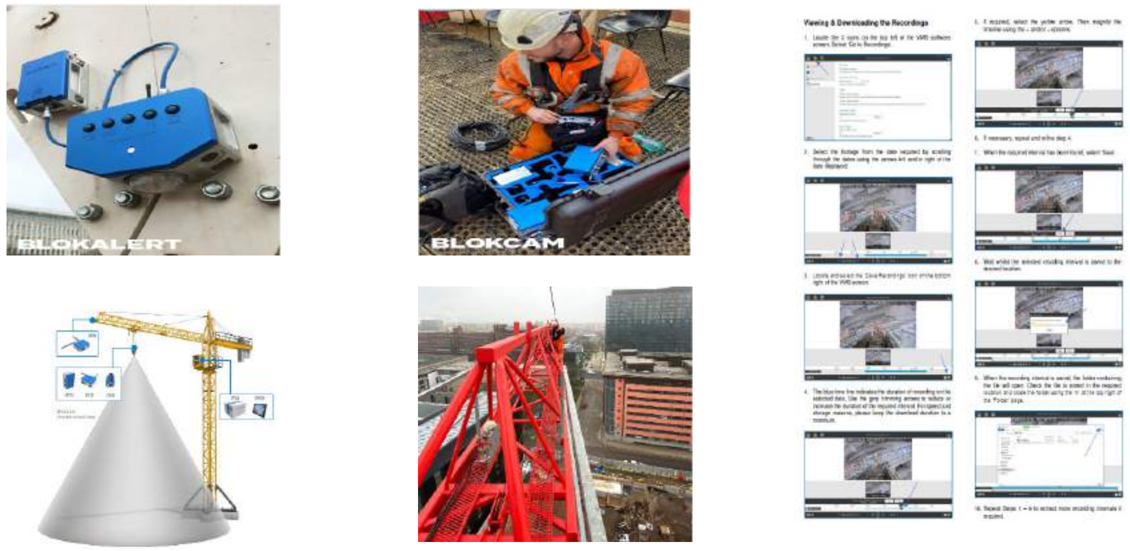
Cloud and real-time collaboration tools are revolutionising construction and site operations by enhancing efficiency, safety, and accountability. NOVADE Software exemplifies this shift by digitising essential site processes such as quality inspections, permits to work, and defect management, facilitating real-time information sharing among consultants, subcontractors, and project teams. Its features, include customisable quality forms, dynamic workflows, and comprehensive inspection checklists, streamlining QA/QC processes and defect tracking, boosting productivity and reducing errors. Complementing NOVADE, Aconex is a comprehensive Common Data Environment (CDE), revolutionising communication and data management with secure document handling, advanced communication tools, and simplified model coordination. Additionally, BlokAlert and BlokCam enhance safety and operational efficiency by providing immediate audio-visual warnings for crane hook block movements and real-time feeds from the crane to the operator's cab. These technologies highlight the critical role of cloud and real-time collaboration in driving safer, more efficient, and coordinated project execution.



a) NOVADE (PTW, Inspection and Defect Management)



b) ACONEX Software (Document Management and Defect Management)



c) BlokCam and BlokAlert

Figure 5.11 Cloud and Real-time Collaboration Application Used for Construction Stage

5.1.2.4 Prefabrication and Modular Construction:

Adopting prefabrication and modular construction techniques underscored the project's dedication to efficiency and innovation. These methods were strategically implemented to accelerate the construction timeline and circumvent potential setbacks. Impressively, the execution of these techniques proceeded without any significant hurdles. The Dscaff Prefab Steel Stair Form System, a modular building unit classified under Level 3 of prefabrication **(as referenced in section 4.1.1.1)**, was manufactured at the factory and assembled on-site as permanent formwork. This system expedites construction activities, reduces reliance on skilled labour, and minimises waste, thereby aligning with 'Green Building' standards.

a) Prefabricated staircase module at the factory

b) Installation of staircase module at the site

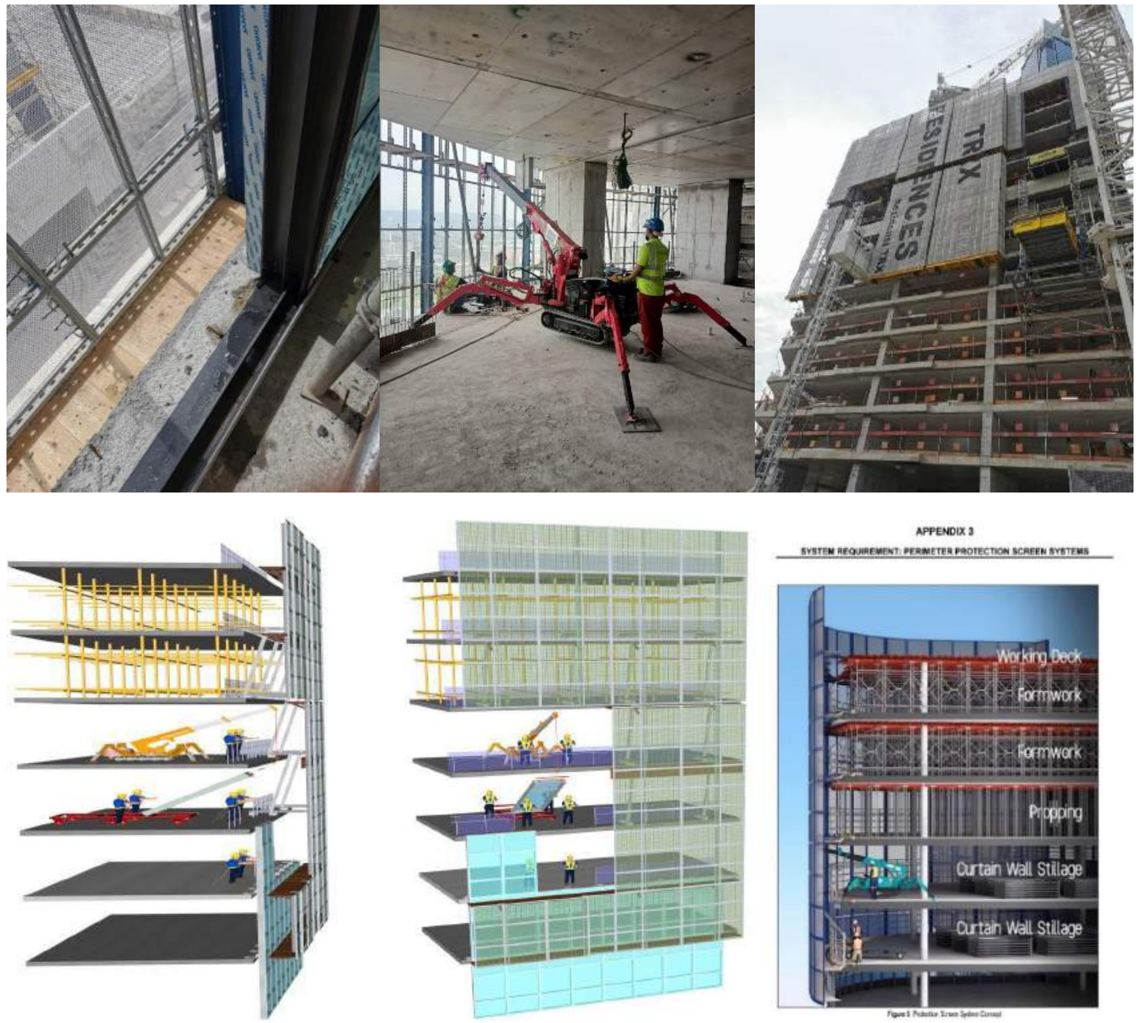
c) Concreting process

d) Finished staircase

Figure 5.12 Used of Modular Permanent Prefab Steel Staircase

5.1.2.5 Other Construction Technology Enhancing Solution

The integration of advanced system technologies is revolutionising the building construction industry by significantly enhancing productivity, efficiency, quality standards, and safety. Technologies such as the Lubeca Self Climbing Jump Form System, which allows for modular and hydraulically lifted formwork for high-rise cores, optimise construction sequences and reduce crane time. The 6.5 Floor Protection System x-climb 60, which has initially been used in Malaysia's TRX Residences, provides dual-section protection screens and an Integrated Table Lifting System (TLS) for rapid repositioning floor-slab formwork, ensuring worker's safety and efficient operations. Additionally, innovations such as the Top-Down Hanging Scaffold offer flexible, secure platforms for various heights, while the Climbing Crane Inside Lift Core optimises material and equipment transport internally. These technologies collectively contribute to faster completion times, lower costs, and a safer, more efficient work environment, meeting the evolving demands of modern construction while upholding sustainability and safety standards.



a) 6.5Floor Protection System x-climb 60

b) Lubeca Self Climbing Jump Form System

Figure 5.13 Other construction technology-enhancing solutions to improve construction productivity and safety.

5.1.2.6 Conclusion

The TRX Residences Plot 1c project is an example of innovative construction practices. The project team has successfully navigated challenges through the strategic adoption of BIM, cloud and real-time collaboration and prefabrication or modular construction. It has achieved exceptional efficiencies, ultimately setting new standards for residential construction in Malaysia.

BEST PRACTICES

5.1.3 Transforming Education Infrastructure: Pembinaan Bangunan Tambahan Di SK Taman Scientex, Pasir Gudang, Johor

The Pembinaan Bangunan Tambahan Di SK Taman Scientex, Pasir Gudang, Johor, is a significant endeavour to enhance educational facilities. With a project value of RM14 million and spanning 5.1 acres, this project reflects the Kementerian Pendidikan Malaysia (KPM) 's commitment to providing quality education infrastructure.

Figure 5.14 Pembinaan Bangunan Tambahan Di SK Taman Scientex, Pasir Gudang, Johor

5.1.3.1 Project Details and Technology Adoption

Table 5.5 Project information in Pembinaan Bangunan Tambahan Di SK Taman Scientex, Pasir Gudang, Johor

PEMBINAAN BANGUNAN TAMBAHAN DI SK TAMAN SCIENTEX, PASIR GUDANG, JOHOR	
Project Category	A 2-storey building - School
Constructed Area	5.1 acres
Project Value (RM)	RM14 million
Project Duration	27/5/2021-4/2/2024
Project Owner	Kementerian Pendidikan Malaysia (KPM)
Developer	JKR Malaysia
Contractor	Kapar Jaya Sdn Bhd
CAS, MEP	JKR Malaysia
Quantity Surveyor Land Surveyor	JKR Malaysia

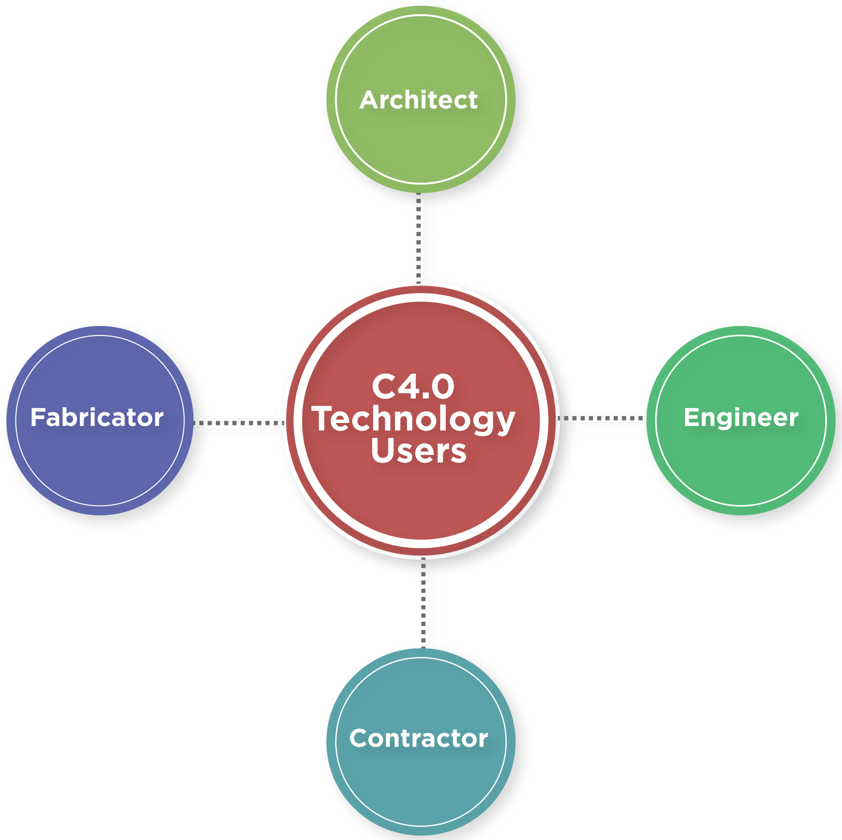


Figure 5.15 C4.0 technology users in Pembinaan Bangunan Tambahan Di SK Taman Scientex, Pasir Gudang, Johor

Table 5.6 Technology used in Pembinaan Bangunan Tambahan Di SK Taman Scientex, Pasir Gudang, Johor

CR4.0	Stage	Conceptual Stage, Planning and Design Stage	Construction Stage
Building Information Modelling (BIM)	Type Of Software/Tools/Machinery Used	Autodesk Revit	
		Autodesk Naviswork	
	Benefits of Implementation	Reduce clashing, rework, and waste on-site.	
Prefabrication and Modular Construction	Type Of Software/Tools/Machinery Used		Prefabricated Volumetric Modules.
			Faster construction time.
			A smaller workforce is required.
	Benefits of Implementation		Ensure high quality of work.

5.1.3.2 Building Information Modelling (BIM) Implementation:

BIM adoption was crucial in facilitating coordination among various design teams, ensuring seamless integration of project elements. The primary reason for adopting BIM was to address coordination issues among design teams.

(a) Challenges and Solutions Implemented for BIM Implementation:

Challenges during BIM implementation included insufficient BIM software and suitable computer resources. To overcome these challenges, training sessions were provided, and suitable computers and software were furnished to the design teams.

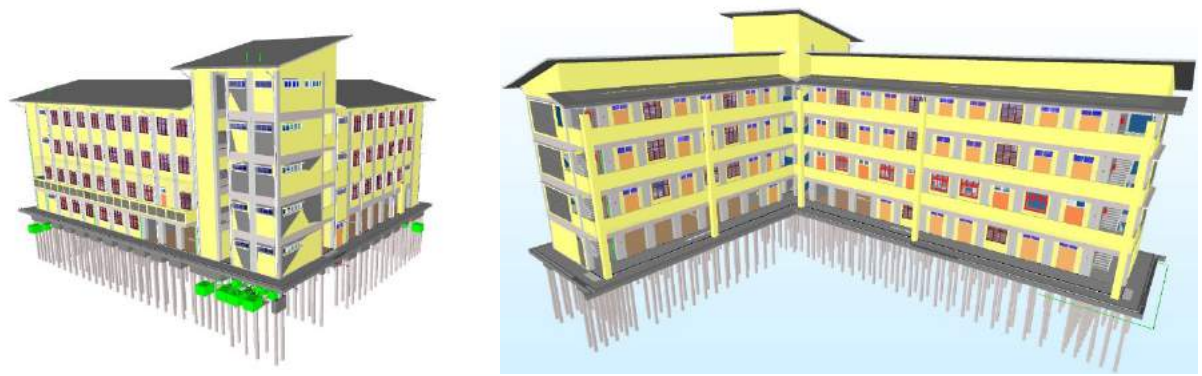


Figure 5.16 Building Information Modelling (BIM) Application used for Conceptual Stage, Planning and Design Stage and Construction Stage

5.1.3.3 Prefabrication and Modular Construction:

Prefabrication Volumetric Modules (PVM) were adopted in this project, revolutionising construction by assembling entire building modules off-site, complete with structural elements. These modular units are then transported to the construction site for rapid installation, significantly reducing construction time and onsite labour requirements.

a) Component casting at the factory

b) Component lifting and installation at the site

c) Component installation at the site

d) Full modular component installation at the site

Figure 5.17 Prefabrication and Installation of Volumetric Module Application Used for Construction Stage

5.1.3.4 Conclusion

In conclusion, the Pembinaan Bangunan Tambahan Di SK Taman Scientex, Pasir Gudang, Johor underscores KPM's commitment to providing sufficient educational facilities. Adopting BIM and Prefabrication and Modular Construction showcases the project's progressive construction and site management approach. Despite the challenges, the project is poised to benefit the educational landscape of Pasir Gudang, Johor, substantially.

5.2 Case Study for Infrastructure Projects

5.2.1 Innovating Infrastructure: A Closer Look at the MRT Putrajaya Line Project

The Putrajaya Line is the second line in the planned Klang Valley Mass Rapid Transit (KVMRT) Project, a monumental infrastructure initiative to enhance public transportation in the Klang Valley. Spanning 57.7km from Kwasa Damansara to Putrajaya, the RM30.53 billion infrastructure project represents a significant investment in Malaysia's railway infrastructure. Initiated in 2015, the project was completed in March 2023, marking an important milestone in Malaysia's urban development journey. The project was developed by Mass Rapid Transit Corporation Sdn. Bhd. (MRT Corp) together with the project's Turnkey Contractor, MMC-Gamuda KVMRT (PDP SSP) Sdn. Bhd.

Figure 5.18 The MRT Putrajaya Line

5.2.1.1 Project Details and Technology Adoption

Table 5.7 Project information in MRT Putrajaya Line

MRT PUTRAJAYA LINE	
Project Category	Railway
Constructed Distance	57.7 km
Project Value (RM)	RM 30.53 billion
Project Duration	2015 - 2023
Project Owner	Mass Rapid Transit Corporation Sdn. Bhd.
Turnkey Contractor	MMC-Gamuda KVMRT (PDP SSP) Sdn. Bhd.

Table 5.8 Technology used in MRT Putrajaya Line project

CR4.0	Stage	Planning and Design Stage	Construction Stage	Operation and Maintenance Stage
Building Information Modelling (BIM)	Type Of Software/ Tools/ Machinery Used	Bentley ProjectWise (CDE)		Bentley AssetWise ALIM (Asset CDE)
		Autodesk Revit		
		Bentley OpenRail and OpenBuilding Designer		
		Navisworks Manage		
		BIMCollab		
	Benefits of Implementation	Clear communication between contractors and Design consultants results in parties making quicker, informed decisions.	Services are efficiently coordinated during the design stage. Detection and resolution of service clashes during the design stage reduce potential clashes during construction.	A centralised system that will ease asset information management, such as change configuration, documentation revision control for future modification projects, etc.
		Minimising rework, reducing delays, and reducing material wastage, thus saving costs.	Efficient collaboration between Architects with M&E and Railway Systems design consultants leads to optimised architectural space-proofing.	Digital Twin enables real-time asset performance monitoring by collecting data from sensors embedded in physical assets. This data can be analysed to predict potential failures or maintenance needs before they occur.
Augmented Reality (AR) and Virtual Reality (VR)	Type Of Software/Tools/ Machinery Used		BIMAR (Developed in-house by the Turnkey Contractor)	
			Ease verification of construction at the site and quick identification of errors.	
3D Scanning & Photogrammetry	Type Of Software/Tools/ Machinery Used		Terrestrial Laser Scanning (TLS)	
			Autodesk Recap (for processing of laser scan data files)	
			Drone photogrammetry	
	Benefits of Implementation		As-built models and drawings have greater reliability than conventional methods due to the recorded scan verification.	
			Greater visualisation of site progress against the construction programme.	

5.2.1.2 Building Information Modelling (BIM) Implementation:

The adoption of BIM has been pivotal throughout the various Putrajaya Line project stages, enhancing collaboration, efficiency, and precision.

(a) Planning and design stage:

BIM was adopted to enhance design clarity and collaboration among the consultants, contractors, and the supply chain. This was achieved through the utilisation of a Common Data Environment (CDE) as the project's single source of truth.

Among the challenges faced during this stage were ensuring a smooth information exchange between the stakeholders, efficient management of large amounts of data, and addressing the lack of awareness and support from the supply chain management.

To overcome these challenges, meticulous steps were taken to select the appropriate CDE platform. Additionally, a set of protocols was implemented, incorporating the industry's best practices in modelling, conducting frequent Virtual Design Review (VDR) sessions, and holding monthly BIM technical meetings to ensure adherence to the established practices as well as ISO19650 standards.

On top of this, BIM In Rail Academy (BIRAC) was established to provide training and awareness to the supply chain during the period under construction.

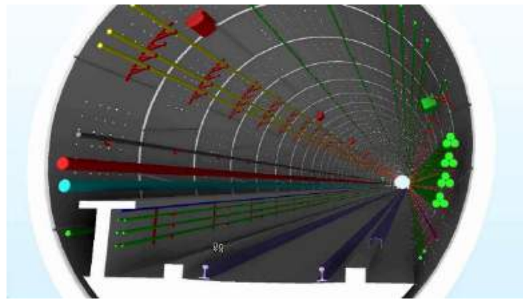
(b) Construction stage:

The adoption of BIM was essential to ensure the continual update of the Final Design Model, capturing all approved changes and facilitating the conversion into the As-Built model. The CDE platform, which was established initially during the planning and design stage was continually leveraged to enhance collaboration between various contractors and design consultants during the construction stage. Virtual Design and Construction (VDC) coordination meetings were utilised to address construction coordination issues efficiently. However, a lack of awareness, understanding, and support from the supply chain management regarding BIM implementation remained a challenge. To address this, comprehensive training initiatives were undertaken, including BIRAC, to equip the supply chain with the knowledge and skills to embrace BIM practices effectively, ensuring smoother project execution and coordination.

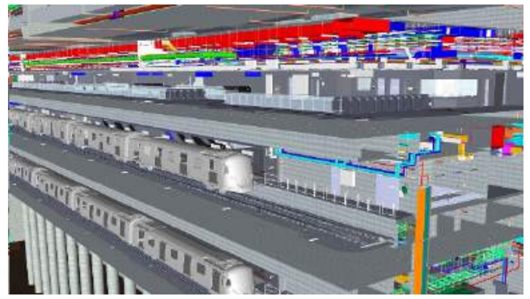
(c) Operation and maintenance stage:

The adoption of BIM was also undertaken to centralise and track all asset information into one system for maintenance purposes as well as to enhance maintenance operations through the utilisation of predictive maintenance, as enabled by the Digital Twin technology.

Challenges during the Operations and Maintenance (O&M) phase were encountered in the setting up and deployment of BIM platforms and the given tools as this is the first attempt by the O&M personnel to utilise and manage this technology. To overcome these challenges, MRT Corp is undertaking close collaboration with vendors to support the engineers with plans to undertake comprehensive training sessions for the relevant personnel, enabling the benefits of BIM to be realised in the asset maintenance phase.

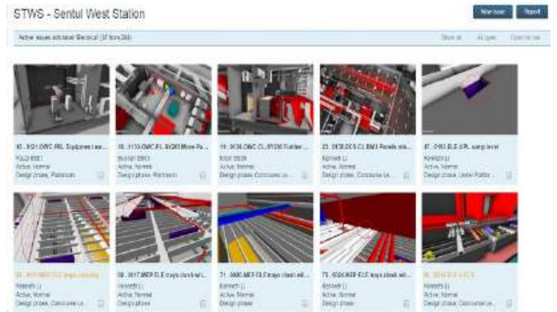


a) Sample tunnel federated model



b) Sample station federated model

c) Virtual Design Review session



d) Screenshot of BIMCollab issues during the design stage

Figure 5.19 Building Information Modelling (BIM) Application used for Planning, Design, Construction, Operation and Maintenance Stage

a) MRT BIM In Rail Academy (BIRAC) class session

b) MRT Corp is the first in Asia to achieve BIM Level 2 Accreditation

Figure 5.20 MRT Initiative in Adopting Technology

5.2.1.3 Augmented Reality (AR) And Virtual Reality (VR)

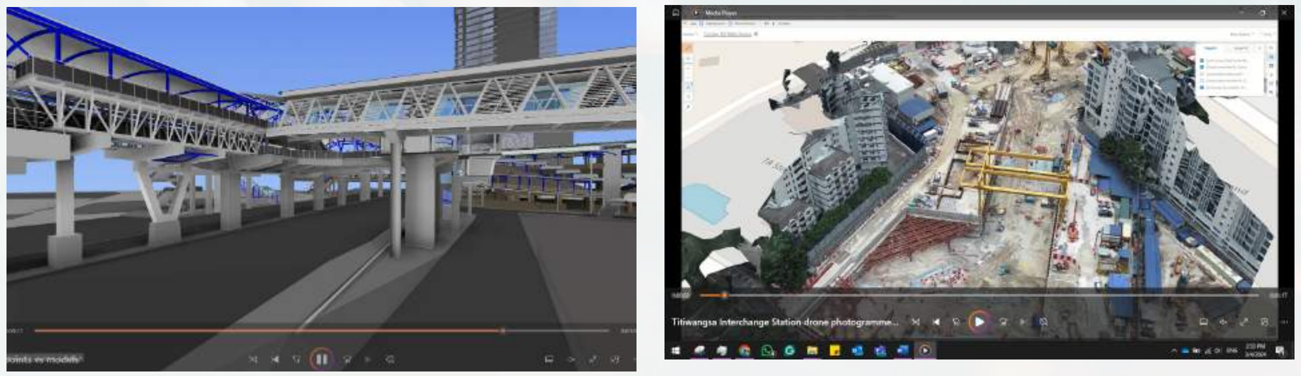
The adoption of BIMAR, an in-house software tool developed by the Turnkey Contractor, provided a streamlined means to check the construction of structural elements against coordinated service models. This adoption aimed to enhance the efficiency and accuracy of on-site construction verification processes. Challenges during AR/VR implementation primarily stemmed from the requirement for expensive equipment, specifically tablets with high-performance capabilities. Nevertheless, the benefits gained from adopting AR/VR were substantial, as it facilitated construction verification at the site and swift identification of errors, ultimately enhancing construction quality and project outcomes.

5.2.1.4 Photogrammetry and 3D Scanning

The adoption of Photogrammetry & 3D Scanning has been instrumental in verifying installed elements across various crucial areas of construction projects. These areas encompass primary concrete and steelwork structures such as walls, floors, columns, roof slabs, stairs, and major mechanical, electrical, and plumbing (MEP) services, including mechanical ducts, electrical systems, and generators. Additionally, architectural fit-out spaces within station boxes and overall site construction progress were monitored through this technology.

Several challenges emerged during the implementation of Photogrammetry & 3D Scanning. These included the limited availability of expensive equipment, restrictions on the time of laser scanning (due to engineering hours to avoid obstructions), management of large scanned data files, and a shortage of personnel certified to operate the equipment.

To address these challenges, various solutions were implemented in the adoption of Photogrammetry & 3D Scanning. These included establishing and closely monitoring proper work programs to ensure smooth scanning operations and optimal use of limited equipment. A series of pilot scans were conducted in selected areas using different scan resolution settings to determine the optimal resolution for accepted file sizes. Scans were saved in the CDE according to rooms or areas to manage file sizes effectively allowing as-built verification to be conducted on a room-to-room or area basis by appending the respective scanned areas into the federated construction model. Additionally, personnel were sent for training to obtain certification or permits to operate drones and equipment, ensuring proficient utilisation of Photogrammetry & 3D Scanning technologies in construction projects.



a) Titiwangsa Interchange Station laser scanned point cloud validation

b) Titiwangsa Interchange Station drone photogrammetry reality modelling

Figure 5.21 Laser Scanning and Photogrammetry Application Used for Construction Stage

5.2.1.5 Conclusion

In conclusion, the adoption of BIM, AR/VR, and 3D scanning technologies has been instrumental in ensuring the success of the MRT Putrajaya Line project, enhancing collaboration, efficiency, and construction quality. These innovative approaches signify Malaysia's commitment to modernising its infrastructure and advancing towards a more sustainable and technologically advanced future.

5.2.2 Transforming Infrastructure: The Pan Borneo Highway Sarawak Project

The development and upgrading of the proposed Pan Borneo Highway in the state of Sarawak, Malaysia, is a testament to Malaysia's commitment to developing infrastructure on a grand scale. Spanning an impressive 786km, this ambitious project aims to transform transportation connectivity in the region. With an estimated value of RM16 billion and a commencement date in 2015, the project is expected to reach completion by 2024, marking a significant milestone in Malaysia's infrastructure landscape. Spearheaded by the Malaysian government and entrusted to a consortium of contractors, the project encompasses various stakeholders, each contributing their expertise to ensure its success.


Figure 5.22 Pan Borneo Highway Sarawak: The Pujut-Link Flyover

5.2.2.1 Project Details and Technology Adoption

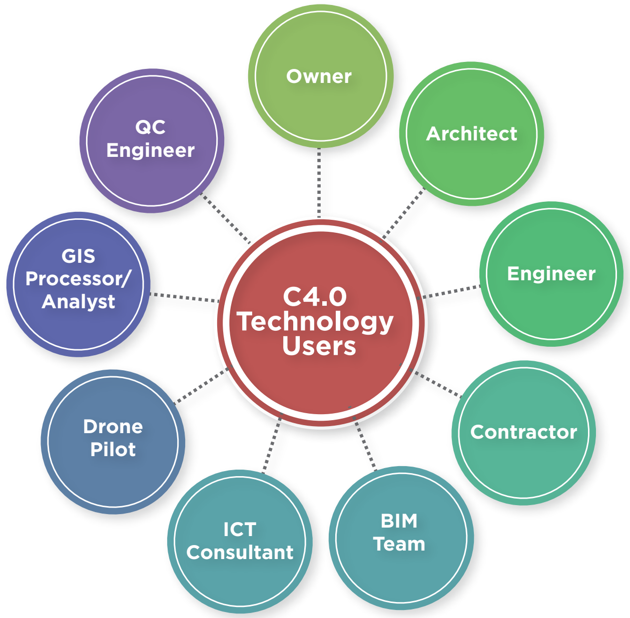


Figure 5.23 C4.0 technology users in Pan Borneo Highway Sarawak

Table 5.9 Project information in Pan Borneo Highway Sarawak

PAN BORNEO HIGHWAY SARAWAK	
Project Category	Infrastructure - Highway
Constructed Distance	786km
Project Value (RM)	RM16 billion
Project Duration	2015-2024
Project Owner	Kerajaan Malaysia
Contractors	Saraworks Sdn Bhd (Formerly known as Samling Resources S/B) Zecon Kimlun Consortium Sdn Bhd NAIM GAMUDA (NAGA) JV SDN BHD Endaya TRC PK JV Sdn Bhd PPESW BPSB JV Sdn Bhd HSL-DMIA JV Sdn Bhd Musyati Mudajaya JV Sdn Bhd KKB-WCT Joint Venture Sdn Bhd Pekerjaan Piasau Konkerit Sdn Bhd Konsortium KPE Sdn Bhd
Civil and Structure (C&S) Consultants:	Perunding Iriz Sdn Bhd KTA (Sarawak) Sdn Bhd Perunding Muhandis Sdn Bhd Jurutera Jasa (Sarawak) Sdn Bhd Sarahill Consulting Sdn Bhd Jurutera Minsar Consult Sdn. Bhd Konsortium Bumi Consultants & Services Sdn Bhd
Mechanical and Electrical (M&E) Consultants:	Perunding KAZ Sdn Bhd SIES Engineers Sdn Bhd Konsortium Bumi Consultants & Services Sdn Bhd
Independent Consulting Engineer (ICE)	OPUS Consultants (M) Sdn Bhd
Quantity Surveyor	PUBM Quantity Surveyors Sdn Bhd
ICT Consultant	Uptrend Technology Sdn Bhd

Table 5.10 Technology used in Pan Borneo Highway Sarawak

CR4.0	Stage	Conceptual Stage, Planning and Design Stage	Construction Stage
Building Information Modelling (BIM)	Type Of Software/ Tools/Machinery Used	Autodesk Revit	
		Autodesk Naviswork	
		Autodesk Civil 3D	
		ProjectWise	
		BIM Collab	
	Benefits of Implementation	The RET can concentrate on the physical progress, whereas the BIM consultant updates the model and discusses it during their monthly coordination meetings.	
CR4.0	**Stage**	**Construction Stage**	
Cloud and Realtime Collaboration	Type Of Software/ Tools/Machinery Used	ProjectWise Common Data Environment	
		Power BI	
		RI Construct	
		Primavera P6	
		Bentley Map Enterprise	
	Benefits of Implementation	The RET can concentrate on the physical progress, whereas the BIM consultant updates the model and discusses it during their monthly coordination meetings.	
		The printing feature is a good transition before the industry can accept paperless approval, etc.	
Photogrammetry & 3D Scanning	Type Of Software/ Tools/Machinery Used	ITwin Bentley	
		DJI Pilot	
		Qbase	
		Agisoft Metashape	
		Google Earth	
	Benefits of Implementation	Achieve completion of the project based on the timeline provided.	
		Reduce time-wasting on unrequired circumstances.	

5.2.2.2 Building Information Modelling (BIM) Implementation:

The adoption of BIM across the Conceptual Stage, Planning and Design Stage, and Construction Stage of the project was driven by its status as the single largest project to be constructed at once, stretching over 786km and involving more than ten consultants and contractors.

(a) Challenges and Solutions for BIM Implementation:

The sheer scale, scope, and stakeholders of the project necessitated the utilisation of BIM to streamline coordination and collaboration. However, challenges emerged during the technology's implementation, including a lack of knowledge among all parties involved, a prevalent preference for hardcopy 2D drawings, and a deficiency in skills to navigate the BIM software. To address these challenges, a consultant was

engaged to develop the BIM model in a separate contract, and monthly coordination meetings were conducted. As a result, the Resident Engineer Team (RET) could focus on physical progress while the BIM consultant continually updated the model, facilitating seamless coordination and enhancing project efficiency.

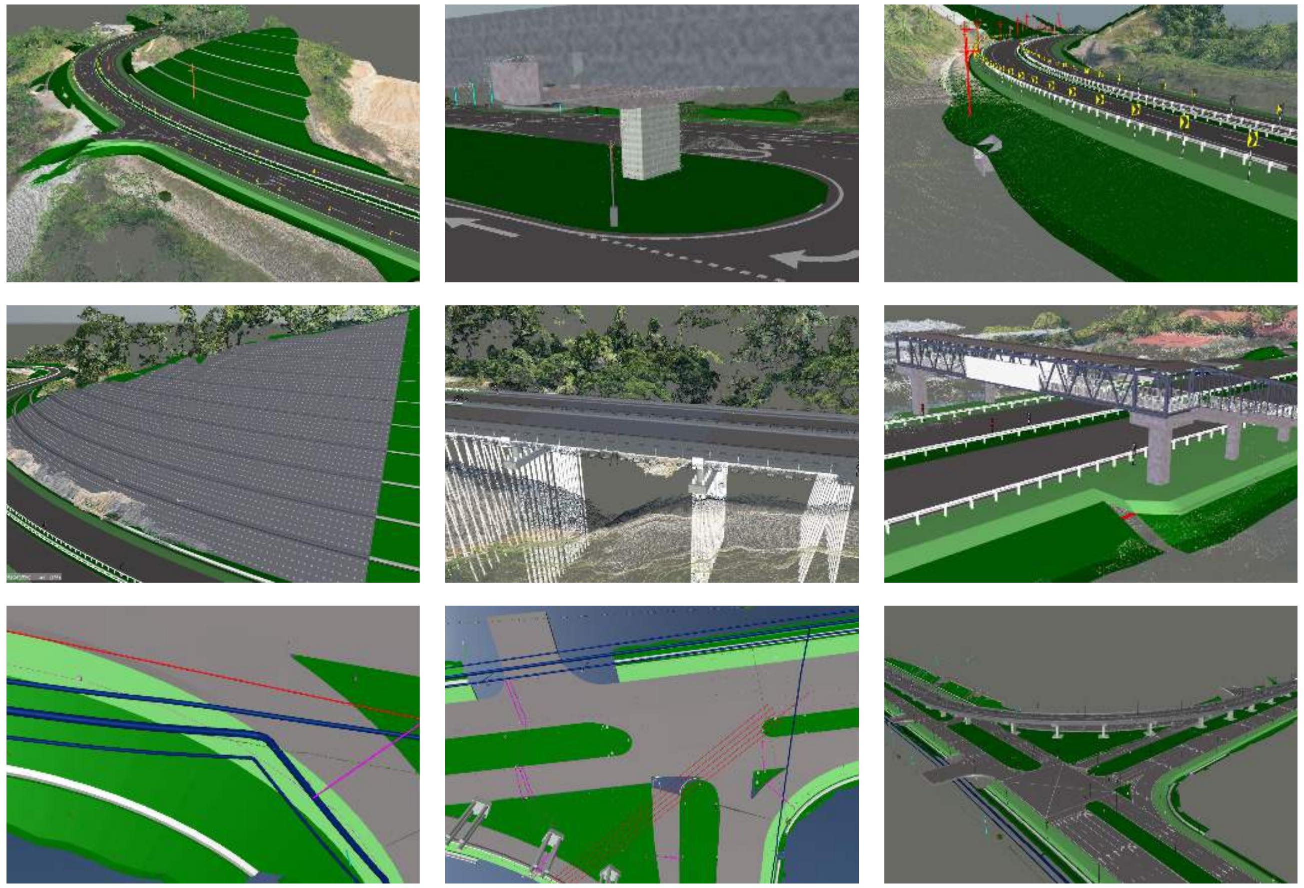


Figure 5.24 Building Information Modelling (BIM) Application used for Conceptual, Planning, Design and Construction Stage

5.2.2.3 Photogrammetry and 3D Scanning

The adoption of Photogrammetry & 3D Scanning during the Construction Stage of the project was driven by various needs, including site monitoring, location pinning, boundary setting, and site mission planning, alongside the requirement for processing and viewing 3D reality images and aerial photos, as well as the implementation of unmanned aerial systems (UAS).

(a) Challenges and Solutions for Photogrammetry & 3D Scanning Implementation:

Some challenges during the technology's implementation include the time-consuming process of processing large tile images, frequent updates with limited functionality upgrades, and the absence of an internet connection on-site. To address these challenges, measures were taken, including early preparation for pre-flight planning, maximising processing workflows and thorough checks of all requirements and planning. As a result, the project was completed as scheduled based on the provided timeline with significantly reduced time wastage due to unnecessary circumstances, enhancing the overall project efficiency and success.

Figure 5.25 3D Scanning & Photogrammetry Application Used for Construction Stage

5.2.2.4 Cloud and Real-time Collaboration:

The adoption of cloud and real-time collaboration during the project's Construction Stage was driven by several factors, including its evident status as the single largest project to be constructed all at once. The project's vast scope, significant cost, and numerous stakeholders made efficient collaboration and data management imperative. Additionally, the requirements for site monitoring and handling large volumes of data, including viewing BIM models, 3D reality images, and aerial photos, further underscored the necessity of adopting cloud-based solutions.

(a) Challenges and Solutions for Cloud and Real-time Collaboration Implementation:

Setbacks and challenges arose during the technology's implementation, such as poor to no internet connection in the rural area of Sarawak, a lack of tech-savvy personnel, and concerns about double handling information. To address these challenges, a web-based system was developed for universal accessibility, offline features were implemented for data entry, and a printing feature was introduced to streamline information handling. As a result, stakeholders gained access to real-time data, facilitating efficient decision-making. At the same time, the printing feature served as a transitional step towards paperless approval processes, ultimately enhancing project efficiency and effectiveness.

5.2.2.5 Conclusion

In conclusion, the development and upgrading of The Pan Borneo Highway Sarawak exemplified Malaysia's dedication to infrastructure excellence. Through the adoption of innovative technologies such as BIM, Cloud and real-time collaboration, and Photogrammetry & 3D Scanning, the project is poised to redefine transportation connectivity in the region, setting a new standard for future infrastructure endeavours.

5.2.3 Revolutionising Infrastructure: The Projek Penswastaan Lebuh Raya Bertingkat Sungai Besi - Ulu Kelang (SUKE)

The Projek Penswastaan Lebuh Raya Bertingkat Sungai Besi - Ulu Kelang (SUKE), is 24.4 kilometres, three-lane, dual-carriageway running from Sri Petaling to Ulu Kelang. With a project value of RM5.27 billion, it has 14 interchanges and reaches out to over 60 residential areas, this expressway promises to alleviate traffic congestion, enhance connectivity, and foster economic growth along its corridor. Initiated on 29th August 2016, the project is fully operational on 20th August 2023. Spearheaded by Lembaga Lebuhraya Malaysia and built by Projek Lintasan Sungai Besi-Ulu Klang Sdn. Bhd., a wholly-owned subsidiary of Projek Lintasan Kota Holdings Sdn. Bhd. (PROLINTAS), the project boasts an illustrious line-up of partners.

Figure 5.26 The Projek Penswastaan Lebuh Raya Bertingkat Sungai Besi - Ulu Kelang (SUKE)

5.2.3.1 Project Details and Technology Adoption

Table 5.11 Project information in Projek Penswastaan Lebuhraya Bertingkat Sungai Besi - Ulu Kelang (SUKE)

PROJEK PENSWASTAAN LEBUHRAYA BERTINGKAT SUNGAI BESI - ULU KELANG (SUKE)	
Project Category	Infrastructure - Expressway
Constructed Distance	24.4 km
Project Value (RM)	RM 5.27 billion
Project Duration	29/8/2016 - 20/8/2023
Owner	Lembaga Lebuhraya Malaysia
Developer	Projek Lintasan Sungai Besi - Ulu Klang
Contractor	Turnpike Synergy Sdn Bhd
Architect	Munirah Architect
Lead Consultants	Sepakat Setia Perunding Sdn Bhd HSS Integrated Sdn Bhd
Quantity Surveyor	ARH Juruukur Bahan Sdn Bhd

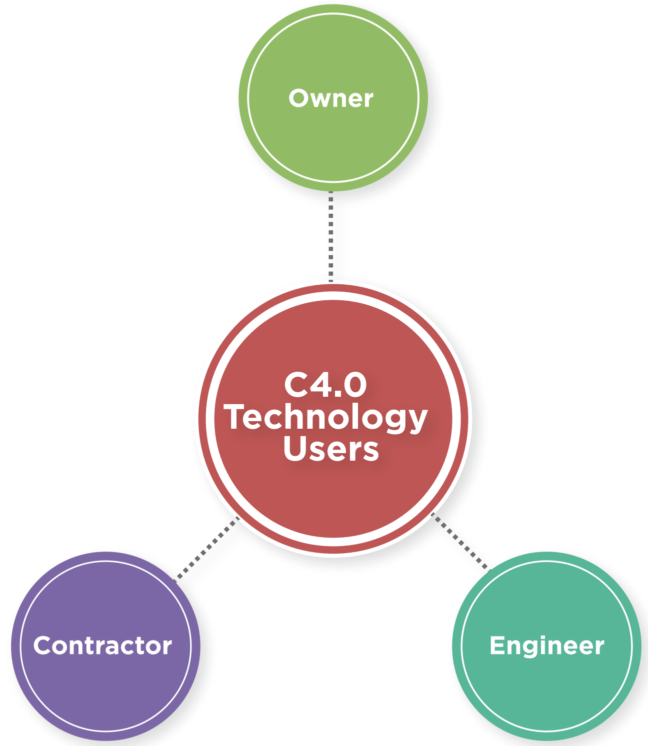


Figure 5.27 C4.0 technology users in Projek Penswastaan Lebuh Raya Bertingkat Sungai Besi - Ulu Kelang (SUKE)

Table 5.12 Technology used in Projek Penswastaan Lebuh Raya Bertingkat Sungai Besi - Ulu Kelang (SUKE)

CR4.0	Stage	Planning and Design Stage	Construction Stage	
Building Information Modelling (BIM)	Type Of Software/ Tools/Machinery Used	MIDAS-CIVIL	Revit	
		Staad-pro		
		SBD		
		Repute		
		AutoCAD for drawings		
	Benefits of Implementation	Clear communication between contractors and design consultants results in parties making quicker, informed decisions.	Efficient collaboration between consultants and contractors leads to time-saving and is cost-effective.	
		Minimising rework, reducing delays, and reducing material wastage, thus saving costs.	Improved quality control before site delivery.	
CR4.0	**Stage**	**Procurement Stage**	**Construction Stage**	**Operation and Maintenance Stage**
Cloud and Realtime Collaboration	Type Of Software/ Tools/Machinery Used	Microsoft OneDrive		
		Oracle Fusion Application		
		Reduce paperwork, enhance accuracy and speed up the process cycle.		
		Enhanced communication by streamlining the work process and improving transparency.		
		Able to access the backup files from anywhere.		
	Benefits of Implementation	Increase efficiency, more systematic processes and improved governance.		
		The printing feature is a good transition before the industry can accept paperless approval, etc.		
Internet of Things (IoT)	Type Of Software/ Tools/Machinery Used		IoT CCTV	
	Benefits of Implementation		Alert on potential risk/ incident.	Automated detection and alert on potential risk/incident.
CR4.0	**Stage**	**Construction Stage**		
Big Data Analytic	Type Of Software/ Tools/Machinery Used	Microsoft Power BI		
	Benefits of Implementation	Provide insights on breakdown trends.		
Artificial Intelligence (AI)	Type Of Software/ Tools/Machinery Used	Vehicle Incident Detection System (VIDS)		
		Smart Surveillance System (S3)		
		Meridian 2000 (Real-time slope monitoring)		
	Benefits of Implementation	Automated alert on incident detection		
		Automated recordings for any incident detection		
		Automated defects and damage detection		
		Improve the efficiency of defects and damage detections.		
		Real-time data for slope movement monitoring		
		Notification of any slope movement		

BEST PRACTICES

5.2.3.2 Building Information Modelling (BIM)

Incorporating BIM into the planning, design, and construction stages was essential for technical requirements. It yielded numerous benefits, such as reduced construction periods, minimised on-site disruptions, enhanced quality control, and was cost-effective.

(a) Planning and Design Stage:

BIM was adopted to speed up construction works and reduce interruptions to existing traffic by enhancing site traffic management. However, challenges arose in coordinating between the prefab yard and the site team. Additional monitoring was implemented during the construction stage to address this. As a result of BIM adoption, the project experienced numerous benefits, including a reduced construction period, minimised work at the site, decreased rework and waste on-site, improved quality control, and reduced traffic management and interruptions to existing traffic.

(b) Construction Stage:

BIM was adopted primarily due to time constraints. However, challenges emerged regarding site and logistic constraints and technical requirements. To address these challenges, designated areas and logistics were provided to facilitate BIM implementation. As a result of BIM adoption, significant benefits were realised, including time-saving measures, cost-effectiveness, and improved quality control before the site delivery.

5.2.3.3 Big Data Analytics (BDA)

During the Operation and Maintenance Stage, BDA was adopted, utilising Microsoft Power BI as the primary tool. This adoption aimed to enable the Owner and Engineer to analyse and visualise breakdown patterns effectively. Challenges arose during the implementation, particularly in fostering a Data-Driven Culture using Power BI. To address this, emphasis was placed on the importance of collecting data records. As a result of adopting BDA, valuable insights into breakdown trends were provided, enhancing operation and maintenance activities' overall efficiency and effectiveness. This analytics integration facilitated better decision-making and contributed to proactive maintenance strategies, optimising the project's performance.

5.2.3.4 Internet of Things (IoT)

IoT CCTV systems were implemented during the construction, operation, and maintenance stages. The implementation of IoT CCTV during the Construction Stage addressed CCTV blind spots at hot spot areas, particularly flood-prone and heavily constructed areas. Similarly, during the Operation and Maintenance Stage, the adoption was driven by the need to mitigate CCTV blind spots, specifically areas related to cable theft. Challenges that were encountered during IoT implementation included the unavailability of power sources; hence, solar or temporary gen-sets were utilised as alternative power sources to overcome this.

5.2.3.5 Cloud and Real-time Collaboration

Cloud and real-time collaboration through Microsoft OneDrive and Oracle Fusion Applications were implemented across the project's Procurement Stage, Construction Stage, and Operation and Maintenance Stage to streamline workflows and manage project documents effectively, including reports, correspondences, and memos. During the Procurement and Construction stages, the adoption aimed to enhance project efficiency by consolidating project-related documents in a centralised platform. In the Operation and Maintenance Stage, the transition from using CD-ROMs for backup storage to cloud-based collaboration tools addressed the challenges of physical access to backup files and the cumbersome process of CD-ROM backup.

5.2.3.6 Artificial Intelligence (AI)

AI has been adopted through various software and tools, including the Vehicle Incident Detection System (VIDS), Smart Surveillance System (S3), and Meridian 2000 for real-time slope monitoring. VIDS detects site incidents and promptly notify the Traffic Management Centre (TMC), enhancing incident response efficiency. The Smart Surveillance System aids highway surveillance by identifying road defects and asset damages while compiling the findings into a comprehensive cloud-based system for effective management. Additionally, Meridian 2000 facilitates real-time slope monitoring to detect any slope movement promptly.

Despite the benefits of AI adoption, challenges did arise during implementation. These include the need to train AI engines to improve the accuracy of incident and defect detection and the requirement for personnel training to handle the data effectively. Solutions have been implemented to address these challenges. Software reconfiguration has been conducted to enhance detection accuracy, while AI training involves checking for false positive detections. Moreover, designated personnel have undergone training to ensure proficient handling of AI-generated data.

Figure 5.28 The SUKE Elevated Expressway: Aerial View of Hillview Interchange, Ulu Kelang

5.2.3.7 Conclusion

As the Projek Penswastaan Lebuh Raya Bertingkat Sungai Besi - Ulu Kelang (SUKE) nears completion, it is a symbolic beacon of progress and innovation in the landscape of Malaysia's infrastructure. By integrating advanced technologies and seamless collaboration among the stakeholders, SUKE promises to transform urban mobility, enhance safety measures, and drive economic growth. As Malaysia continues its journey towards sustainable urban development, the SUKE project is a testament to its vision for a modern, interconnected, and resilient future.

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List of abbreviation

2D	2 Dimensional
3D	3 Dimensional
5G	Fifth Generation
AEC	Architecture, Engineering & Construction
AGV	Automated Guided Vehicle
AI	Artificial Intelligent
ALON	Aluminium Oxynitride
AM	Additive Manufacturing
API	Application Programming Interface
AR	Augmented Reality
BDA	Big Data Analytics
BIM	Building Information Modelling
BIRAC	BIM In Rail Academy
BMS	Building Management System
C&S	Civil and Structure
C4.0	Construction 4.0
CAD	Computer-Aided Design
CCTV	Closed-circuit Television
CDE	Common Data Environment
CD-ROM	Compact Disk – Read-Only Memory
CFRC	Carbon Fibre Reinforced Concrete
CIDB	Construction Industry Development Board
CIM	Civil/City/Construction Information Modelling
CIS	Construction Industry Standard
CLT	Cross-laminated timber
CNC	Computer numerical control
CREAM	Construction Research Institute of Malaysia
EPS	Expanded Polystyrene/ Polyurethane
ESG	Environmental, Social, and Governance
FM	Facility Management
FRC	Fibre-Reinforced Concrete
GFA	Gross Floor Area
GIS	Geographic Information Systems
GNSS	Global Navigation Satellite Systems
GPS	Global Positioning System
GPT	Generative Pre-trained Transformer
HMD	Head-mounted Display
IBS	Industrial Building System

Industry4WRD	National 4.0 Industry Policy
IoT	Internet of Thing
IR4.0	Fourth industrial revolution
ISO	International Standard Organisation
JKR	Jabatan Kerja Raya
KPI	Key Performance Index
KPM	Kementerian Pendidikan Malaysia
LCD	Liquid-Crystal Display
LiDAR	Light Detection and Ranging
LIM	Landscape Information Modelling
LOD	Level of Development
LOd	Level of Detail
LOG	Level of Geometry
LOI	Level of Information
LOIN	Level of Information Need
MEP	Mechanical, Electrical, and Plumbing
ML	Machine Learning
MR	Mixed Reality
PMCS	Project Management and Control System
PPE	Personal Protective Equipment
PVC	Polyvinyl Chloride
PVM	Prefabricated Volumetric Modules
RET	Resident Engineer Team
RM	Ringgit Malaysia
RTK	Real-time Kinematic
S3	Smart Surveillance System
SDGs	Sustainable Development Goals
SIM	Structure Information Modelling
SIP	Structural Insulated Panel
sqft	Square foot
TLS	Table Lifting System
TMC	Traffic Management Centre
TNB	Tenaga Nasional Berhad
ToF	Time-of-Flight
UAS	Unmanned Aerial Systems
UK	United Kingdom
VDC	Virtual Design and Construction
VIDS	Vehicle Incident Detection System
VIP	Vacuum Insulation Panel
VR	Virtual Reality

List of Figures

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