

kajian literatur yang komprehensif dan analisis bibliometrik, kajian ini menyetengahkan faedah, ciri-ciri, dan status pelaksanaan semasa teknologi-teknologi ini. Dapatan menunjukkan bahawa walaupun inovasi ini menawarkan kelebihan ketara berbanding kaedah konvensional—seperti peningkatan kecekapan, keselamatan, dan membuat keputusan—tahap pengintegrasian di Malaysia masih di peringkat awal. Kajian ini menekankan keperluan terhadap kesedaran yang lebih tinggi, sokongan dasar, dan perancangan strategik untuk memajukan sektor pembinaan ke arah industri digital yang lebih bersedia untuk masa hadapan.

Kata kunci: Evolusi teknologi pembinaan, revolusi industri dalam pembinaan, transformasi digital, pembinaan pintar, analisis bibliometrik

© 2026 Penerbit UTM Press. All rights reserved

1.0 INTRODUCTION

The construction industry serves as a major economic driver in both developed and developing nations. It generates employment opportunities and enhances operational efficiency by addressing various social, energy, and environmental challenges on a global scale. In Malaysia, construction waste is estimated to account for 30% to 35% of total project output, with projected daily waste reaching 368.31 tonnes by 2023, resulting in substantial financial losses [1]. While digitalization has made notable progress in the construction sector by improving productivity and introducing incremental technological advancements, the adoption of modern technologies has yet to fully meet expectations. Delays in the implementation of automated systems and emerging technologies hinder the industry from fully leveraging the benefits of digitization [2].

Digitalization refers to the transformation of analogue data into formats that are accessible and usable by computer systems. This process enhances the creation, storage, processing, and dissemination of information through digital tools such as computers, software, and the internet. Whereas digitization primarily involves data capture and processing, digitalization focuses on improving systems by optimizing workflows. In contrast, digital transformation involves the integration of computer-based technologies into an organization's core operations. This integration enables businesses to boost productivity and operational efficiency by automating processes, streamlining workflows, and expanding market reach [2].

According to the Construction Industry Development Board (CIDB) Malaysia, several technologies currently used in developed countries, including Malaysia, are becoming increasingly prominent in the construction sector. These include pre-fabrication and Modular Construction, Autonomous Construction, Augmented Reality (AR), and Virtualization. In addition, technologies such as Cloud and Real-Time Collaboration, 3D Scanning, Photogrammetry, Big Data, and Predictive Analytics are also being adopted. Furthermore, the industry is witnessing the integration of the Internet of Things

(IoT), Blockchain, Artificial Intelligence (AI), Building Information Modelling (BIM), 3D Printing, and Additive Manufacturing.

Although the Malaysian construction industry has begun adopting emerging technologies, their integration remains limited and inconsistent. Previous studies often highlight the potential benefits of these technologies but lack a consolidated overview of their implementation status, the specific barriers to adoption, and how these technologies align with Malaysia's transition into Industry 4.0. Moreover, the issue of digital technology adoption is not confined to small-scale construction projects; even large-scale and mega projects continue to face similar challenges across various phases of implementation.

Therefore, this study aims to identify the thematic gaps in the adoption of emerging technologies within Malaysia's construction industry through a comprehensive literature review and bibliometric analysis.

2.0 EVOLUTION OF TECHNOLOGY IN THE CONSTRUCTION INDUSTRY

2.1 Traditional Methods and Materials (Pre-20th Century)

The origins of construction are traditionally believed to date back to a period prior to the 20th century. During this era, traditional structures were designed to serve multiple purposes for village residents and local communities, not only addressing daily living needs but also providing essential shelter during times of crisis. These buildings were constructed using entirely natural materials, directly sourced from the earth and the surrounding environment. Commonly used resources included soil, stone, wood, clay, and other zero-energy or sustainable materials that were readily available. These materials were locally sourced, cost-effective, environmentally friendly, recyclable, hygroscopic, and bioclimatic, enabling structures to integrate harmoniously with the natural landscape [3]. Table 1 presents three categories of traditional materials and associated construction

techniques that were commonly employed prior to the 20th century.

As shown in Table 1, traditional construction methods can be grouped into three main categories: soil-based, stone-based, and timber-based techniques. Soil-based materials such as raw earth, rammed earth, and adobe were widely used due to their abundance and natural thermal insulation properties. Stone-based construction provided superior structural strength and was often utilized for building elements such as walls, arches, and vaults. Timber, on the other hand, offered design flexibility, ease of use, and aesthetic value, with regional variations in wood types and craftsmanship. These materials not only reflected local availability and sustainability but also demonstrated early forms of environmentally conscious design. The continued use of some of these traditional techniques in modern sustainable construction underscores their long-standing effectiveness and relevance.

The evolution and adoption of these traditional construction methods, however, did not occur uniformly across regions. Differences in geography, climate, cultural preferences, and technological access all played a role in shaping local building practices. For instance, a study by Scuro *et al.* [4] found that during the 15th century, the Mediterranean region experienced distinct architectural progress. Architects in this area began to favour brick over stone, recognizing its greater durability, resistance to environmental wear, and improved structural capabilities. This shift marked an important transition point in construction history, setting the stage for further technological advancement in subsequent centuries.

Table 1 Traditional building materials and techniques [3]

Buildings based in soil	Buildings based in stone	Timber building
<ul style="list-style-type: none"> Raw earth The rammed earth Compressed earth blocks Traditional plaster 	<ul style="list-style-type: none"> Earth masonry walls Stones for masonry Kind of stone masonry walls Arches, vaults, and cupolas 	<ul style="list-style-type: none"> Wood characteristics Wood durability Kind of traditional wooden buildings Wood in traditional Moroccan buildings
<ul style="list-style-type: none"> Cob building The torchis 	<ul style="list-style-type: none"> Traditional mortar Mechanical properties of stone masonry units 	
<ul style="list-style-type: none"> The adobe 		

2.2 Industrial Revolution (Late 18th – 19th Century)

The Industrial Revolution, which began in the 1700s, played a pivotal role in transforming the construction and manufacturing sectors, laying the foundation for

the technological advancements we benefit from today [5]. This era of industrialization unfolded in distinct phases, each characterized by specific innovations aimed not only at boosting productivity but also at promoting sustainability by reducing reliance on raw materials and enhancing waste regeneration systems [6].

The revolution progressed through multiple stages, each contributing to the strengthening of national industrial capabilities. In the early 1800s, water power was a critical resource for driving production processes [7]. However, reliance on water power began to decline with the advent of steam technology. Figure 1 illustrates the findings from the 1880 Water Power Census, which depicts the decreasing use of water power across U.S. counties [8].

The transition truly began with the First Industrial Revolution (IR 1.0) in the late 18th century, marked by the introduction of mechanical loom technology powered by water and steam [9]. In 1784, the first mechanical weaving loom was constructed, enabling greater mechanization in the textile industry. Steam engines soon replaced manual labour in powering machinery, providing mobility for transporting goods and people and advancing manufacturing processes. Unlike water power, which was geographically limited to natural sources, steam power offered flexibility in site selection and industrial scalability. According to Guilfoos [8], steam energy not only enhanced engineering potential but also proved to be more cost-effective, contributing to broader economic growth.

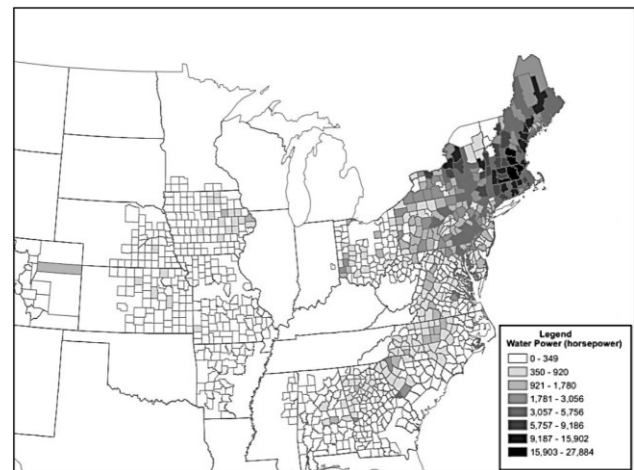


Figure 1 Water Power Census Data by County in 1880 [8]

The momentum continued with the Second Industrial Revolution (IR 2.0) in the 1870s, which introduced electricity as a driving force behind mass production. This phase saw the emergence of transformative technologies such as the assembly line, telecommunications, and the automobile industry, all of which played vital roles in the rise of globalization [5], [9]. As noted by Sharma and Singh

[10], Henry Ford's inspiration for assembly line manufacturing came from observing animal carcasses being transported on conveyor belts in Chicago slaughterhouses—an approach that significantly improved efficiency and reduced production costs. These early industrial revolutions have been extensively studied and continue to influence modern manufacturing and construction methods, with several principles still applicable today [11].

2.3 Modern Construction Techniques and Advanced Materials (20th Century)

According to Kumar Mohajan [12], the Third Industrial Revolution (IR 3.0) began in the 1950s and was primarily driven by technological advancements that transformed manufacturing, distribution, and energy systems. A pivotal moment came in 1969 with the creation of the Advanced Research Projects Agency Network (ARPANET), an early packet-switching network that laid the foundation for modern internet communication through the introduction of the TCP/IP protocol suite [13]. At the same time, the development of the Programmable Logic Controller (PLC) marked a significant milestone in industrial automation [10].

By the 1970s, IR 3.0 had begun to reshape the global economy by integrating computers, lean production, the internet, and biotechnology into factory operations and telecommunications. This integration led to enhanced manufacturing efficiency, real-time data exchange, global connectivity, and significant advancements in fields such as healthcare, agriculture, and sustainability [14]. Didier [11] categorizes IR 3.0 into two major technological waves: first, the introduction of computers in the workplace; and second, the widespread adoption of internet-based tools and digitalization, underscoring the increasing role of information and communication technology (ICT) as a critical production factor.

The widespread adoption of digital design and manufacturing tools further revolutionized industry practices. These tools enabled greater collaboration by allowing professionals to share and edit designs across geographical boundaries. The rise of direct digital manufacturing also allowed organizations to utilize shared production resources on a much broader scale than previously feasible [15]. This shift not only expanded production capabilities but also cultivated a more interconnected and resource-efficient ecosystem.

In addition, the Third Industrial Revolution encouraged the implementation of new management techniques such as Six Sigma and Just-in-Time (JIT) production systems. These strategies emphasized process optimization, quality control, and operational efficiency, aligning industrial practices with evolving market demands [11]. As a result, IR 3.0 set the stage for a transition toward

increasingly automated, digitized, and intelligent construction and manufacturing environments.

2.4 Digital Revolution (Early 21st Century)

Since the First Industrial Revolution (IR 1.0), the construction and manufacturing industries have undergone a profound transformation—evolving from steam-powered systems to automated electrical manufacturing and, eventually, to digitally driven production. This ongoing shift has increased the complexity of manufacturing processes while simultaneously enhancing their efficiency and sustainability. Human labour is progressively being supplemented or replaced by machines, which offer greater reliability and productivity [6]. In fact, technological advancements in modern manufacturing, particularly in European countries, have contributed to a 17% increase in GDP and generated more than 32 million new jobs within the European Union [6].

The transition from analogue to digital systems marked the beginning of the Digital Revolution, which laid the groundwork for a more advanced era: the Fourth Industrial Revolution (IR 4.0). IR 4.0 builds upon the digital foundation, further enhancing the integration between people, processes, and smart technologies. This revolution promotes more sustainable and energy-efficient industrial practices across the globe [5]. Figure 2 illustrates the core components of IR 4.0, which include the digitization and integration of vertical and horizontal value chains, the digitization of product and service offerings, and the creation of innovative digital business models [6]. According to Alaloul *et al.* [5], IR 4.0 aims to improve industrial systems by addressing the growing complexity of production through social, economic, and environmental considerations.

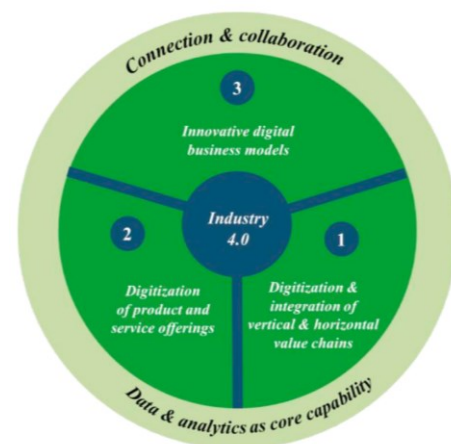


Figure 2 Components of Industry Revolution 4.0 [6]

At its core, IR 4.0 involves the digitization of industrial processes to form highly connected and intelligent production networks [5]. In the

construction sector, this revolution is expected to accelerate over the next three to ten years, catalyzing the adoption of innovations such as Building Information Modelling (BIM), Machine Learning, 3D printing, and robotics [16]. Further integration of Information and Communication Technology (ICT) is also anticipated, encompassing technologies like the Internet of Things (IoT), cloud computing, cyber-physical systems, and cognitive computing [5]. However, despite the potential benefits, the construction industry still faces significant barriers in effectively implementing IR 4.0 technologies. These challenges span political, economic, social, technological, environmental, legal, and security dimensions.

Table 2 Challenges of Industrial Revolution 4.0 (IR4.0) [5]

Factor	Details	Explanation
Political	Governance	Many construction support companies are SMEs with limited capacity to invest in technologies with unclear benefits. They depend on government support and collaboration.
Economical	Financial transparency	High implementation costs, uncertain returns, and added expenses for training and maintenance hinder adoption.
Social	Cultural habits	Technology adoption affects the entire construction process and involves multiple stakeholders.
Technological	Technical challenges	Existing standards must be updated, and highly skilled labour is required to operate new systems.
Environmental	Organizational processes	Organizational changes may disrupt workflows and require redesigns for smoother adaptation.
Legal	Uncertain regulatory	Vague stakeholder responsibilities and regulatory gaps complicate implementation.
Security	Threat risk	Data exchange introduces cybersecurity risks and privacy concerns.

Table 2 presents the key challenges that hinder the successful adoption of Industry 4.0 technologies in the construction industry. Politically, many construction-related companies are small and medium-sized enterprises (SMEs) that lack sufficient capital to invest in new technologies, especially when the benefits are not immediately clear. They often depend on government funding and partnerships to move forward. From an economic perspective, the high initial costs of implementation,

combined with ongoing expenses for training, maintenance, and system upgrades—pose significant financial barriers. Socially, the industry faces resistance due to entrenched cultural habits and reluctance to change among stakeholders, which complicates the transition process. Technologically, many existing construction standards are outdated and not suited for integration with modern systems, while the shortage of skilled workers further limits effective adoption. Environmentally, the shift to digital processes often disrupts existing workflows, requiring organizations to undergo structural and procedural adjustments. Legally, the absence of well-defined regulations and stakeholder responsibilities increases uncertainty and risk. Lastly, from a security standpoint, the use of interconnected systems and real-time data exchange raises concerns over cybersecurity threats and data privacy. Addressing these challenges holistically is essential for maximizing the benefits of Industry 4.0 in construction.

Table 3 Opportunities of Industrial Revolution 4.0 (IR4.0) [5]

Factor	Details	Explanation
Political	Global competitiveness	Adoption of advanced technologies allows local firms to compete globally by improving project quality and outcomes.
Economical	Product demand and supply	Digital tools expedite construction and reduce labour and material costs.
Social	Image enhancement	A digital environment fosters innovation and enhances collaboration and client satisfaction.
Technological	Reliable productivity	Improved systems reduce errors, increase quality assurance, and support better decision-making.
Environmental	Promotes sustainability	Technology helps minimize energy consumption and waste, supporting green practices.
Legal	Established framework	Widespread adoption will lead to more defined regulations and reduce legal uncertainty.
Security	Safety enhancement	IR 4.0 improves safety through smarter training and project execution alternatives.

To counterbalance these challenges, IR 4.0 also presents considerable opportunities across similar domains. Table 3 outlines the key opportunities that Industry 4.0 brings to the construction industry. Politically, the adoption of advanced technologies can enhance global competitiveness by improving the quality and outcomes of construction projects. Economically, innovations such as automation and data-driven systems can speed up project delivery

while reducing labour and material costs. From a social perspective, digitalization fosters a more modern and collaborative work environment, improving communication and client relationships. Technologically, Industry 4.0 tools enhance productivity, reduce errors, and support better decision-making. Environmentally, smart technologies help lower energy usage and minimize waste, contributing to more sustainable practices. Legally, as adoption becomes more widespread, clearer regulations and frameworks are expected to emerge, reducing uncertainty. In terms of security, digital systems can improve safety through better risk management, alternative execution methods, and enhanced worker training. Together, these opportunities highlight the transformative potential of Industry 4.0 for a more efficient and forward-looking construction sector.

According to Figure 3, the Industrial Revolution has progressed through four distinct phases, each contributing significantly to the advancement of industry from IR 1.0 to IR 4.0 [9]. The first and second industrial revolutions, characterized using steam power and electricity for mechanization and mass production have been widely studied and continue to influence current practices. In contrast, the third and fourth revolutions, which introduced automation, computing, and digital technologies, are still evolving and remain active subjects of research as scholars work to define and refine emerging technologies [11].

Figure 3 visually depicts this progression, highlighting how each stage marks a technological leap: from steam-powered mechanization (IR 1.0) to electrical-driven mass production (IR 2.0), to computer-based automation (IR 3.0), and finally to digitally integrated and intelligent systems (IR 4.0). The diagram underscores the increasing sophistication, efficiency, and interconnectivity of modern industries, particularly in the construction sector, as digital tools and smart technologies become more prevalent.

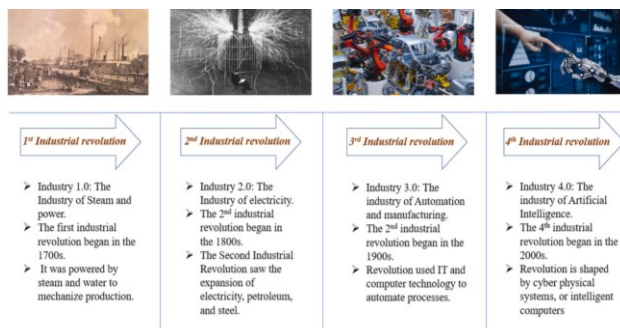


Figure 3 The stages of Industrial Revolution [9]

The Digital Revolution marks a turning point where industries moved from analogue systems to digital technologies. This transition has made manufacturing and construction more efficient, sustainable, and less reliant on manual labour. Industry 4.0 (IR 4.0) builds upon this shift by integrating advanced tools like BIM, IoT, machine learning, robotics, and cloud computing

into construction processes. These technologies promote smarter operations and better resource management. However, their adoption faces challenges in areas like cost, skills, regulations, and cybersecurity. Despite these obstacles, IR 4.0 also presents many opportunities, including improved productivity, global competitiveness, sustainability, and safety. The construction sector must strategically address these challenges to fully benefit from the potential of IR 4.0.

2.5 Future Trends

Technology in the construction sector is evolving rapidly as the world moves into a new era known as the Fifth Industrial Revolution (IR 5.0). Although many Malaysian companies have begun adopting technologies introduced under Industry 4.0, their application remains limited and often suboptimal. Several barriers continue to hinder full integration, including a persistent scepticism among stakeholders, who are often reluctant to embrace new technologies due to a deep-rooted resistance to change. Compounding this issue is a shortage of skilled professionals and labour, which further slows the adoption of innovation and digital transformation within the national construction industry [17].

Recognizing the need for modernization, CIDB Malaysia launched the Construction Industry Transformation Plan (CITP) in 2016, as part of the 11th Malaysia Plan (RM11). This five-year strategic framework aimed to transform the industry into a world-class sector by emphasizing four key objectives: enhancing quality, safety, and professionalism; promoting environmental sustainability; increasing productivity; and boosting internationalization as illustrated in Figure 4 [18]. This initiative collectively drive a long-term industry transformation and economic resilience. By 2020, the plan sought to develop a more efficient and competitive construction industry that could meet global standards while ensuring long-term innovation and growth.



Figure 4 Construction Industry Transformation Plan (CITP) 2016-2020 [18]

The CITP agenda continues under the 12th Malaysia Plan (2021–2025), reaffirming the government's commitment to achieving these goals. Looking ahead, Industry 5.0 is expected to focus on collaboration between human intelligence and cognitive computing, marking a shift from automation-driven processes to human-centre technology integration [10]. According to Ngcobo et al. [19], the future of building maintenance and operations will be defined by the seamless blending of advanced technology with human expertise. This synergy aims to create smart, adaptive, and sustainable environments that are more efficient, user-friendly, and environmentally responsible, supporting Malaysia's long-term vision of becoming a high-tech, developed nation.

The development of construction technology has progressed through five major phases, each bringing significant changes to how buildings are designed, constructed, and maintained. In the pre-20th century, traditional construction used natural materials like soil, stone, and timber. These methods were sustainable, locally sourced, and well-suited to environmental conditions, reflecting early eco-friendly practices. The First and Second Industrial Revolutions (IR 1.0 and IR 2.0) introduced steam and electrical power, enabling mass production, mechanized tools, and improved transportation. These advances greatly increased construction efficiency and scale. The Third Industrial Revolution (IR 3.0) brought digital tools, computers, and automation, leading to better planning, quality control, and global collaboration.

In the Fourth Industrial Revolution (IR 4.0), smart technologies such as BIM, IoT, robotics, and AI began reshaping the industry. These tools enhance productivity and sustainability but face challenges like cost, regulations, and workforce readiness. Still, they offer major opportunities for innovation and competitiveness. Looking ahead, Industry 5.0 focuses on combining human intelligence with advanced technology to create smarter, more adaptive, and sustainable environments. In Malaysia, the Construction Industry Transformation Plan (CITP) supports this transition by emphasizing quality, sustainability, productivity, and global reach. Together, these phases show how construction has evolved from manual, material-based methods to intelligent, technology-driven systems that continue to shape the industry's future.

3.0 EMERGING TECHNOLOGIES DRIVING MALAYSIA'S INDUSTRIAL REVOLUTION 4.0

3.1 Building Information Modelling (BIM)

Based Building Information Modelling (BIM) is both a method and a technology that supports collaborative project management within the architecture, engineering, and construction (AEC)

sectors. BIM utilizes various software tools to enhance the way infrastructure is planned, visualized, designed, built, and maintained. It integrates data-rich 3D models that support decision-making throughout a project's lifecycle—offering improved accuracy, coordination, and efficiency.

The concept of BIM was first introduced by Professor Charles M. Eastman in 1970. The United States was the first country to implement BIM, and since then, several countries, including the United Kingdom, Australia, Hong Kong, Denmark, Norway, Finland, and Singapore—have adopted it widely in their construction industries [20], [21]. In Malaysia, the Public Works Department (PWD) initiated interest in BIM in 2007, recognizing its potential to reduce construction costs and prevent design conflicts at the early planning stages. BIM has been promoted as a tool to enhance collaboration among stakeholders, such as contractors, architects, engineers, and project managers, by creating a shared digital model of the project. The Multipurpose Hall at Universiti Tun Hussein Onn Malaysia (UTHM) was the first project in the country to formally recommend BIM usage. Other early BIM projects in Malaysia include the Ancasa Hotel in Pekan, Pahang, the Educity Sports Complex in Nusajaya, Johor, and the National Cancer Institute of Malaysia [20].

Table 4 The benefits of Building Information Modelling (BIM) in the construction industry

No.	Benefits of BIM	References
1.	BIM supports asset design, scheduling, and budgeting.	[20], [21], [22]
2.	BIM improves design conceptualization, visualizations, and material selection.	[20], [21], [22]
3.	4D BIM helps assess project impacts on traffic, storage, and scheduling.	[20]
4.	BIM enhances the quality of design and documentation.	[20]
5.	Clash detection can reduce contract value by up to 10%.	[20], [22]
6.	BIM improves stakeholder communication and project understanding.	[22], [23]
7.	BIM increases cost estimation accuracy by approximately 3%.	[20], [22]
8.	Enables real-time monitoring of construction progress.	[22]
9.	BIM helps reduce construction waste.	[21], [22], [23]
10.	BIM minimizes conflict errors and drawing coordination issues.	[20], [21]
11.	Enhances both project management and construction efficiency.	[23]

Table 4 highlights the key benefits of Building Information Modelling (BIM) in Malaysia's construction industry. BIM enhances project planning, design visualization, scheduling, and cost estimation, contributing to more accurate and efficient decision-making. It supports better collaboration among stakeholders and helps detect design clashes early,

potentially reducing contract costs by up to 10%. BIM also improves documentation quality, enables real-time progress tracking, and helps minimize construction waste and coordination errors. Overall, BIM significantly boosts project management effectiveness and construction efficiency.

3.2 Internet of Things (IoT)

The Internet of Things (IoT) refers to an extended internet-based system that enables real-time interaction among machines, humans, and objects using various advanced technologies. Introduced in academic literature as early as 2002 by Schoenberger, who proposed the use of wireless chips in retail as digital “eyes”, IoT has since evolved into a transformative tool. Nearly two decades later, its value is increasingly recognized by policymakers, business leaders, and researchers as a means of enhancing daily life, infrastructure, and industry [24].

IoT operates through an array of sensors such as RFID, image sensors, motion detectors, GPS, proximity sensors, and biosensors. These devices detect physical conditions or changes and convert them into digital signals understandable by computers or humans. When connected to the internet, these signals enable real-time communication between physical assets and their digital counterparts (digital twins), improving control and operational transparency [2]. The global IoT market was valued at \$1.90 billion in 2018 and is expected to grow to \$11.03 billion by 2026, highlighting its increasing relevance across industries [24].

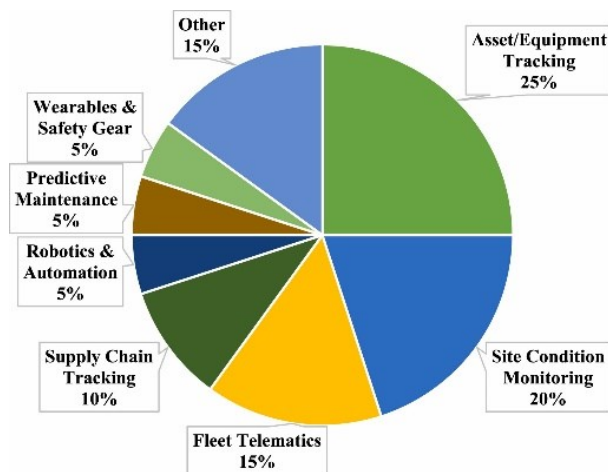


Figure 5 IoT applications in construction [2]

In the construction industry, IoT has numerous applications. Figure 5 illustrates the various applications of Internet of Things (IoT) technology in the construction industry, highlighting areas where IoT integration is most impactful. The largest portion is dedicated to asset and equipment tracking (25%), reflecting the importance of monitoring the location and usage of machinery to improve efficiency and

reduce loss or theft. This is followed by site condition monitoring (20%), which helps ensure safety and environmental compliance through real-time data on temperature, humidity, and dust levels. Fleet telematics (15%) is used to optimize vehicle usage and fuel efficiency. Supply chain tracking (10%) enhances material management, ensuring timely delivery and reducing delays. Applications such as predictive maintenance (8%), robotics and automation (8%), and wearables and safety gear (5%) support worker safety and equipment reliability. The remaining 15% is categorized as “other,” covering emerging or less common uses. This distribution underscores the diverse and growing role of IoT in improving productivity, safety, and operational transparency in construction.

A review conducted by Katiyar & Kumar [25] summarizes how various researchers have applied IoT technologies in construction. Table 5 presents a concise overview of the types of IoT tools used and their respective application fields, ranging from structural health monitoring and automation to worker safety, prefabrication, and smart project management.

Table 5 Summary of application of IoT technology in construction industry [25]

Application Field	Technology Used
Construction Project Management	5G Construction
Structural Health Monitoring	Wireless Sensor Network (WSN)
Prefabricated Construction	RFID and NFC tags
Worker safety in Construction	RFID
Construction Automation	RFID, Barcodes, WSN, GPS
Site Management	Wireless Sensor Network (WSN)
Construction material supply chain	RFID, GPS
Smart Construction	GPS, SONAR
Facility Management	Wireless Sensor Network (WSN)
Prefabricated Construction	RFID, BIM
Structural Health Monitoring	Sensor Network
Health and Safety	Wireless Sensor Network (WSN)
Worker safety in Construction	RFID

3.3 Artificial Intelligence (AI)

The term Artificial Intelligence (AI) was first introduced in 1979 by computer scientist John McCarthy, who defined it as “the science and engineering of making intelligent machines.” AI involves developing systems that mimic human thinking and decision-making processes, including reasoning, learning, communication, mobility, and problem-solving [26], [27]. Waqar et al. [28] describe AI as the capability of computers to perform tasks traditionally requiring human intelligence. AI is typically categorized into three types: Artificial Narrow Intelligence (ANI), Artificial General Intelligence (AGI), and Artificial Super Intelligence (ASI) [29].

In the construction industry, AI has gained considerable attention in recent years, particularly for enhancing health and safety management. Construction sites are known for high accident rates, and AI-powered safety systems offer significant potential to reduce injuries and fatalities through real-time risk detection, predictive analytics, and automated monitoring [28].

AI comprises several subfields such as machine learning, computer vision, automated planning and scheduling, robotics, knowledge-based systems, natural language processing (NLP), and optimization. Each of these subfields supports different construction applications, from project planning and cost estimation to site monitoring, supply chain management, and risk mitigation. Table 6 summarizes the application areas of these AI subfields across construction tasks.

Table 6 Application of AI based on subfields in construction industry [29]

AI Subfields	A1	A2	A3	A4	A5	A6	A7
Health and Safety	✓	✓			✓	✓	
Scheduling	✓		✓		✓		✓
Cost Estimation	✓				✓		✓
Legal (Contracts & Conflict Management)	✓	✓			✓	✓	✓
Supply chain & Logistics	✓				✓		✓
Site Monitoring & Performance Evaluation	✓	✓		✓	✓	✓	
Material Management	✓	✓		✓		✓	✓
Offsite Assembly Plant and Equipment Management	✓	✓		✓			✓
Project Planning	✓	✓	✓	✓	✓	✓	✓
Knowledge Management	✓	✓			✓	✓	
Design	✓	✓			✓		✓
Risk Management	✓			✓	✓	✓	✓
Temporary Structures	✓						✓
Bids/ Tenders	✓				✓		
Energy Management				✓			
Sustainability					✓		

Note: A1 – Machine Learning; A2 – Computer Vision; A3 - Automated Planning & Scheduling; A4 – Robotics; A5 - Knowledge-based Systems; A6 - Natural Language Processing; A7 - Optimization

Table 6 presents the diverse applications of Artificial Intelligence (AI) subfields within the construction industry. The most widely applied subfields are Machine Learning, Knowledge-based Systems, and Optimization, which are used across nearly all functional areas, ranging from project

planning and scheduling to risk management, cost estimation, and site monitoring. These technologies enable predictive analytics, decision support, and operational efficiency. Computer Vision is particularly prominent in areas requiring visual analysis such as health and safety monitoring, site inspections, and material management, where speed and accuracy are essential. Meanwhile, Robotics finds its strongest use in offsite assembly, plant and equipment management, and design execution, offering increased consistency, precision, and safety in physically demanding tasks.

Automated Planning and Scheduling helps optimize logistics and timelines, especially in project planning and construction sequencing, contributing to reduced planning effort and improved workflow control. Natural Language Processing (NLP) enhances communication, knowledge management, and contract analysis, making it useful for tasks involving unstructured text, documentation, or stakeholder interaction. Overall, Table 6 highlights how different AI subfields complement each other across various domains of construction, demonstrating AI's potential to improve safety, productivity, quality, and decision-making throughout the project lifecycle.

On the other hand, Table 7 outlines the specific advantages offered by each subfield of Artificial Intelligence (AI) in the construction industry. Machine Learning stands out for its ability to provide predictive and prescriptive insights that enhance efficiency, reduce errors, and lead to cost savings and better resource utilization. Computer Vision contributes to faster and more accurate inspections, improving safety, transparency, and productivity on-site.

Table 7 Advantages of AI based on subfields in construction industry [29]

AI Subfields	Advantages in Construction
Machine Learning	Predictive insights, increased efficiency, cost savings, improved safety, better resource use, fewer errors.
Computer Vision	Faster inspections, improved accuracy and reliability, cost-effectiveness, enhanced safety and productivity.
Automated Planning & Scheduling	Reduced planning effort, higher productivity, cost savings, streamlined logistics, optimal schedules.
Robotics	Safer and faster operations, higher precision and consistency, improved quality, and productivity.
Knowledge-based Systems	Easy access to information, updatability, reasoning transparency, consistent logic, capability to function with incomplete data.
Natural Language Processing	Improved stakeholder communication, enhanced productivity, and cost efficiency.
Optimization	More efficient workflows, increased productivity, reduced time and cost.

Automated Planning and Scheduling enables optimized logistics and workflows, reducing planning efforts and improving overall project timelines. Robotics enhances both safety and performance by automating repetitive and high-risk tasks, ensuring consistency, speed, and precision beyond human capability. Knowledge-based Systems offer structured decision-making support by storing and updating domain-specific knowledge, promoting consistent logic and usability even with incomplete information. Natural Language Processing (NLP) improves communication among stakeholders and streamlines documentation analysis, contributing to cost and time efficiency. Finally, Optimization drives overall project performance by enhancing productivity, reducing waste, and ensuring more effective time and resource allocation. Together, these advantages demonstrate how AI technologies can significantly transform construction processes by improving safety, reducing costs, and enabling smarter, data-driven decision-making.

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

Virtual Reality (VR) and Augmented Reality (AR) are transformative technologies increasingly adopted in the construction industry to enhance planning, communication, and safety. VR creates a fully immersive, computer-generated 3D environment that users can explore and interact with, whereas AR overlays virtual elements onto the real world, blending digital and physical environments simultaneously [30]. According to Zahrizan *et al.* [31], AR enriches real-world experiences by integrating digital content in real time, improving engagement and sensory interaction in construction tasks.

The concept of AR has historical roots. One of the earliest conceptualizations appeared in L. Frank Baum's 1901 novel *The Master Key*, which described special spectacles that revealed personal traits. The illusion technique known as Pepper's Ghost, dating back to the 1860s, also laid the groundwork for modern AR by creating layered visual effects, although it lacked digital components. The term "Augmented Reality" itself was popularized in 1990 by Tom Caudell and David Mizell. Meanwhile, early immersive experiences resembling VR included panoramic paintings, which surrounded viewers with lifelike scenes. A more practical VR application emerged with the Link Trainer, a flight simulator used to train pilots during World War II [32].

Both AR and VR are now used to solve practical problems in construction. Table 8 highlights the distinct advantages of Augmented Reality (AR) and Virtual Reality (VR) in enhancing construction operations. AR proves particularly useful in improving project scheduling, monitoring progress, and streamlining communication and data access on-site. It also aids in detecting construction defects early, reduces time and costs, and helps stakeholders better understand complex design elements. On the other hand, VR is primarily employed for immersive

safety training and accident prevention, offering a controlled environment for workers to familiarize themselves with hazardous scenarios and procedures. VR also supports more effective defect management by allowing users to virtually inspect construction components before physical execution.

Table 8 Advantages of Augmented Reality (AR) and Virtual Reality (VR) in the construction industry [30]

Technologies	Advantages in Construction
Augmented Reality	<ul style="list-style-type: none"> • Improves project scheduling • Monitors and tracks progress in real time • Enhances communication and data access on-site • Facilitates data collection and distribution • Identifies hidden defects • Saves time and cost • Aids in understanding complex designs.
Virtual Reality	<ul style="list-style-type: none"> • Enables immersive safety training • Supports construction safety programs • Simplifies defect management • Allows users to explore projects in realistic detail

Figure 6 illustrates how AR facilitates the real-time acquisition and visualization of field data and design information, helping construction professionals align physical site conditions with digital models. Together, AR and VR significantly enhance decision-making, accuracy, and safety, making it valuable tools for modern construction practices.

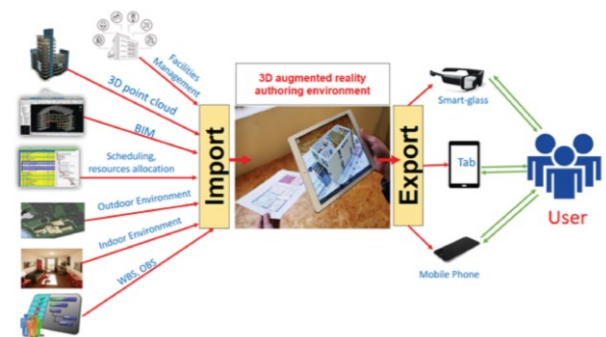


Figure 6 Process of acquisition field data construction and design information using AR [30]

4.0 BIBLIOMETRIC ANALYSIS

4.1 Publications Dataset

The advancement of construction technology in a country reflects its overall development trajectory. According to Jaafar *et al.* [7], research on emerging construction technologies not only enriches academic knowledge but also serves a practical role by providing innovative solutions for Malaysia's construction sector. Drawing insights from international technological developments, this research supports national innovation and policy planning.

A bibliometric study was conducted using the Scopus database to examine the extent of research related to technological advancements in Malaysia's construction industry. The search was based on the keyword string TITLE-ABS-KEY (technolog* AND construction AND industr* AND Malaysia) up to the year 2024. Figure 7 shows the distribution of 511 documents published in Scopus according to document type. The majority were research articles (49.9%), followed by conference papers (38.3%), indicating a high level of academic engagement in both theoretical and applied aspects. Other types include review papers (3.8%), book chapters (3.4%), and conference reviews (3.2%). Smaller percentages were noted for notes (1.0%), books, short surveys, and reports. This distribution reflects the diverse formats through which knowledge is disseminated in this field.

Documents by type

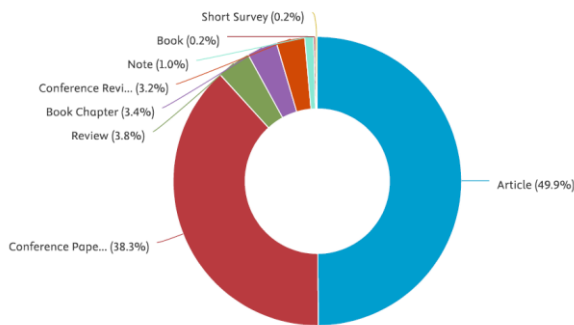


Figure 7 Types of documents available until 2024 for TITLE-ABS-KEY (technolog* AND construction AND industr* AND Malaysia)

Figure 8 illustrates a year-by-year trend of publications from 2000 to 2024, revealing a steady increase in research output, especially over the past five years. Notably, publication numbers rose from 42 in 2019 to 48 in 2021, and peaked at 58 in 2022, with continued strong output in 2023 and 2024. This upward trend highlights growing academic and industry interest in construction-related technological research and suggests that it will remain a research priority moving forward.

Documents by year

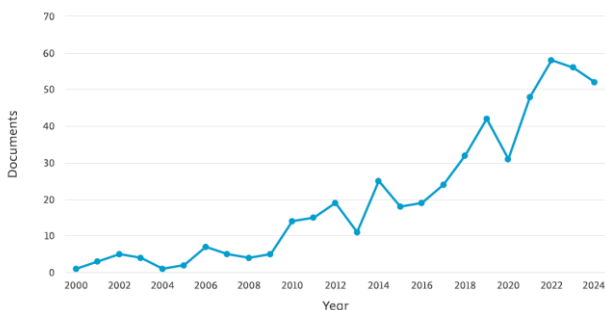


Figure 8 Number of publications by years 2000-2024 for TITLE-ABS-KEY (technolog* AND construction AND industr* AND Malaysia)

4.2 Research Keywords

To further understand the focus areas within this body of research, keyword co-occurrence analysis was performed using VOSviewer on the same dataset of 511 documents. The analysis identifies key terms most frequently used by researchers, offering insights into dominant themes and evolving interests in Malaysia's construction technology landscape.

As shown in Table 9, top keywords include "Construction industry" (198 occurrences), "Malaysia" (164), "Architectural design" (47), "Building Information Modelling" (56), and "Sustainable development" (48). The keyword "Industrial Revolution 4.0" and related terms such as "technology adoption," "digital transformation," and "Internet of Things (IoT)," and "Emerging technologies" also appear frequently, indicating strong research momentum toward digitalization and innovation. This indicates that researchers are beginning to explore next-generation solutions such as automation, smart monitoring, modular construction, and integrated project delivery systems, although much of this work is still in its early stages. Nevertheless, the steady progress observed each year suggests that these advancements have the potential to lead to significant success for the construction industry in Malaysia.

Table 9 Keyword used in previous research according to VOSviewer analysis

S/N	Keyword	Occurrences	Total Link Strength
1	Construction industry	198	1013
2	Malaysia	164	702
3	Architectural design	47	372
4	Construction	59	355
5	Malaysian construction industry	54	300
6	Surveys	40	298
7	Projects management	43	288
8	Building Information Modelling	56	284
9	Sustainable development	48	282
10	Information theory	26	212
11	Construction projects	26	168
12	Decision making	22	143
13	Developing countries	17	129
14	BIM	24	114
15	Contractors	17	112
16	Questionnaire surveys	15	105
17	Malaysians	16	98
18	Information technology	17	94
19	Buildings	11	86
20	Sustainability	18	79
21	Green buildings	9	77
22	Technology adoption	15	75
23	Accident prevention	10	74
24	Competition	10	74
25	Sustainable construction	14	74
26	Semi structured interviews	11	73

5.0 CONCLUSION

This paper has explored the evolution and impact of emerging technologies in Malaysia's construction industry, particularly in the context of Industrial Revolution 4.0. The technologies reviewed, Building Information Modelling (BIM), Internet of Things (IoT), Artificial Intelligence (AI), Augmented Reality (AR), and Virtual Reality (VR), demonstrate significant potential in transforming construction processes, enhancing safety, improving project planning, and increasing overall efficiency. Through historical context, case examples, and bibliometric analysis, it is evident that these innovations are steadily gaining traction in Malaysia, though their adoption remains limited compared to global benchmarks.

The bibliometric data further confirms growing academic interest in this field, with a rising number of publications and a strong focus on themes such as sustainability, digital transformation, and Industry 4.0. However, while the technological foundation exists, challenges such as limited awareness, stakeholder hesitation, regulatory uncertainty, and lack of skilled talent continue to hinder widespread implementation. It is therefore crucial to address these barriers and promote strategic, large-scale integration of digital technologies to ensure the Malaysian construction sector remains globally competitive and future ready.

6.0 RECOMMENDATIONS

While this review provides a comprehensive overview, several gaps have been identified that future research and industry initiatives should address:

1. Investigate the barriers and enablers of software technology adoption in Malaysian construction projects, including organizational readiness, training needs, and cost-benefit analysis.
2. Evaluate the comparative impacts of adopting emerging technologies versus traditional construction methods in terms of cost, time, quality, and sustainability outcomes.
3. A comparative study with a survey that involves construction firms within Malaysia to understand why the emerging technologies adoption is delaying. This aims at creating tailored/customized solutions to the challenge.

Acknowledgement

The authors would like to acknowledge Universiti Malaysia Pahang Al-Sultan Abdullah for providing financial support under Postgraduate Research Grant Scheme (RDU230301).

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

References

- [1] Abdullah Abkar, M. M., R. Yunus, Y. Gamil, and M. A. Albaom. 2024. Enhancing Construction Site Performance through Technology and Management Practices as Material Waste Mitigation in the Malaysian Construction Industry. *Heliyon*. 10(7): e28721. <https://doi.org/10.1016/j.heliyon.2024.e28721>.
- [2] Musarat, M. A., W. S. Alaloul, A. M. Khan, S. Ayub, and N. Joussemaume. 2024. A Survey-Based Approach of Framework Development for Improving the Application of Internet of Things in the Construction Industry of Malaysia. *Results in Engineering*. 21: 101823. <https://doi.org/10.1016/j.rineng.2024.101823>.
- [3] Belabid, A., H. Akhzouz, H. Elminor, and H. Elminor. 2023. Characteristics of Traditional Building Materials and Techniques Based on Earth, Stone and Timber: An Overview and Focus on Morocco. *Journal of Engineering Research and Technology*. <https://doi.org/10.33976/JERT.11.1/2024/2>.
- [4] Scuro, C., S. Tiberti, R. Codispoti, G. Milani, and R. S. Olivito. 2018. Fictile Tubules: A Traditional Mediterranean Construction Technique for Masonry Vaulted Systems. *Construction and Building Materials*. 193: 84–96. <https://doi.org/10.1016/j.conbuildmat.2018.10.156>.
- [5] Alaloul, W. S., M. S. Liew, N. A. W. A. Zawawi, and I. B. Kennedy. 2020. Industrial Revolution 4.0 in the Construction Industry: Challenges and Opportunities for Stakeholders. *Ain Shams Engineering Journal*. 11(1): 225–230. <https://doi.org/10.1016/j.asej.2019.08.010>.
- [6] Carvalho, N., O. Chaim, E. Cazarini, and M. Gerolamo. 2018. Manufacturing in the Fourth Industrial Revolution: A Positive Prospect in Sustainable Manufacturing. *Procedia Manufacturing*. 21: 671–678. <https://doi.org/10.1016/j.promfg.2018.02.170>.
- [7] Jaafar, M., A. Salman, F. E. M. Ghazali, M. Z. M. Zain, and N. M. Kilau. 2024. The Awareness and Adoption Level of Emerging Technologies in Fourth Industrial Revolution (4IR) by Contractors in Malaysia. *Ain Shams Engineering Journal*. 15(5): 102710. <https://doi.org/10.1016/j.asej.2024.102710>.
- [8] Guilfoos, T. 2025. The Evolution of the Value of Water Power during the Industrial Revolution. *Explorations in Economic History*. 95: 101645. <https://doi.org/10.1016/j.eeh.2024.101645>.
- [9] Muthunandhini, R., and K. Palanivel. 2025. Optimizing Industrial Growth: A Spherical Fuzzy MCDM Framework for Industrial Revolutions. *Results in Engineering*. 25: 103844. <https://doi.org/10.1016/j.rineng.2024.103844>.
- [10] Sharma, A., and B. J. Singh. 2020. Evolution of Industrial Revolutions: A Review. *International Journal of Innovative Technology and Exploring Engineering*. 9(11): 66–73. <https://doi.org/10.35940/IJITEE.I7144.0991120>.
- [11] Didier, N. 2024. Turning Fragments into a Lens: Technological Change, Industrial Revolutions, and Labor. *Technology in Society*. 77: 102497. <https://doi.org/10.1016/j.techsoc.2024.102497>.
- [12] Mohajan, H. K. 2021. Third Industrial Revolution Brings Global Development. *Journal of Social Sciences and Humanities*. 7(4): 239–251. <http://www.aiscience.org/journal/paperInfo/jssh?paperId=5493>.
- [13] Roberts, B. H. 2015. *The Third Industrial Revolution: Implications for Planning Cities and Regions*. <https://www.researchgate.net/publication/278671121>.
- [14] Taalbi, J. 2019. Origins and Pathways of Innovation in the Third Industrial Revolution. *Industrial and Corporate Change*. 28(5): 1125–1148. <https://doi.org/10.1093/icc/dty053>.
- [15] Troxler, P. 2013. *Making the 3rd Industrial Revolution*. Transcript Verlag. <https://doi.org/10.14361/transcript.9783839423820.181>.

- [16] Taher, G. 2021. Industrial Revolution 4.0 in the Construction Industry: Challenges and Opportunities. *Management Studies and Economic Systems*. 6 (3/4): 109–127. <https://doi.org/10.12816/0060000>.
- [17] Ahmed, S. 2019. A Review on Using Opportunities of Augmented Reality and Virtual Reality in Construction Project Management. *Organization, Technology and Management in Construction*. 11(1): 1839–1852. <https://doi.org/10.2478/otmcj-2018-0012>.
- [18] Aziz Abdul Samad, A., N. Mohamad, A. Zurisman Mohd Ali, J. Hadipramana, N. Ali, G. Wan Inn, and K. Fah Tee. 2017. Development of Green Concrete from Agricultural and Construction Waste. In *World Renewable Energy Congress XVI*. https://doi.org/10.1007/978-3-319-69844-1_36.
- [19] Ngcobo, N., C. Aigbavboa, and D. Aghimien. 2025. Sustainable Maintenance in the Fourth Industrial Revolution. In *Maintenance Engineering for Buildings*. 49–77. Woodhead Publishing. <https://doi.org/10.1016/B978-0-443-23687-7.00003-7>.
- [20] Latiffi, A. A., S. Mohd, N. Kasim, and M. S. Fathi. 2013. Building Information Modeling (BIM) Application in Malaysian Construction Industry. *International Journal of Construction Engineering and Management*. 2013(4A): 1–6. <https://doi.org/10.5923/s.ijcem.201309.01>.
- [21] Obeidat, I., S. Obeidat, S. Abu Rumman, et al. 2018. Building Information Modelling: Challenges and Barriers in Implementation for Interior Design Industry in Malaysia. *IOP Conference Series: Earth and Environmental Science*. 140(1): 012002. <https://doi.org/10.1088/1755-1315/140/1/012002>.
- [22] Othman, I., Y. Y. Al-Ashmori, Y. Rahmawati, Y. H. Mugahed Amran, and M. A. M. Al-Bared. 2021. The Level of Building Information Modelling (BIM) Implementation in Malaysia. *Ain Shams Engineering Journal*. 12(1): 455–463. <https://doi.org/10.1016/j.asej.2020.04.007>.
- [23] Haron, N. A., R. P. Z. A. R. Soh, and A. Harun. 2017. Implementation of Building Information Modelling (BIM) in Malaysia: A Review. *Pertanika Journal of Science and Technology*. 31: 208.
- [24] Wang, J., M. K. Lim, C. Wang, and M. L. Tseng. 2021. The Evolution of the Internet of Things (IoT) over the Past 20 Years. *Computers & Industrial Engineering*. 155: 107174. <https://doi.org/10.1016/j.cie.2021.107174>.
- [25] Katiyar, A., and P. Kumar. 2021. A Review of Internet of Things (IoT) in Construction Industry: Building a Better Future. *International Journal of Advanced Science Computing and Engineering*. 3(2): 65–72. <https://doi.org/10.30630/ijasce.3.2.53>.
- [26] Herath, H. M. K. K. M. B., and M. Mittal. 2022. Adoption of Artificial Intelligence in Smart Cities: A Comprehensive Review. *International Journal of Information Management Data Insights*. 2(1): 100076. <https://doi.org/10.1016/j.jjime.2022.100076>.
- [27] Debrah, C., A. P. C. Chan, and A. Darko. 2022. Artificial Intelligence in Green Building. *Automation in Construction*. 137: 104192. <https://doi.org/10.1016/j.autcon.2022.104192>.
- [28] Waqar, A., Qureshi, A., H. R. Almujiabah, L. E. Tanjung, and C. Utami. 2023. Evaluation of Success Factors of Utilizing AI in Digital Transformation of Health and Safety Management Systems in Modern Construction Projects. *Ain Shams Engineering Journal*. 14(11): 102551. <https://doi.org/10.1016/j.asej.2023.102551>.
- [29] Abioye, S. O., L. O. Oyedele, L. Akanbi, A. Ajayi, J. M. D. Delgado, M. Bilal, O. O. Akinade, and A. Ahmed. 2021. Artificial Intelligence in the Construction Industry: A Review of Present Status, Opportunities and Future Challenges. *Journal of Building Engineering*. 44: 103299. <https://doi.org/10.1016/j.job.2021.103299>.
- [30] Ahmed, S. 2019. A Review on Using Opportunities of Augmented Reality and Virtual Reality in Construction Project Management. *Organization, Technology and Management in Construction*. 11(1): 1839–1852. <https://doi.org/10.2478/otmcj-2018-0012>.
- [31] Zahrizan, Z., M. A. Omardin, R. A. Rahman, and A. T. Haron. 2021. Barriers to Augmented Reality Application in Construction: An Exploratory Study in Malaysia. *UMP Research Series: Construction Engineering and Management*. 1. <https://doi.org/10.15282/cem.1.04.2022.01.06>.
- [32] Rauschnabel, P. A., R. Felix, C. Hinsch, H. Shahab, and F. Alt. 2022. What is XR? Towards a Framework for Augmented and Virtual Reality. *Computers in Human Behavior*. 133: 107289. <https://doi.org/10.1016/j.chb.2022.107289>.