Review: Identification of roadmap of fourth construction industrial revolution

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Review: Identification of roadmap of fourth construction industrial revolution

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Abstract. Industrial revolution is a series of events driven by the growth of technological innovations, and so far, the world had witnessed the first three industrial revolutions. Today, a new revolution referred to as the fourth industrial revolution is entering even though it is still in its early stages of development. Many developed countries had established their own roadmap or strategic plan as a first step. However, only a few of them touched the construction sector even though the construction industry provides a significant contribution to the country's GDP. Based on this understanding, there is a fundamental need to give a clear view of Industry 3.0 to Industry 4.0 from the construction industry's perspective, since most users are still finding their way in this transition. An extensive literature review is used to define the scope and terms of the field of construction in the industrial revolution. Towards this goal, a clear definition and concept of each revolution, key technologies related to construction and challenges faced by the industry will be explored. Simultaneously, this review paper also benchmarked a few documents as a simple guide in the transition process to the fourth industrial revolution to avoid a lag in a world where changes are swift and sudden. Therefore, this review paper contributes by providing a better understanding of the challenges and trends in Construction 4.0 to academics and practitioners. Moreover, it will spark new ideas on the policy or strategic roadmap development in the future.

1. Introduction

Industrial revolution began across the earth, but it started in Europe, especially in Britain. The first three revolutions were a result of mechanization driven by water and steam power utilizing mass labour and electrical energy, which then evolved due to electronic and automated production, respectively [1]. Today, the increasing number of complexity in technologies is ushering the fourth industrial revolution.

Manufacturing, automobile, and banking are among the sectors that are advanced in terms of technologies and have tapped into the fourth industrial revolution by applying digitalization into their applications [2]. However, the construction industry is considered as a latecomer in this revolution and has yet to fully realize the benefit of digitalization, even though this sector provides a significant contribution to the country's GDP. According to The World Bank Group [3], the introduction of

digitalization as a new driver of development will ensure the growth in the digital economy and boosts the development of Malaysia.

For the past years, few countries have stepped up and created their own roadmap of the fourth industrial revolution such as Industry 4.0 in Germany, Made in China 2025 in China and Roadmap of Industry 4.0 in Mexico. However, most of the available roadmaps or policies are focusing more on the manufacturing sector and neglect the construction sector. Roadmapping is a method of developing and conveying strategy and innovation in organizations [4]. Roadmap is an effective strategy as practitioners are usually hesitant to determine the "right" guidelines for the organization's development towards the revolution. To transform the construction firms into digitalization, management needs to have a clear understanding of the current readiness level and action plan for the future. Thus, every country needs to develop its own policy or roadmap to support the rising technologies, especially in the sector of construction.

Therefore, the subject matter of this paper is an intensive roadmap analysis that can be used as a basis by scholars and industry players towards the development of a detailed strategic plan or policy in the future. A well-organized strategic and technological roadmap can be created by having a clear understanding of the component of Industry 4.0. Thus, this review contributes by outlining the available documents, overview the emerging technologies that are the building the blocks of Industry 4.0. The process of transforming the industry to fit with emerging technologies might confront few challenges, but their potential in the economic benefits for people, process, and productivity should not be forgotten.

2. Fourth industrial revolution review approach

The procedure begins by obtaining a comprehensive set of papers. An initial search was conducted through the Google search and Google scholar engine. Then, a systematic search via two electronic databases, namely Web of Science and SCOPUS were used to identify and finalize the papers that are related to the key technologies and policy reports of the Fourth Industrial Revolution and Construction 4.0. The combination of the string "and" and "or" in between each of these terms of "fourth industrial revolution," "digitalization development," "key technologies" and "Industry 4.0," were used. These advanced initial searches collectively resulted in the identification of several papers that might explain the properties and circumstances of the fourth industrial revolution towards the construction industry. 54 papers were extracted at the first stage, and irrelevant papers were subsequently dropped after carefully reviewing the key and citations. In the end, only 26 papers left. The category of these papers is shown in table 1. Then, the content analysis method was used to review the content of each document. Figure 1 provides a schematic flowchart of the procedure to conduct this systematic review.

Table 1. Research categories of selected papers.

Research categories	No of publications
Concept and overview of industry 4.0	14
Challenges in the industry 4.0	5
Key technologies of industry 4.0	10
Roadmap/policy industry 4.0	7

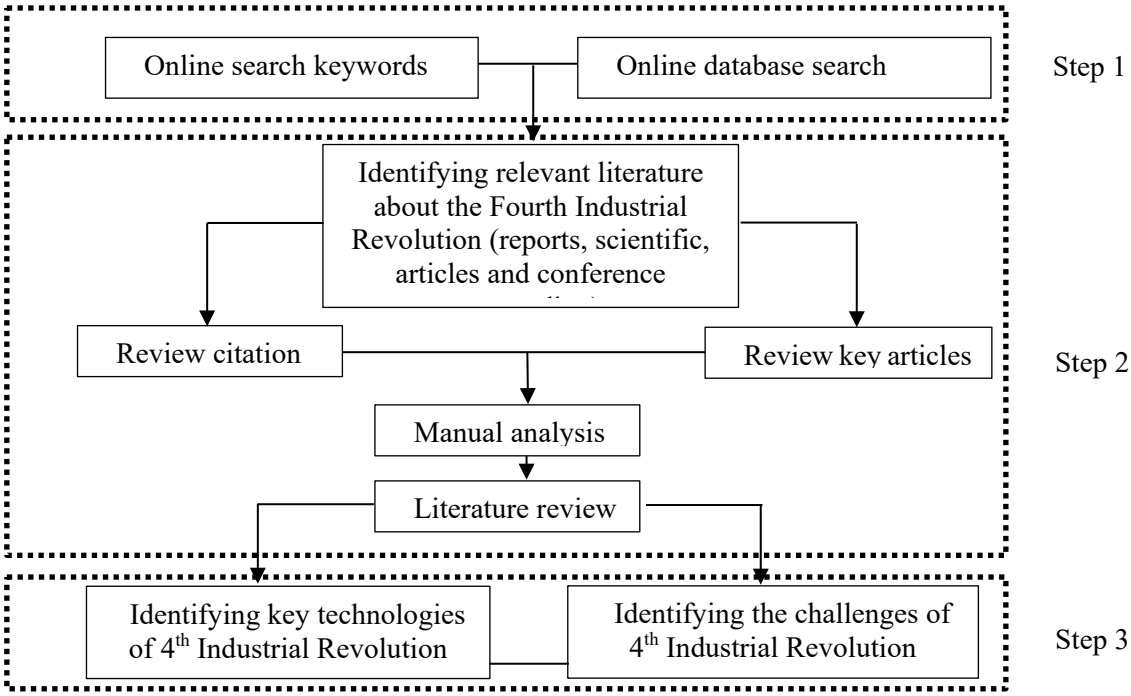

Figure 1. Schematic flow chart of the procedure to conduct this review.

3. Theoretical background

3.1. An overview of industrial revolution

The world has undergone a series of "Industrial Revolutions" due to the rapid booming of information and communication technologies (ICT). The transformation from manual works to mechanization marked the first industrial revolution [5], which was driven by steam and water power. The second industrial revolution was due to the mass production contributed by electricity. However, Qin et al. (2016) stated that the second industrial revolution actually complicates the manufacturing process, yet it makes the manufacturing process automatic and sustainable (as cited in [6]). The massive production triggered the incorporating of information technology and computers, which took place in 1870 [6]. This contributes to the third industrial revolution. Supported by Epicor Software Corporation [7], the third industrial revolution slowly began at the end of the 1950s and represented by the integration of electronic and computer technology into their factories. Now, the new revolution era (fourth industrial revolution) is entering, which is defined as the next level of digitalization where machines or systems are able to learn, communicate, and improve themselves from the existing experiences without the needs to be explicitly programmed. Figure 2 below represents the summary of the industrial revolution's path.

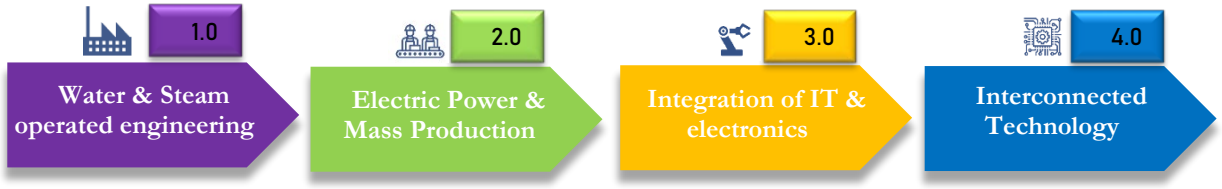

Figure 2. Evolution of industrial revolution [8].

In the context of construction perspective, the definition of each revolution is slightly different as defined in figure 3. It is asserted that the first revolution for construction was driven by the use of tools such as shovels; the second stage resulted in mechanization and the use of machinery like backhoes; while the third stage is triggered by the information technology that brings in software such as BIM, and Revit, among others [2].

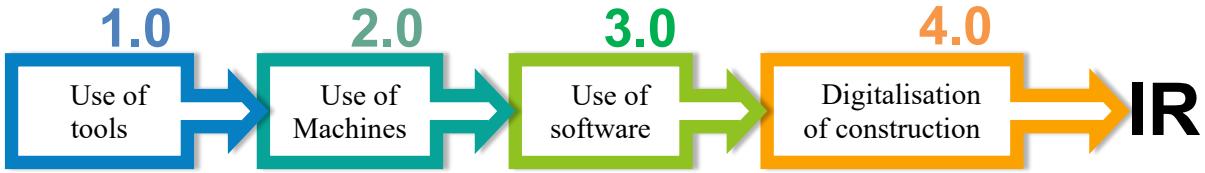

Figure 3. Evolution of construction revolution [2].

Digitalisation and electrical automation are among the keywords in this revolution. According to Lange, Bähre, Finetti-IImhof, Klamma, & Oppermann [9], the fourth industrial revolution emphasizes on the Internet of Things, Services, Data and People. Whereas, Muhuri, Shukla, & Abraham [8] stated that the critical elements in Industry 4.0 are cyber-physical systems (CPS), 3D printing, virtual reality (VR), augmented reality (AR), cloud computing, big data, data science etc. Everyone has their own opinion and definition of the fourth industrial revolution. Table 2 summarizes the definition of the fourth industrial revolution by various researches. After all, it can be summarized as a set of technologies or digitalisation era that helps the integration of all actors in the whole value chain.

Table 2. Definitions of the fourth industrial revolution.

Research categories	No of publications
[10]	The increasing **digitilization, automation and creation of digital value chain** in the manufacturing sector, enabling communication between product and business partner.
[11]	Collective term for **technologies** and concepts of **value chain organisation**
[12]	It can be described more precisely as a conjunction of several new and existing **technologies**, which now work together
[13]	Creation of intelligent, autonomous, decentralized factories and integrated product-services with **integrated technologies**
[5]	A promising approach based on the integration of businesses and manufacturing processes, as well as the integration of all actors in the company's **value chain** (suppliers and customers).
[6]	A new level of organization and control over the **entire value chain** of the life cycle of products, it is geared towards the increasingly individualized customer requirements
[7]	**Embedded of virtual and the real world** to engineering applications such as **robotics, digitalization, and automation**

People often get confused in understanding the fourth industrial revolution and Industry 4.0. Industry 4.0 is used as a synonym for the fourth industrial revolution. It is coined from Germany's manufacturing sector, which represents the development of digitalization in the manufacturing sector [1]. In Malaysia,

Industry4WRD is the synonym that represents the fourth industrial revolution in the manufacturing sector.

3.2. Bridging Industry 3.0 and Industry 4.0

Industry 3.0 (IT and automation) practices and Industry 4.0 (digitalisation). Table 3 shows the comparison of Industry 3.0, Industry 3.5 and Industry 4.0. In this case, Industry 3.5 acts as a bridge that helps the transition to Industry 4.0. There are five primary features that differentiate Industry 3.0 and Industry 4.0. The third industrial revolution is characterized as the "highly automated system", whereas the fourth industrial revolution uses the term "Smart", which allows the communication via Internet of Things (IoT) between human beings and devices. Smart intelligence is also embedded in the devices, supporting decentralized analytics and even digital decision-making to produce an intelligent output improving the existing environment. At this rate, manual decisions that require human interaction is no longer required.

Table 3. Comparisons among Industry 3.0, 3.5 and 4.0 [14].

Features	Industry 3.0	Industry 3.5	Industry 4.0
Concept	Operational decision	Digital decision	Self-flexible, self-adaptable and self-learning
Production	Mass Production	Flexible Manufacturing	Mass Customization
Quality Control	Statistical Process Control	Advanced Process Control	Self-aware and Self-predict
Resources Management	Materials and Human Resource Management	Total resource Management	Self-configure and Self optimize
Development Priorities	Hardware investment	Integration of ability of data analysis and experience of management	CPS and IoT

3.3. Document review

Roadmap is defined as a detailed plan to guide progress towards a particular goal [15]. Several countries have developed technology roadmaps or strategic plans to accelerate the development of the fourth industrial revolution. Table 4 presents the reviewed roadmaps or policies. Based on the seven analysed documents, only one focuses on construction. It can be concluded that most of the roadmaps or strategic plans focused a lot on the manufacturing sector instead of construction, even if it significantly contributed to the country's GDP.

Table 4. Summary of Industry 4.0 roadmaps or policies of selected countries.

Country/Project	Core Value	Core Technology	Focus Industry
Germany industrie 4.0 [16]	Strategic initiative to revolutionize the manufacturing engineering sector in industrial IT.	•IoT •CPS • IoT, Data and Services • Smart Factory	•Manufacture
European Roadmap for Industrial Process Automation [17]	Provide guidance and input for process industry companies, providers of process industrial IT and automation solutions	•Circular economy •Modularisation •Artificial Intelligence and Big Data •Autonomous plants and remote operations • Cybersecurity	•Pulp and Paper • Metals •Mining and Minerals •Chemical •Energy and Power •Pharmaceutical

Country/Project	Core Value	Core Technology	Focus Industry
		•Safety •Human-Machine Interfaces •Machine-to-Machine	•Food Production and Processing •Infrastructure •Mobile platforms •Oil and Gas
A Roadmap for Industry: Mexico [18]	Build up two hyper-flexible manufacturing Clusters that will develop a I4.0 framework and a Manufacturing Operating System.	• Big Data Analytics •Modeling & Simulation • Robots • IoT	•Manufactures •Automobiles
Made in China 2025 [19]	This initiative aims to be a state leadership to advance manufacturing with the application of technology.	• Networking • Smart Manufacturing • Industrial foundation • IoT • Intelligent products • New production models	•ICT •Advanced Numerical Control Machine Tools and Robotics •Aerospace •Ocean Engineering Equipment •Rail Transit Equipment •Energy Saving and Smart Vehicles •Electricity Equipment •Agriculture Equipment •New Materials •Biopharmaceuticals
Towards 2040: UK [20]	Determine how the automotive industry meets pressing environmental and sustainability challenges.	•Electrical energy storage •Electric machines •Power electronics •Thermal propulsion systems •Lightweight vehicle and powertrain structures	•Automotive
Taiwan productivity 4.0 [21]	This initiative aims to address labor and productivity issues in Taiwan.	•IoT •Smart robotics •Big data	•Agriculture •Commerce •Manufacturing
Built Environment 2050: UK [22]	This initiative aims to shape the future to 2050 by researching and reporting on what an interdisciplinary scope of work may look like as construction technology develops.	•Additive manufacturing •Advanced Robotics •Analogue Decisions •Artificial Intelligence •Automated regulation checking and audits •Autonomous Vehicles •BIM •Common data environment •Cyber physical systems •Digital Decisions •Graphene •Modularised construction	•Construction

3.4. Industry 4.0 key technologies

Even though "Industry 4.0" is a common term referring to the fourth industrial revolution, scholars are still struggling to accurately define this revolution, especially if it is related to construction. This makes it even harder to differentiate the main construction technologies inside this revolution. In fact, a single Google search will reveal a few related technologies that are widely representing the fourth industrial revolution. Thus, a summary related to emerging technologies is perceived in figure 4.

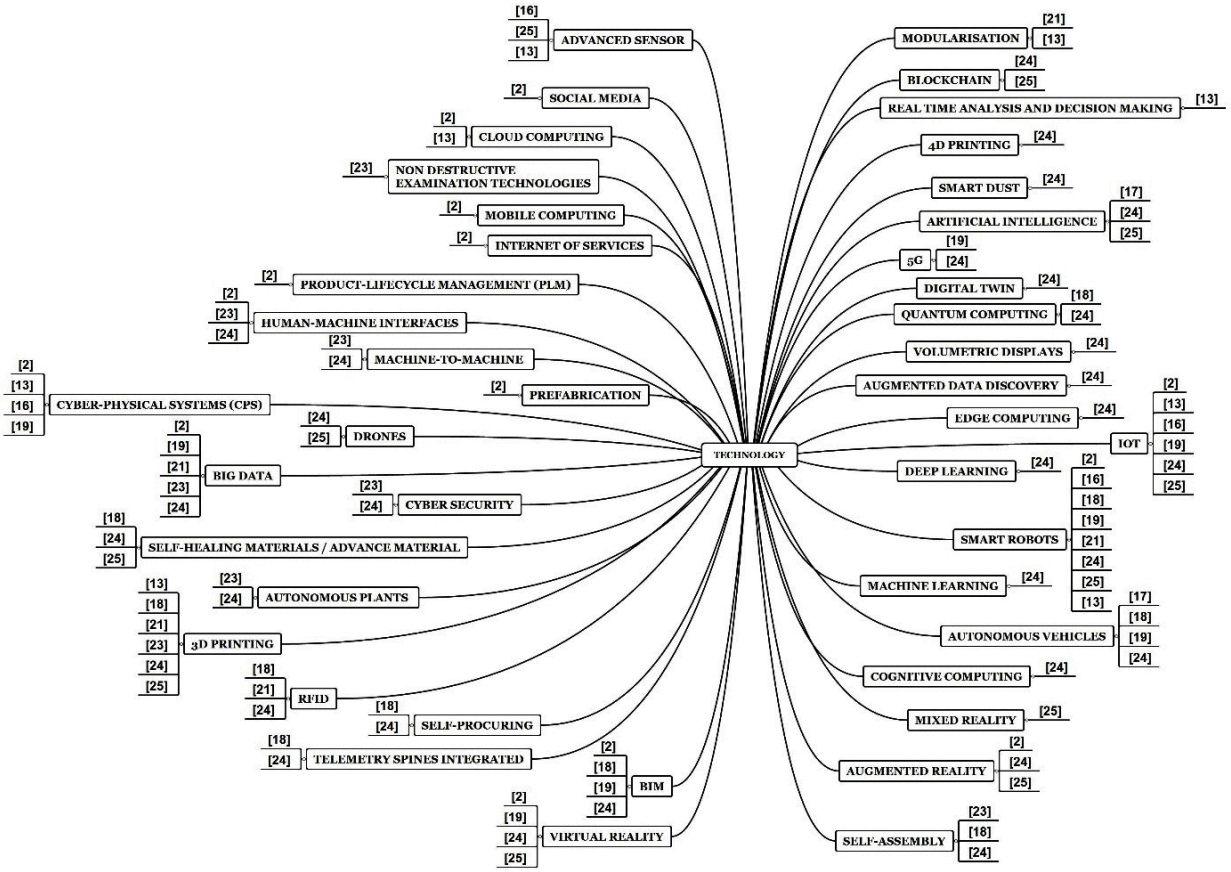

Figure 4. Benchmarking analysis for technology.

3.5. Road-mapping process

Several papers have outlined the road mapping process, as presented in figure 5. Generally, it started by reviewing the related literature, technology and application. Followed by the expert's classification based on maturity. To give precise definitions of the aforementioned key technologies and to gain insight into the market maturity and technology maturity, experts' assistance in a particular sector will be needed. In the construction context, the presence of experts from the whole life cycle construction will be required to create a precise result. One of the effective methods that can be used to collect data is by conducting a focus group discussion. The last step is to develop the integrated roadmap using the collected data during the previous steps.

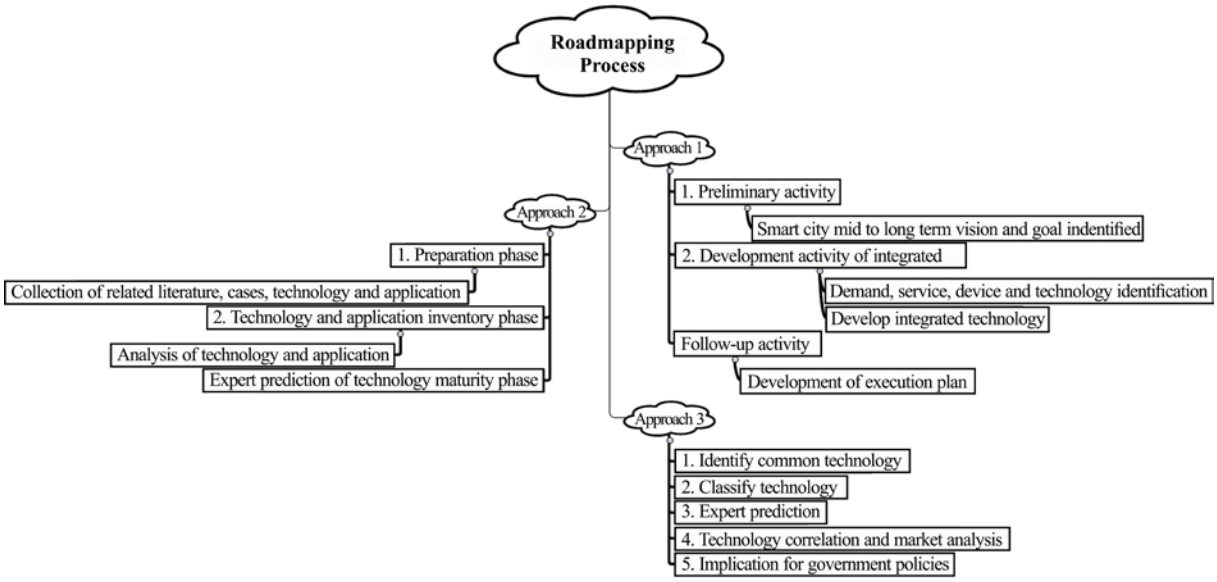

Figure 5. Roadmapping process [26, 27, 28].

3.6. Issue and challenges of Industry 4.0 towards the construction industry

When the conversation drifted towards the construction industry, there has to be a discussion whether the engineering and construction (E&C) industry was ready for a new evolution or what are the challenges faced by the industry to catch up with the advancements of technology that are currently available. It cannot be denied that in a connected era, digitalization and other disruptive technologies will enable construction firms to improve their efficiency. Chen, Soto & Adey [29] emphasizes that construction 4.0 can help to improve productivity by strengthening the alliance between different actors in construction and reduce the time taken to complete a project.

However, changing from a highly automated system to smart factory and IoT is a challenging process as it requires people to leave from their comfort zone [9]. Employees already used to the conventional system, new technologies demand them to pick up new processes and technology fast. There are ten different primary issues facing the construction industry in the context of the fourth industrial revolution, as depicted in table 5. Each issue has its own challenges. Addressing Malaysia's issues and challenges on Construction 4.0 is a crucial step to ensure better suggestions that can be provided as action plans in the future.

Table 5. Challenges on the way of construction 4.0 adoption.

Issue	Challenges	[30]	[25]	[9]	[31]	[32]
Delivery forces	Pressure to improve services while increasing quality and lowering costs.	/				
	Data management (large quantities of data)			/		
Market forces	Price, demand and availability of engineering services affected by economic rate	/				
	Unclear economic return for digital investments		/			
	Required high financial investment		/		/	/
Cost	High cost of implementations					/

Issue	Challenges	[30]	[25]	[9]	[31]	[32]
Culture	No training provided and the absence of digital culture		/			
Organisation	Unclear vision of digital operations		/			
Leadership	Lack of support from top management		/			
Skills	Lack of skilled talent		/			/
	Loss of unskilled job				/	
	New application requires retraining or further training in operating them			/		
	Existing employees might feel unsecured due to process-dependent systems that make greater use of technology			/		
	Unreadiness of in-house technical staff.					/
Right standard	Lack of digital standards, norms and certification		/		/	
	Complicated procedure as Industry 4.0 will need to comply with the existing law and need to adapt to a new innovative law.			/		
Intellectual property protection/Security	Data security and privacy		/		/	
	Data theft, industrial espionage, and attacks by hackers			/	/	
	Cyber-attacks and viruses			/		
	Loss of control over company's intellectual property		/			
Technological changes	Requires new modeling techniques and data formats			/		
	Technology keeps on changing and has to be adapted constantly			/		
	Organisation does not possess the technology					/

4. Discussion

The fourth industrial revolution is a subset of the industrial revolution. The basic concepts when mentioning the fourth industrial revolution are technology, value chain, digitalisation and IoT as discussed previously in Chapter 3. Manufacturing is among the competitive industry that forges ahead with the fourth industrial revolution, and in order to mobilize it further, the construction industry needs to change and be a part of those. The one who refused to keep up with the rapid changes in the present technology will be eliminated and left behind. Technology will keep on updating and evolving. In the future, more emerging technologies need to be included in the roadmap. As listed in Chapter 3, some of it might not be suitable and not applicable to be applied in several countries. The implementation is at a rela-tively early stage in its evolution. Thus, a proper and deep understanding of every technology is needed before developing the roadmap. Industries might not be capable of reaching the goal if a proper and deep understanding of technology is not reached. There is no quick fix to make the fourth industrial revolution happens. The main priority, however, is to increase aware-ness and understanding among practitioners that the fourth industrial revolution is more than just technology and BIM. It is a collaboration of three critical factors; process, people and technology, with the output of low productivity, low cost, and high quality. In the end, the benefit will outweigh the barriers faced in implementation.

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