THE INGENIEUR

Construction 4.0 to Transform the Malaysian Construction Industry

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Construction 4.0 is the term used to represent the fourth industrial revolution for the construction industry. It describes the increasing level of digitisation of the industry, changing how infrastructure, real estate and other built assets are designed, constructed, operated, and maintained. The 12 emerging technologies listed in the Construction 4.0 Strategic Plan (2021-2025) act as the main catalyst.

The construction industry plays an important role in global economic growth. Over the past 40 years, previous statistics have demonstrated the significant relationship between the construction industry and economic growth in countries worldwide *(Dehdasht et al. 2021; Lopes, Oliveira, and Abreu 2017; Musarat, Alaloul, and Liew 2021; Pheng and Hou 2019).* The entire construction process, starting from the production of building materials and components, professional services such as design and project management, construction processes on-site, and operations and management, contribute extensively to economic growth across other sectors *(Hilal, Maqsood, and Abdekhodaee 2019; Pheng and Hou 2019).* It was highlighted that the entire supply chain in the construction industry is critical to national wealth creation with significant multiplier effects on the economy *(Chan 2010; Khan, Liew, and Ghazali 2014).* The construction industry has a two-times multiplier effect on another 120 sectors relying on construction for their progress and sustainability *(Rashidi and Ibrahim 2017).* With more than 1.2 million job opportunities generated by the construction industry, the Malaysian construction industry plays a remarkable role in socio-economic growth by providing employment opportunities and income sources.

Even though the construction industry has a significant influence on the socio-economic aspects of a nation *(Khan et al. 2014),* transformation in many aspects is needed to ensure competitiveness. Due to globalisation, the construction industry's future will depend on innovative techniques, smart industrial processes, digitalisation and automation, and a skilled workforce *(Alaloul et al. 2021; Craveiro et al. 2019; García de Soto et al. 2019).* The shift towards this approach requires the construction industry to undergo radical process changes by adopting digital technologies.

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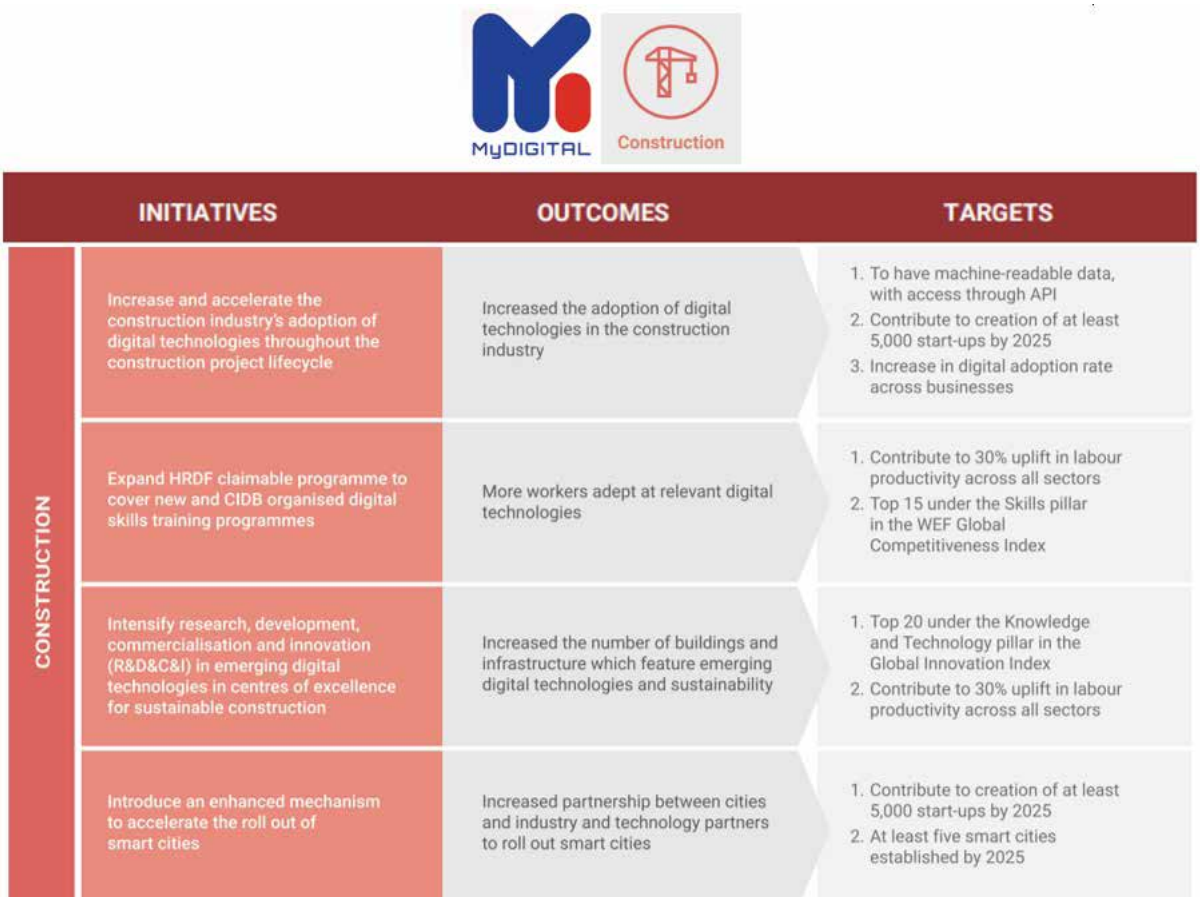

Figure 1: Four initiatives under the construction sector from overall 28 sectoral-focus initiatives to grow the digital economy (Source: Economic Planning Unit Malaysia 2021).

Recently, the construction industry was highlighted amongst four sectoral-focus initiatives that will grow the digital economy under the Malaysia Digital Economic Blueprint (MyDIGITAL) *(Economic Planning Unit Malaysia 2021).* The MyDIGITAL aims to transform Malaysia into a digitally driven, high-income nation and a regional leader in the digital economy. Four sectoral-focus initiatives are recommended to grow the digital economy, including the construction sector. **Figure 1** outlines four construction initiatives that will build the foundation to drive the growth of the digital economy. To accelerate innovation and create a holistic digital ecosystem, the construction sector is expected to: a) increase the adoption of digital technologies throughout the construction project lifecycle; b) build the digital capacity of the construction workforce; c) intensify research, development, commercialisation, and innovation (R&D&C&I) in emerging digital technologies through a centre of excellence; and d) introduce a mechanism to accelerate the rollout of smart cities.

Accelerating digital transformation during the COVID-19 pandemic

Initially, the construction industry's previous development relied on conventional methods to operate, control, and manage project lifecycles. However, poor operation and project management have negatively affected the industry's productivity and quality processes. The construction industry is still highly dependent on unskilled manual labour, which results in low productivity. With the increasing complexity of construction projects, added with demand for time reduction, quality

improvement and cost reduction, industry players can no longer run away from adopting the necessary technologies which will ensure their competitiveness through higher efficiency and productivity *(García de Soto et al. 2019; San Cristóbal et al. 2018).*

It is timely for the construction industry to embrace technology and innovation in line with the new construction revolution. Since the imposition of the Movement Control Order (MCO), followed by the Conditional and Recovery MCO, activity in the construction sector declined by 44.5% in the first quarter of 2020, as almost all activities were not allowed *(Bank Negara Malaysia 2020)*. The global COVID-19 pandemic has created a sense of urgency for industry players to raise their ability in adopting technology and innovation. According to the report produced by McKinsey and Company, the digital shift has already begun, and the COVID-19 crisis will accelerate the transformations *(Ribeirinho et al. 2020).*

Digitalising the Malaysian Construction Industry

The Ministry of Works, together with the Construction Industry Development Board of Malaysia (CIDB), through the Construction Research Institute of Malaysia (CREAM), has developed the Construction 4.0 Strategic Plan (2021-2025). The strategic plan was developed in collaboration with experts from various disciplines and multiple stakeholders in the industry. The document was officially launched by YB Dato' Sri Haji Fadillah Bin Haji Yusof, Senior Minister (Infrastructure), Minister of Works Malaysia, on November 17, 2020 during the International Construction Week (ICW) 2020. The document provides a framework that will drive the industry towards embracing the digital revolution in construction. Through the document, we aspire to be the leading country in implementing Construction 4.0 in the Southeast Asia region. With the mission to transform the Malaysian construction industry by empowering smart construction for future society, the concept of agile governance is used to enable a strategy that is more inclusive and "human-centred" by involving various stakeholders. The approach used in implementing the initiatives for the strategic plan will be dynamic and holistic. The interactive quadruple helix actions explained at the end of this article will ensure smooth measurable deliveries.

CONSTRUCTION 4.0 STRATEGIC PLAN (2021-2025)

The Fourth Industrial Revolution

We have been listening to a panoply of buzzwords within the industry, known as The Fourth Industrial Revolution or Industry 4.0. These terms represent two concepts that bring different meanings. The fourth industrial revolution, a term coined by Klaus Schwab, helps people to understand what has already changed. It represents a technological revolution that is characterised by the evolvement of innovations which have an impact on human life. **Figure 2** shows stages of the industrial revolution for readers' understanding. Industry 4.0 is reminiscent of the fourth industrial revolution, which became the Government's focus in Germany and other European countries.

Industry 4.0 is explained as applying the cyber-physical system within industrial production systems *(Ghobakhloo 2018).* Industry 4.0 offers a more comprehensive, interlinked, and holistic approach to manufacturing. It connects physical with digital, such as the Internet of Things (IoT), Artificial Intelligence (AI), additive manufacturing, cloud computing, robotics and others. It allows for better collaboration and access across departments, partners, vendors, products, and people. Industry 4.0 is an integrative value creation system consisting of 12 design principles and 14 technology trends.

The proliferation of Industry 4.0 (or the digital revolution) has improved the productivity and sustainability of many industries, and redefined the skills and competencies they need to thrive. In this revolution, the survivors of industry are dependent on their ability to transform their business processes into competitive digital ecosystems. Aware of the impact of this revolution, Governments all over the world have started to plan effective transformation approaches. Due to the complex, transformative and distributed

nature of this revolution, it demands a new type of governance to address the interlinked dynamics of the pace and synergistic nature of emerging technologies; the transnational impact of technologies and broader societal implications; and the political nature of technologies (*World Economic Forum 2018).*

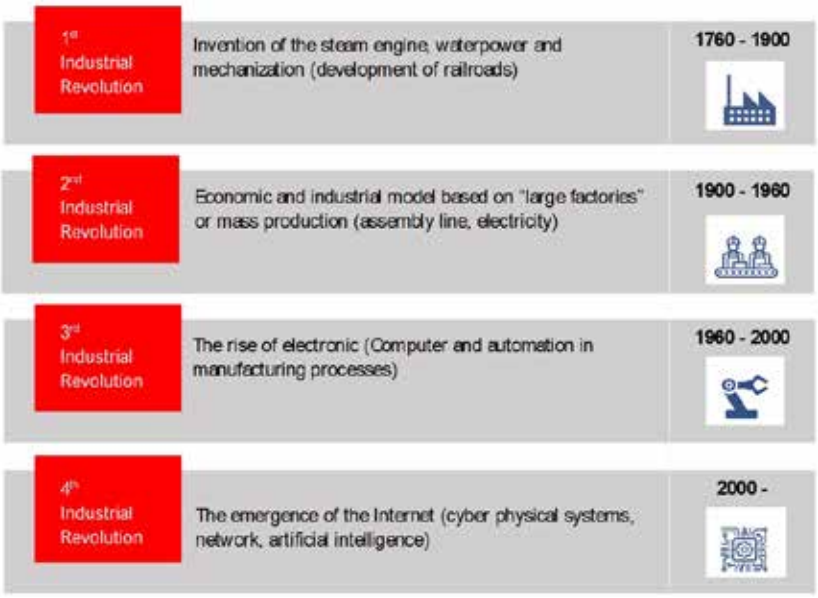

Figure 2: Stages of the industrial revolution

Shifting the Intervention Gauge

The construction industry is ripe for digitalisation. The rapid change in organisations worldwide with current global megatrends brings new challenges for the construction industry. The increasing population of the world leads to the provision of affordable housing, social, transportation and infrastructure. The construction industry needs to consider the wider society by providing affordable costs, sustainable construction, and improving economic development. The current rapid shift towards a new dimension of the fourth industrial revolution will require the industry to prepare for the technological and cultural changes into digital construction.

Construction 4.0 is the term used to represent the fourth industrial revolution for the industry. Construction 4.0 describes the increasing level of digitisation of the construction industry from automated production *(Craveiro et al. 2019).* It is gradually changing how infrastructure, real estate and other built assets are designed, constructed, operated, and maintained. **Figure 4** shows the technology that can transform construction to digitalisation, bringing innovations into the business behaviour.

The construction industry is currently in the middle of a technological transformation that will fundamentally change the overall construction

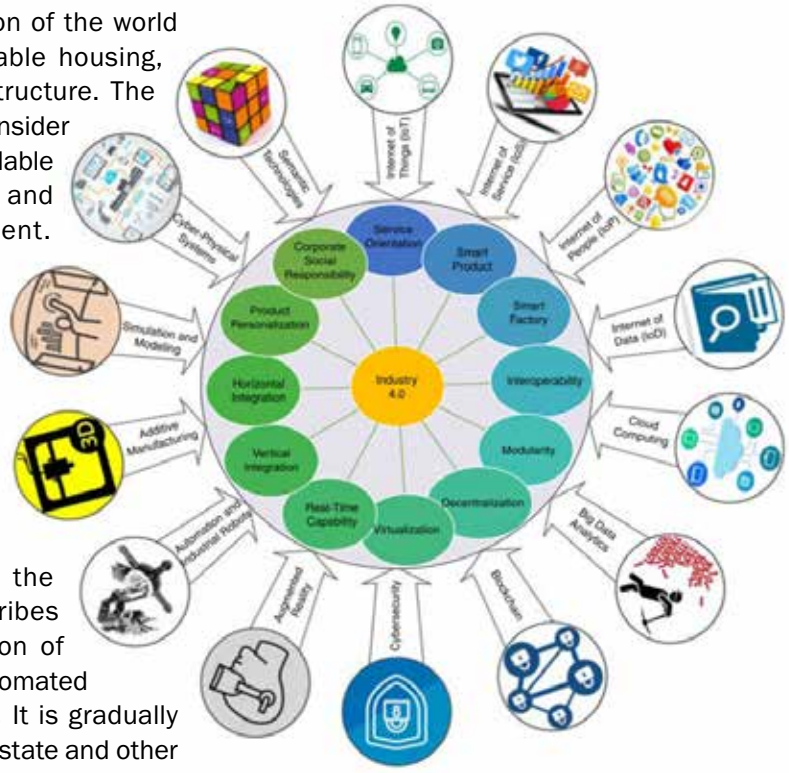

Figure 3: Design principles and technology trends of Industry 4.0 (Source: Ghobakhloo, 2018)

Figure 4: Technology trends for Construction 4.0

value chain, including suppliers of building materials, construction equipment, contractors, engineering, architecture and planning firms, and project owners, from the design stage to demolition. The Construction 4.0 Strategic Plan envisions growth and opportunity by transforming the Malaysian construction industry through digitalisation towards embracing smart construction. The concept is connecting the physical environments with digital ecosystems.

The revolution is more than just technology-driven change *(Lavopa and Delera 2021).* It creates an opportunity, especially in creating collaborative governance ecosystems through Government intervention, to develop mechanisms in supporting the innovators and technology adopters to create an inclusive, human-centred future. In short, it can be summarised as a set of technologies that helps to formulate and empower business leaders to control better and understand aspects of business processes and operations, which allows them to leverage real-time data to boost productivity, improve methods, and drive growth.

> *"The Fourth Industrial Revolution, finally, will change not only what we do but also who we are. It will affect our identity and all the issues associated with it: our sense of privacy, our notions of ownership, our consumption patterns, the time we devote to work and leisure, and how we develop our careers, cultivate our skills, meet people, and nurture relationships." (Schwab 2016)*

Being smart in everything brings the benefits of digitalisation, especially in smart devices, increase the number of smart buildings and cities, along with green technology and sustainability initiatives, benefitting the construction industry.

12 Emerging Technologies disrupting the construction processes

Technologies are emerging and evolving faster than ever before. A wide range of emerging technologies has changed the way work was previously conducted. A glance at the performance of other industries, such as manufacturing, finance and healthcare shows the extent to which technologies have entirely replaced their business operation *(Osunsanmi et al. 2020).* By comparison, the construction industry is still lagging in technology adoption and adaption compared with others. According to *Agarwal, Chandrasekaran, and Sridhar (2016),* construction is portrayed as slow in adopting innovative technology. Only a few construction companies have fully utilised digital planning tools *(Dallasega, Rauch, and Linder 2018).* This matter also has been highlighted in World Economic Forum (2016) as the reluctance of the construction industry towards technology adoption, although most other sectors are experiencing tremendous changes these past few decades.

To better drive the transcending technological waves of today, it is very important to select the appropriate technologies that can bring great improvement to the industry. Thus, understanding, identifying, examining, sorting out, and selecting suitable emerging technologies are among the crucial matters that companies and Governments must undertake. A total of 12 technologies were identified in the Construction 4.0 Strategic Plan (2021-2025) that could potentially shape the Malaysian construction companies to become more technology competent. Technologies that are listed as important to grasp Construction 4.0 at present are Building Information Modelling (BIM); Prefabrication and Modular Construction; Autonomous Construction; Augmented Reality and Virtualisation (AR & VR); Cloud and Realtime Collaboration; 3D Scanning and Photogrammetry; Big Data and Predictive Analysis; the Internet of Things (IoT); 3D Printing and Additive Manufacturing; Advanced building materials; Blockchain and Artificial Intelligence (AI).

BIM. The construction industry is a complex sector that entails many different parties such as clients, developers, contractors, architects, and others. Implementing BIM throughout all stages of the value chain can increase the communication and collaboration process among all parties involved. BIM has been mentioned in several strategic documents such as – UK Construction 2025 *(HM Government 2013*), UK Built Environment 2050 (*Philp and Thompson 2014)*, Singapore Construction ITM *(Building and Construction Authority 2017*) as one of the key technologies for digital transformation. It can be concluded that there is mutual agreement, particularly on the opportunities offered by BIM. Governments all over the world have recognised the positive contribution of implementing BIM in the construction industry. For sure, BIM will soon be the backbone of the construction process. Therefore, pushing BIM to be used by all parties throughout the whole construction value chain is a holistic approach to achieve an integrated environment.

IBS. Likewise, Prefabrication and Modular Construction create many potential improvements in construction. In Malaysia, prefabrication and modular construction are widely known as Industrial Building Systems (IBS). The use of IBS is said to bring advantages such as: improving the quality of construction *(Arashpour et al. 2018; Hao et al. 2020; Zhou et al. 2019)*; reduction of construction waste *(Hao et al. 2020; Lu et al. 2021; Zhou et al. 2019*); on-site and off-site parallel co-ordination *(Hao et al. 2020; Lu et al. 2021*); reduction of construction-induced carbon emissions (*Hao et al. 2020; Lu et al. 2021; Zhou et al. 2019);* and reducing cost (*Arashpour et al. 2018).* CIDB revealed that the adoption rate of IBS in the public sector currently stands at 81% as of June 2019, seeing a threefold improvement from 24% in 2014 *(Construction Industry Development Board Malaysia 2019).* Despite this positive achievement, the uptake in the private sector is slower than expected. The private sector adoption rate of IBS sees an estimated 35% in 2019, out of its 2020 target of 50% *(Jaafar 2019).* If the private sector was more aware of its capabilities and benefits, the implementation of IBS would steadily increase. Thus, comprehensive approaches and strategies are necessary to untangle what is holding back the majority of construction companies in Malaysia from trying the IBS method.

SAM. As an emerging technology, autonomous construction is also expected to offer a promising solution to replace the traditional method. Semi-Automated Masonry robots (SAM), demolition robots, drones, and autonomous construction vehicles are being actively piloted in the industry as autonomous construction. Adopting autonomous construction could create substantial advantages such as increasing work safety *(Gharbia et al. 2020; Jud et al. 2021; Melenbrink, Werfel, and Menges 2020)*, increasing work efficiency *(Gharbia et al. 2020; Yang et al. 2021)*, handling repetitive tasks *(Melenbrink et al. 2020*), and enabling construction in areas not currently feasible *(Gharbia et al. 2020; Melenbrink et al. 2020*). Despite these benefits, automated construction is perceived as having a low adoption rate mainly due to its high cost and technological challenges *(Gharbia et al. 2020*). However, the construction industry depends heavily upon mechanical operations. Therefore, the adoption of fully autonomous construction systems would be best suited for the future construction environment.

AR & VR. Augmented Reality and Virtualisation (AR & VR) are technologies that can revolutionise the industry. Although it could be easy to combine these two technologies, there are some significant differences to consider. *Zhou, Luo, and Yang (2017*) describe augmented reality as the superimposition of digital information over the existing environment. On the other hand, the main purpose of virtual reality is to generate immersive environments where users can experience the real world *(Li et al., 2018).* AR & VR are not a new and are widely used in gaming. There are many stages in the construction sector waiting to be explored by these technologies. A prime example here is the integration of BIM and AR. AR-BIM allows users to visualise immersive views into reality, improve existing challenges and on-site integration and view the as-planned information onto the as-built environment *(Chai et al. 2019).* Looking at the success of its use will bring excitement to the industry.

CLOUD. Cloud and Realtime Collaboration represent a significant departure from conventional construction approaches. Construction 4.0 will open up a new level of data management and integration by using cloud management. The old school way of storing data is through personal desktop, laptop, smartphone, or hard disk. Cloud and real-time collaboration aim to access data over a network connection instead of the traditional method and ease data accessibility. With the advent of technologies, the construction industry can leapfrog to a more synchronised data storage and collaboration process. Cloud and Realtime Collaboration can be a great help at this stage. With the data stored in the cloud, all information can be shared with everyone anywhere. Moreover, it reduces issues such as file storage problems, cross-communication risks and data loss. Inability to access data or data loss eventually will affect project performance, profitability, and time *(Bello et al. 2021)*. In a nutshell, it promises reliable data services storage.

3D SCANNING. It is almost impossible to capture and record a large entity or area. However, 3D scanning, and photogrammetry play an important role in capturing real-world objects accurately. These technologies are widely used in model construction like topographic surveys, the protection of cultural relics and digital city construction (*Liu, Luo, and Yang 2020).* Working with 3D scanning helps obtain an accurate measurement of an object, contributing to the solid foundation for effective control and management of post-sequence engineering quality *(Binjin et al., 2019).* Photogrammetry is another approach for data collection where the geometrical properties of an object on site are generated from its photo image *(El-Omari and Moselhi 2008*). 3D Scanning and Photogrammetry can be integrated with other technologies such as BIM and AR & VR. Therefore, this integration will become the most novel method in the construction engineering field.

BIG DATA. Big data and predictive analytics technologies are included in BIM, Prefabrication and Modular Construction, Autonomous Construction, AR & VR, Cloud and Realtime Collaboration and 3D Scanning and Photogrammetry as the emerging technologies of Construction 4.0. Big data is defined as applying a series of analytical techniques to a large set of data to predict behaviour patterns and monitor business performance *(Ngo,*

Viewing a 3D city model in virtual reality using Augmented Reality Headsets

Hwang, and Zhang 2020). There is a great deal of potential for the industry to benefit from big data and predictive analytics. Part of it is predicting project delays and estimating the energy consumption of a building *(Ngo et al. 2020).* The advancement of technologies will lead to data volume growth. Leaving available data without analytics is a futile action. So, if the construction industry is not up to speed yet, they are at risk of being left behind. Hence, to maximise the potential of big data and predictive analytics, the maturity, and competencies of Malaysian construction companies towards big data and predictive analytics adoption must be evaluated first.

IoT. Put simply, IoT is a technological innovation that changes the way humans interact with devices and the internet *(Goumagias et al., 2021).* Nowadays, most of the appliances or equipment can be connected to the internet. IoT helps to capture the real-time information needed with the power of the network to ensure seamless functioning. Then, all this information will be transferred to the cloud. IoT is making human lives so much easier. Looking at the construction industry perspective, IoT can be used for infrared and heat sensors, temperature, humidity and pressure sensors, track circuit monitoring and motion detectors *(Gbadamosi et al. 2021).* This way, the IoT helps to assess and monitor the risks associated with the construction projects, either in quality or safety.

3D PRINTING. 3D Printing, and Additive Manufacturing also have the potential to modernise the construction industry as it opens a conventional constraint on design. The description of 3D printing and Additive Manufacturing technology is a process of producing 3D solid objects from CAD models that later are deposited by the printer to construct the model (*Bai et al., 2017; Olsson et al., 2019*). 3D Printing and Additive Manufacturing technology is used to produce personalised products with lower costs, in shorter times, with less energy consumed and less material waste *(Rane, Potdar, and Rane 2019*). This way, it also can mitigate the future risks associated with a construction project. On the whole, 3D printing will spark a new industrial revolution journey by digitally transforming entire product development.

NEW MATERIALS. Investing in advanced building material technology is helping companies to stay a step ahead in the digital competition. Traditionally, concrete is used as the main component in the construction sector due to its low cost and ease to produce despite being associated with various drawbacks *(Makul 2020*). The advancement of technologies has offered new materials to improve the functionality of these traditional cement-based materials. One example is the application of advanced concrete technologies such as nanomaterial (*Bautista-Gutierrez et al. 2019*) in modern methods of concrete structures production. Addition of such an advanced material enhances the mechanical strength and reduces the environmental impact *(Makul 2020*). Apart from that, it offers opportunities to deliver buildings and infrastructure that are both resilient and intelligent. After all, the potential of advanced building material is enormous and as long as construction players are willing to combine traditional materials with modern materials, then smarter and more sustainable buildings will soon emerge.

BLOCKCHAIN. Blockchain is one of the ground-breaking technologies that could potentially impact every sector and not just the construction sector. It is predicted to completely overhaul the digital economy *(Perera et al. 2020).* The hypothesis behind blockchain is blocks of information like a chain which can substantially improve the data integrity and data reliability *(Kim, Lee, and Kim 2020*). This technology focuses on decentralised, transparent, open source, autonomy, immutable, and anonymity *(Niranjanamurthy, Nithya, and Jagannatha 2019*). Remarkable applications of blockchain in construction are smart contracts, construction coins, blockchain-based BIM, securities, digital currency, and record keeping (*Kim et al. 2020*). Among advantages served by blockchain are enhancing security, reducing construction costs, and excellent transparency *(Kim et al. 2020*). To conclude, the adoption of blockchain concept could address several problems and improve project delivery processes.

AI. These past years, artificial intelligence (AI) has provided benefits to construction projects especially in overcoming some of the toughest work. Generally, AI is defined as the science and engineering of making intelligent machines, especially intelligent computer programmes (*Cioffi et al. 2020*). To simplify, AI is a simulation of computer science to make machines act like humans *(Abduljabbar et al. 2019*). The subset of AI such as machine learning, deep learning, and robotics are profoundly important too. There are many uncertainties and problems within the data that cannot be solved by human or traditional approaches. Basically, AI helps to solve those uncertainties by using the available data and producing better analysis. This will create a safer, smarter, and more productive construction environment. However, without appropriate policies and strategies for adoption, AI in construction may depend largely on the motivation of construction players themselves.

At the heart of this paper is a realisation that we are living in a period of adaption. Construction 4.0 transformation is necessitated by the aforementioned disruptive technologies. A step closer to the transformation can only be achieved through the active participation and engagement from four major actors of a quadruple helix. It can be concluded that creating collaboration and integrating these technologies offers significant opportunities to improve construction productivity and to meet other potential challenges of the future. At the present time, Governments need to focus on strengthening collaboration and technology adoption through developing policies and strategies that cultivate innovative actions.

Vision, Goals, Core Values, and Strategic Thrust for Construction 4.0

Transformation of construction towards the current wave of digitalisation seems vital among construction players. However, a holistic approach and planning are needed to successfully transform all the construction phases. The 12 emerging technologies listed in Construction 4.0 strategic plan act as the main catalyst. In summary, their roles are aligning the digital data, twinning with real-world conditions, besides enriching the construction layout with accurate data and measurement. Acceptance of the construction supply chain

Figure 5: SWOT Analysis for Focus Group Discussion (FGD) with Construction Industry

towards a revolution through people, process and technology advancement and its intellectual capital drives this transformation by a proper planning on operation, tactical and strategies. **Figure 5** shows the key features of the industry's natural strengths and weaknesses, and the challenges faced by industry players in implementing Construction 4.0.

Game Changers: Vision and Goals

Looking into the existing support for construction markets, with tight fiscal constraints, it is important to bring construction businesses to a high level of performance and deliver high-quality technical products and services. Creating and orientating core values in line with a digitised strategy will incentivise the growth of technology and bring about improved business performance. A clear vision "to be the leading Construction 4.0 Country in the Southeast Asian region" has created a network among its members across disciplines to jointly discuss, develop and execute construction strategies towards digital transformation. These multiconcerted efforts will benefit industry participants and prepare the region for this revolution.

By adopting the 12 technologies, lots of game changers become available such as the modular factory, with its ability to distribute and automate production in terms of scalability and flexibility of design and manufacturing processes. With this transformation more valuable products can be offered which involve several different entities that will be managed by different plant owners. Standardised business interfaces allow fast and efficient negotiations and contracts to be agreed upon using automated brokers employing smart contracts via blockchain technology. Prior to changing production methods, it is desirable to simulate and optimise processes by using the BIM platform which comprises multiple production units, to meet customer demand and support.

The goals of the smart construction game changer are:

- Fast decision-making and support both for humans and machines in the construction industry.
- Enable 'to do' decisions, based on big data derived from multiple sources.
- Improve Machine Learning and AI to support monitoring and automated decision making of production processes, predictive maintenance and to speed up response

times to issues within a cybersecurity environment.
- Engineering processes and tools to simplify the adoption, usage and evolution of emerging technology in processing industries.

Hence, by applying these goals we will be able to provide related services and knowledge in construction which require changes from the traditional business environment and the old business models.

Creating the Core Values of Construction 4.0

Digital construction has the potential to deliver huge benefits for everyone involved in the industry. Through the adoption of digital tools, the industry will benefit from increased profitability by working more efficiently, as well as making the workplace safer for everyone involved. The current skills gap can also be addressed by offering a more attractive career option for ambitious young people. To make a success of these skills, there is a need for construction players to uphold the key core values that help to define the non-negotiable standards guiding the decisions for the construction entity. **Figure 6** illustrates the core values for Construction 4.0.

Strategic Thrusts of Construction 4.0

Malaysia's construction sector, aligning with the envisioning of MYDIGITAL has to create a Construction 4.0 Strategic Plan, by adopting the quadruple helix approach. This requires collaboration between multi-disciplinary functions in Government, Industry, Academia and Society sharing the long-term vision for the industry and its future action plan. The key objectives of the Strategy are to lower construction life cycle costs, besides being productive through increasing the performance of delivery and reducing greenhouse gas emissions in the built environment. In addition, one of the strategic aims is to align manpower needs, smart solutions, sustainability, growth, and leadership. Therefore, there are four main strategic thrusts that have been aligned in this document including:

1. Building Capacity;
2. Research, Innovation, Commercialisation & Entrepreneurship (RICE);
3. Smart Integrated Technology, Innovation, & Infrastructure; and
4. An Enhanced Business Environment.

With these strategic thrusts, more efficient and technologically advanced solutions in all areas of construction can be achieved and spearheaded by investment in research and innovation, we can maintain our global standing. The commitment of management especially in adopting the BIM programme will create a great opportunity as the way forward for Malaysian construction. Attracting future engineers by reskilling and upskilling the existing workforce is key to boosting capacity and capability. This strategic thrust will also create a great opportunity to build a strong and resilient supply chain. **Figure 7** displays the summary of the strategic thrusts and strategic objectives for Construction 4.0 Strategic Plan 2021-2025.

a. Building Capacity

One of the challenges facing the industry is addressing the need for a capable workforce. As the wider economy emerges from the recession, construction firms must be able to recruit and retain skilled, hard-working people in sufficient numbers to meet the increasing demand for construction. A new type of reskilling and upskilling programme that includes training for anticipated new skills is needed to build a competent workforce which is recognised by the industry. An incubator is one of the practices that might be useful in developing the skills required to support and innovate those organisations that adopt new technologies.

Another approach that might be effective in driving transformation is an apprenticeship programme supported by manufacturers, and contractors that can be delivered over a two-year period for new entrants.

b. Research, innovation, commercialisation, and entrepreneurship

Research, innovation, commercialisation, and entrepreneurship (RICE) is a strategy which aims

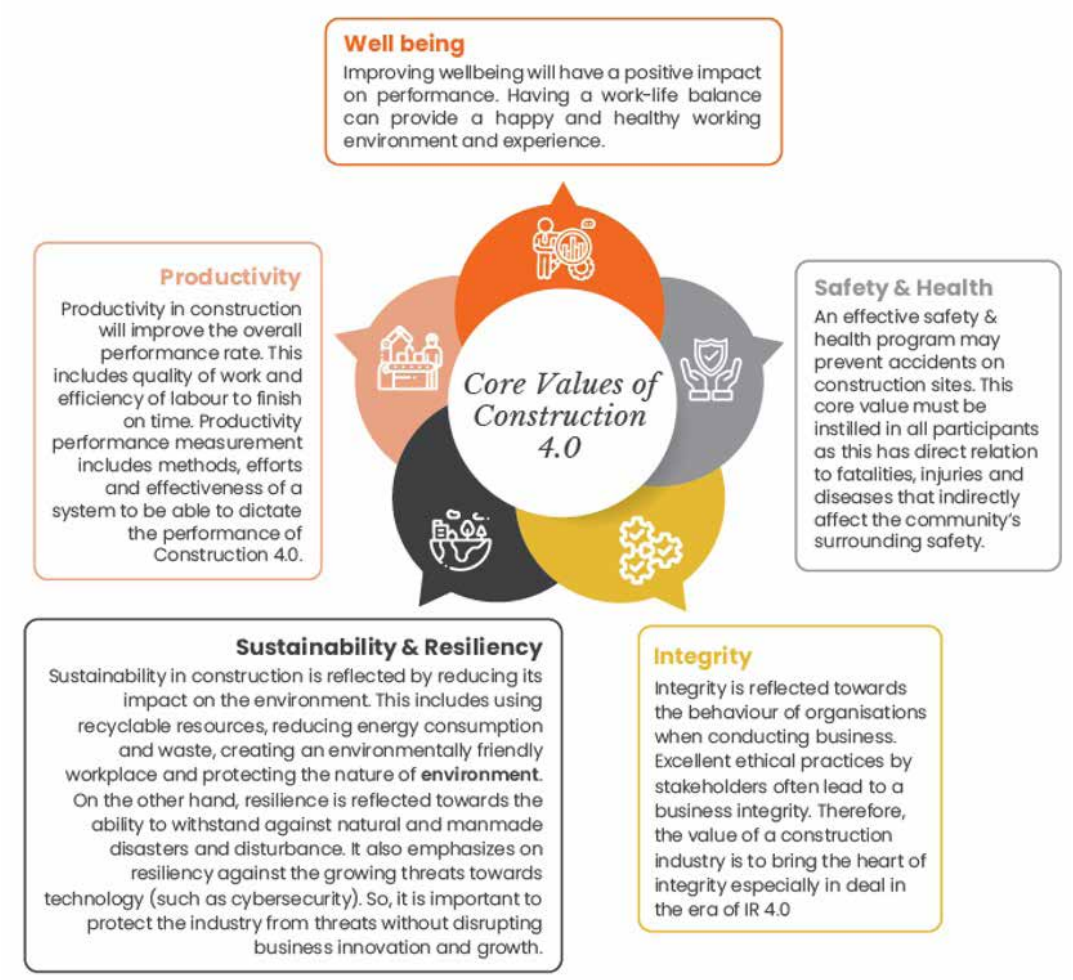

Figure 6: Core Values for Construction 4.0

Figure 7: Strategic thrusts and strategic objectives for Construction 4.0

to create an effective platform for digitalisation and re-industrialisation within the construction industry. In many roadmaps most of the innovations are designed to collect, analyse and use adequate data for and from simulations to support decision-making. Hence, bringing these strategies to fruition, would enable key players in construction to co-ordinate their approach to innovation across the sector supporting the uptake of research. Therefore, to achieve this, a proper knowledge developed research community needs to be created, that is more visible to the public. The innovations should include most of existing technologies, upgraded in scope to meet the needs of future research as part of a long-term vision for the sector.

c. Smart Integrated technology, innovation, and infrastructure

Smart Integrated technology, innovation and infrastructure are of the highest priority to continuously increase the efficiency and availability of production processes and the utilisation of plant equipment. The focus should be on agile and multi-use plants that can deliver both the economies of a large single stream plant, and the flexibility of a batch plant as well as be part of a global production process, while within limits, being able to make multiple products. This would allow for production flexibility and the possibility of ramping up production capacity for specific on-demand products.

To support the above, the platforms, products, and services used in the production processes will need advanced lifecycle management and collaborative functionality. Here, production-related data must be collected and used as input, and integration and interoperability must be improved. Tools for modelling, design and simulation will be necessary and later combined with tools to monitor the production process and its equipment/platforms, connectivity, productivity as well as quality of services used or provided.

Certain design steps can be replaced with design automation. Based on a survey conducted in 2017 (*Lackman et al., 2017*), design automation methods have been applied in sub-disciplines of plant design, e.g., automated tube and pipe path design. Application to conceptual or basic plant design seems today to be missing. Further, continuous and on-line optimisation together with professional training of workers will ensure productivity and efficiency. Monitoring and optimising knowledge of the production process and its equipment is essential in order to be able to model it, understand which relations and dependencies are most important, as well as collect and analyse data to provide inputs to decision-making and KPIs. Maintenance and the ability to predict problems and act in a planned and proactive manner rather than react to problems that have already arisen is an example of what is required. An issue resulting from the growth in collecting and using data is how to manage the data on a long-term basis as well as who can use it, for what and when. The data must be preserved using a well-considered strategy to retain its usability and future value, and furthermore, some of the software used may also need to be preserved, so that old data can be used/available in the future when needed. This matter will become increasingly complex as the amount of data collected and stored grows and external data and metadata are used, and a lot of data will in the future not be stored but streamed and only a few data points will be stored for historical purposes.

d. Enhanced Business Environment

In line with the goals set out in the Construction Strategic Plan, it is hoped that this strategic objective will help Malaysian construction companies, in particular SMEs, to adapt to global competitive pressures. This will be achieved by enhancing the business environment.

WAY FORWARD

Implementing the interactive quadruple helix model to strengthen the partnership.

The quadruple helix is human-centred and focuses on democratic knowledge to produce innovative systems that should serve society (*Hasche, Höglund, and Linton 2020).* Aligned with the mission to transform the Malaysian construction industry by empowering smart construction for the future of society, a paradigm shift in how building and infrastructure projects are being delivered must provide more value-added to the quality of life

Figure 8: Roles and responsibilities of actors for implementing quadruple helix innovation in Construction 4.0 strategic plan.

for future society. The quadruple helix approach in Construction 4.0 Strategic Plan promotes an open platform for relevant stakeholders to participate in decision-making and innovative processes. Four main actors involved in the quadruple helix include Government bodies (public authorities, regional development agencies, and policymakers), industry, academia, and citizens (*Hasche et al. 2020; Schütz, Heidingsfelder, and Schraudner 2019; Värmland County Administrative Board and Värmland County Administrative Board 2018)*. The strategic plan highlights how the four key actors need to work collaboratively in the innovation system.

Due to rapid changes with more emerging technologies produced in the future, an in-depth understanding of every technology is critical before implementation *(Lau et al. 2019*). The foundation to embark on any technologies and innovative solutions should be determined by the user's needs and the problems that need to be solved. New solutions developed will create value for both users and relevant stakeholders based on the user needs and problems. With the concept of user-oriented innovations embedded in the Construction 4.0 strategic plan, the definition of users in the quadruple helix approach remains vague. According to *Hasche et al. (2020)*, users are not only limited to society or citizens, but users also can be found in all of the three actors of Government, industry, and academia. The concept of end-users includes the users who will use the output of the value-creating process. However, it is important to ensure that all quadruple helix actors are involved from the beginning of the innovation development process.

CREAM as a Centre of Excellence for digital construction

To facilitate and implement the quadruple helix approach, CREAM aims to develop a platform to create and improve the delivery of innovation for Construction 4.0. The platform also will enhance co-operation between stakeholders in co-creating and disseminating advanced innovation for the nation. With the Ministry of Works and with CIDB support and a concerted effort by industry players, the initiative to digitally transform the construction industry could materialise. The construction technology, digitalisation, and innovation committee was established recently by the Ministry of Works to discuss the issues, challenges, and ways of transforming the construction industry towards digitalisation. Six technical working groups (TWG) were formed to discuss and obtain better insights into how the construction industry can effectively accelerate digital transformation. Under the TWG 5, CREAM is responsible for providing an appropriate platform for quadruple helix collaboration.

A centre of excellence for digital construction facilitated by CREAM is proposed to create a comprehensive digital ecosystem to transform

the Malaysian construction industry. The centre of excellence seeks to digitalise the entire construction project lifecycle by:

1. Developing a mechanism (e.g., Construction 4.0 Living Lab) to intensify research, development, commercialisation, and innovation (R&D&C&I) in emerging digital technologies.
2. Developing and promoting guidelines, standards, best practices, and policies in implementing Construction 4.0.
3. Assisting Malaysian construction stakeholders and relevant parties (Government, industry, society) to seize opportunities offered by adopting digital technologies and innovations.
4. Upskilling and reskilling future workforce for Construction 4.0.

CONCLUSION

The construction industry has to leapfrog from the traditional way of doing things to an innovation-driven approach. The world economy has changed tremendously in innovation and digitalisation. It is high time for industry players, academia, and society to embrace innovation and digitalisation to move a step ahead. CREAM can bridge the gap between all these stakeholders and act as a facilitator for this innovative approach through the quadruple helix. Industry participation, strong support in Construction 4.0 and innovation are key success factors. Building vibrant technologies also needs strong support and clear policies from the Government. We should capitalise opportunities in Construction 4.0 to transform industry. ■

Acknowledgement

This work was supported by CIDB under the consultancy work entitled "Development of Construction 4.0 Strategic Plan." CREAM would like to acknowledge the Universiti Teknologi Malaysia (UTM) for their dedicated commitment and contribution as a research associate for this work. We also want to acknowledge the CREAM project team members for their insightful feedback. Special thanks to CIDB top management and officers for their support and valuable insights in developing the Construction 4.0 Strategic Plan. Finally, thank you to all stakeholders, including representatives from Government agencies, industry, academia, and society, for making the strategic plan a living document for the nation.

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