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CONSTRUCTION WASTE MANAGEMENT: PREPAREDNESS TOWARDS THE 4TH INDUSTRIAL REVOLUTION

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ABSTRACT

Construction waste management (CWM) has progressively improved in a few years, especially in the reduction of waste generated on site and less waste disposal to the landfill. However, there are still a few constraints in operating the waste through the 4R's concept efficiently. The 4th Industrial Revolution has slowly assimilated into stakeholder engagement in many businesses from various perspectives. The CWM is one of the perspectives in the construction industry that needs emergent response to these evolving trends. Intensive literature review has identified several factors that must be considered by construction practitioners in CWM, mainly for achieving the 4th Industrial Revolution. Furthermore, several technologies applied in different developed countries are reviewed, particularly to explore waste management technology through the 4R's concept (Reduce, Reuse, Recycle, Remove). This paper has discovered adaptability, the robustness of the technology and accessibility as factors that need to be considered in introducing technology in CWM. The findings give direction to technologists from the public or private organizations in developing proper guidelines of CWM.

Keywords: construction waste management, sustainable construction, 4th industrial revolution

INTRODUCTION

The 4th industrial revolution is ultimately interconnected in several perspectives in the construction industry where it actually hints for all stakeholders to integrate to the changes. It is due to differences in scale, scope, and complexity where the transformation will not be the same as what humankind has experienced before. To integrate with, there should be a comprehensive understanding of the technical background of this 4th industrial revolution to ease stakeholders to take steps towards its application (Mavropoulos, 2017).

The industrial revolution 4.0 is characterized by a fusion of technologies that is blurring the lines between the physical, digital, and biological spheres. Artificial Intelligence, Robots, Drones, Driverless Cars, 3D Printers, Internet of Things and The Revolution of Sensors, Decentralized Energy, DNA Engineering and the Rise of Bio-economy create a new

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landscape that will reshape manufacturing. It will also reshape the waste management procedure in terms of recycling, redefining the meaning of "waste", creating new technologies, delivering robotic solutions and driverless collection patterns (Mavropoulos, 2017; Park, 2016).

SUSTAINABLE CONSTRUCTION WASTE MANAGEMENT VERSUS THE 4TH INDUSTRIAL REVOLUTION

Since several years ago, some researchers and experts in waste management have contributed their effort tremendously to find a way of minimizing construction waste that is generated during the construction phase. Chung and Poon (2000) stated that the 3R's concept is a way that should be emphasized on site for minimizing the waste. In addition, a charge should be enforced to the contractor who disposes the waste to landfill (Deng, Liu, & Hao, 2008). Therefore, the waste disposal approach is expected as the last option among contractors. Nevertheless, waste disposal was still the top approach which has been practised among contractors. This approach was seen among researchers and experts as one of the critical issues that needs an urgent action. Thus, sustainable construction has been intensively promoted among contractors which aimed to reduce waste disposal to the landfill. However, sustainable construction has been destructively debated among researchers in various contexts. It has long been recognized as one of the measures being emphasized to reduce the negative impacts towards environmental, economic and social. Construction waste management (CWM) as one of the components has been reported to experience greater contribution to sustainable construction (Saidu Ibrahim & Shakantu, 2016; Jannatun Naemah Ismam, Ida Nianti Mohd Zin, & Mohammad Redza Rosman, 2017). Furthermore, previous research trends have proposed several initiatives and some of it has been implemented by the public and private organizations to ensure continuous efforts are tremendously done for achieving sustainable construction. It is also supported by Yuan (2012) and Ibrahim (2016) who pointed that the government and several institutions have strived in improvising few policies, guidelines, and strategies of CWM by considering sustainable concept into practice.

As a way towards the 4th industrial revolution, those initiatives introduced for sustainability in construction seem to need several efficient tools with basic technology application to ensure the quality of 3R's implementation in CWM to be achieved. It was agreed by Saieg, Sotelino, Nascimento and Caiado (2018) and Won and Cheng (2017), who opine that several issues related to poor design quality, inefficient material handling and poor procurement and planning could be eliminated by means of absorbing kind of technologies such as spatial technologies, identification technologies, data acquisition, and data communication technologies.

CONSTRUCTION WASTE MANAGEMENT IN 4TH INDUSTRIAL REVOLUTION TECHNOLOGIES

At present, the 4th industrial revolution is being perceived by the human being through various perspectives as a way of addressing the challenges of achieving sustainable development. Over the few years, the 4th industrial revolution perceived has been intensively applied especially in developed countries. There is an emergent action taken from these developed countries in integrating the technology advancement with various perspectives of human life. According to Mavropoulos (2017) and Herweijer (2017), the 4^{th} industrial

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revolution is the era where such production and manufacturing process be reshaped into a fusion of technologies (Mavropoulos, 2017; Park, 2016).

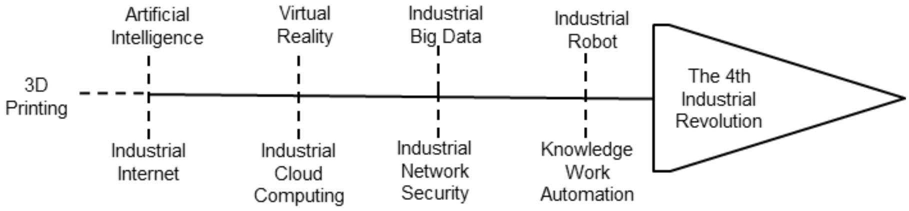

Figure 1: Different Potential Technologies in the 4th Industrial Revolution

Figure 1 indicates that the technologies comprise of different potential directions and opportunities. The potential opportunities are not only directed to individual prospects but also to business organizations where intervention in this new phase of development is possible (Park, 2016). An urgent response to the change of trends is required to ensure the challenges of sustainable development could be addressed optimally. Some researchers have highlighted a few technologies which it could be applied in a certain aspect of CWM. Recapitulating on what has been recognised by Jannatun Naemah Ismam, Zulhabri Ismail, Harwati Hashim and Alam (2014), there are three bases of initiative implementations comprising strategy, enforcement and involvement. Nonetheless, the National Academy of Science and Engineering has highlighted on the probability of efficient technology to prevent the faulty product, which in some ways reduce the waste of materials. The unavailability of basic technologies has directed the 4th industrial revolution working group to formulate 8 prior areas as initial steps to widespread business networks. The areas are related to regulatory, broadband infrastructure, professional development, architect standardization, work organisation, managing complex system, safety and security and resource efficiency. Among those 4th industrial revolution 8 keys priority areas, Marshall and Farahbakhsh (2013) and Wu, Yu and Shen (2017) had reviewed that regulatory framework is an approach that encompasses not only the technical and environmental but also the political, social, financial, economic, and institutional elements of waste management. Besides that, mandatory requirements from regulations enforced might be directed to increase the level of usability of technology in construction waste management. Additionally, Pan, Linner, Pan, Cheng and Bock (2018) had a different perception of CWM in the 4th industrial revolution. It should be according to several factors, namely robustness, adaptability and accessibility as to assess its suitability before being regularly enforced (Figure 2).

Adequacy of guidelines seems significant to ensure the technology introduced is capable in tackling different working environments with the different object to be coordinated. It is supported by Ofori and Kien (2010) who confirmed that level of responsibility among construction practitioners towards CWM technology adoption might be increased when there are mandatory requirements by regulations with specific guidelines. Therefore, the government's role in the construction industry is necessary to be studied further in order to underline the scope of works in a specific context as to ensure the technology is adaptable to users and system smoothly. On the other hand, the technology should be followed by robustness which concerns validity and reliability during operation (Pan et al., 2018).

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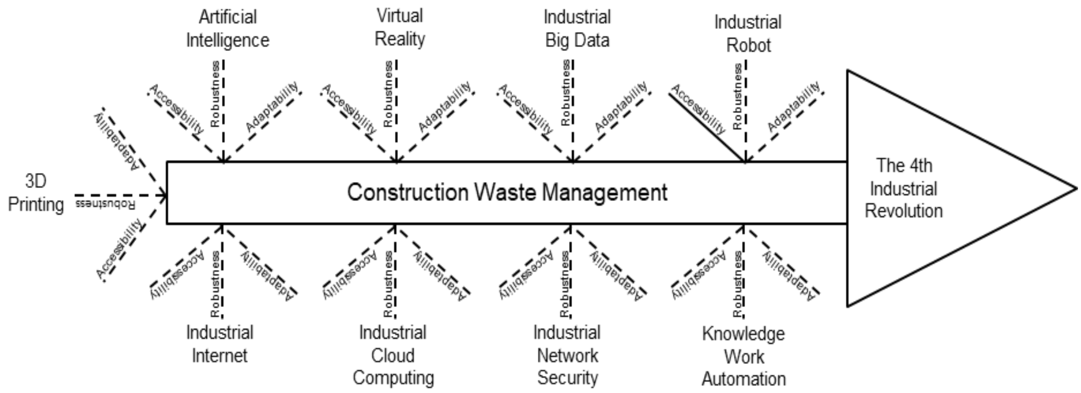

Figure 2: A framework of Successful CWM in the 4th Industrial Revolution

In previous research, one of the limitations has been recognized through existing construction waste management tools where the waste data recorded using CDW estimation tools was still insufficient. The potentials to be fully systemised by technology has not been realised due to the accuracy of the waste data entry that involved a high level of human intervention, which is prone to errors (Saieg et al., 2018). Subsequently, in many scenarios ahead the technology has to deal with the machine and its components. Accessibility of technology proposed is important to entirely foresee application scenarios. It is agreed by Jupp (2017) that the gap in communication technology and poor quality information flow was identified from fragmentation between project participants and inconsistencies in information accessibility. Therefore, Udawatta, Zuo, Chiveralls and Zillante (2015) opine that effectiveness technologies implementation should be considered between information delivery and communication technology inbounded with some factors such as energy, the cost for manufacturing, and dismantling. BIM, for instance, has widely been suggested as a software that is capable to deal with scheduling and cost of materials.

REVIEW OF 4R'S PRINCIPLE IN 4TH INDUSTRIAL REVOLUTION TECHNOLOGIES

Construction waste has different characteristic compared to other waste in terms of 4R's perspective. Critical challenges are faced by stakeholders when these waste are disposed to landfill as a last resort. It should be properly managed during the designing stage for minimising waste production along with project implementation. Nonetheless, there is still lack of concern given to design supervision and as much as 60% of architects do not generally acknowledge this issues (Kern, Dias, Kulakowski, & Paulo Gomes, 2015).

Reducing waste in the construction industry begins with the learning and development process where practitioners acquired some input and create a relationship between technology and CWM as well as measuring a level of adaptability. Concerning the difficulty of adapting technology, some organizations are called to formulate a holistic education and training which focus on technology or building soft innovation by way of investing in knowledge management as to reach a fast movement of Sustainable CWM (Ooi, Lee, Tan, Hew & Hew, 2018). In the context of the construction life cycle (CLC), most previous research has emphasized the same viewpoints where reducing waste that are generated should start from the design stage. Several researchers had suggested the construction waste technologist to

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critically analyze during the designing stage through identifying potential waste material to be reused or recycled (Ajayi et al., 2017; Akinade et al., 2018; Mohd Reza Esa, Halog, & Rigamonti, 2017). Table 1 summarizes the construction waste reduction via designing stage and construction stage recommended by different authors in different view of the research field.

Waste reduction recommendation strategy	Author
• standardization and dimensional coordination, • employ principles in modern methods of construction, • provides measures for spatial and components flexibility, • make provisions for end of life deconstruction • employs techniques in BIM for design coordination	(Ajayi, et al., 2017)
• prefabricated components application, • reduced design modification at the design stage, • on-site sorting and material reuse at the construction stage, • provide references for governments in assessing the reduction management outcomes of construction projects and the environmental benefits	(Ding, Zhu, Tam, Yi & Tran, 2018)
• team building and supervision; • strategic guidelines in waste management; • proper design and documentation; • innovation in waste management decisions; and lifecycle management.	(Udawatta et al., 2015)
• waste management plan and construction methods in the planning and designing stage; • awareness and awards and regulations enhancement during procurement phase; • effective management during the stages of construction and demolition	(Esa, et al., 2017)
• tackling of waste at design stage, • whole life waste consideration, • compliance of waste management solutions with BIM, • cheaper cost of waste management practice, • increased stringency of waste management legislation and fiscal policies, and research and enlightenment	(Ajayi and Oyedele, 2018)

Table 1: Waste Reduction Recommendation Strategy

Malaysia has been exposed to IBS system since a few years ago where it was expected to reduce waste generation during the construction stage. It was discovered by experienced contractors where 52% of construction waste could be minimized during project implementation. This prefabrication component has been moderately practised in a holistic approach. Instead of the lack of explicit legislature governing in construction waste management, it is merely convenient to the huge and costly investment of project (Yu, He, Li, Huang, & Zhu, 2014). As a continuous and proactive contribution from various organizations towards construction waste management, there is Building Information Modeling (BIM) which is a overlay to the RIBA Outline Plan of Work in conjunction with the Green Overlay.

Moving towards the 4th industrial revolution, the BIM was introduced to architects as to assist them as a stage by stage guidance especially in design subsequently managing the construction projects (Liu, Kong & Santibanez Gonzalez, 2018). BIM is aimed at alleviating reduction of waste in the first stage. Several findings have indicated that the BIM has slowly being accepted among contractors in the construction industry. Again, it is not only because the collaborative facilities but also because the government's influences which have succeeded in shifting the industry towards its adoption. The capability of BIM is to represent great digital storage, allowing project database being assessed throughout its life cycle and give positive feedback to this BIM (Ajayi et al., 2015). Furthermore, BIM application has the potential to reduce the waste in the construction stage by reviewing a few recommended strategies for BIM implementation. For instance, in the context of technology, 3D printing building as one of the techniques suggested by Wu et al. (2017) as an innovative method was developed from BIM technology application.

In the context of technology, an innovative 3D printing has been discussed by Camacho et al. (2018) who emphasized on additive manufacturing (AM) as component fabricated in a layer wise fashion directly from a digital model. Since it is generated from a digital file, these 3D printing processes build a finished structure with waste reduction and reduce the cost of construction as well. It has been proven by Sakin and Kiroglu (2017), who found that the 3D printer, which is able to develop a 3D model of the building has been adopted in China and it has resulted in the reduction of construction waste between 30% and 60%. At present, STL format is commonly utilized among software agents. In China, 3D Printing with STL file format has been executed towards recycled materials which came from construction waste, industrial waste and mining waste (Sobotka & Pacewicz, 2016). Different technologies and methods introduced have actually succeeded depending on the companies' mindset to absorb and accept the changes since it might be complex and takes time to disseminate these new trends (Kern et al., 2015).

The issues of recycling the waste generated on site have been tremendously discussed but still not wisely practised even in developed countries. For instance, in Spain, there is around 13.6% of waste recycled from 45 million tons of construction waste generated. In addition, in Denmark there is about 25% to 50% of waste generated on site and recycle method has already been applied due to the limited space of landfill (Bernardo, Gomes & de Brito, 2016). Recycling has diverted any waste produced on site from disposal to limited landfill. Inherently, a common approach is used in recycling waste generated by the production of recycled aggregates (RA) which is utilized to replace natural aggregates (NA) by way of various applications (Maria, Eyckmans, & Van Acker, 2018). Based on review from several different fields of research, it is indicated that most of the materials used in construction projects have been reutilized in many ways.

There are a few areas of concern about construction waste recycling technologies. However, it is perceived that most of the authors had suggested 3D printing technology as the best way to recycle the waste generated on site. For example, Jayanthi (1983) a few years ago had experimented a variety of raw materials including recycled plastic, bio-plastics, concrete and a synthetic "stone-like" material created from a combination of sand and chemicals. By producing alternative materials concrete mixtures, it has resulted in significant environmental benefits. It has been proven by Hossain and Poon (2018) that there were at least a 25% reduction in energy consumption and a 15% reduction in CO2 eq., in comparison to conventional concretes manufactured with virgin materials.

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In Bangkok, the waste management system has been set up under clear policies but there are still some problems which occurred during the operation, especially the transportation performance which was ineffectively and inappropriately used and takes time to sort all recyclable and valuable waste during collection and transportation. By introducing Global positioning system (GPS) and fuel level devices (FLDs), the performance has improved the organization of collection routes and the number of trips in each area (Sukholthaman & Shirahada, 2015). At least, this service is able to respond to the growing amount of waste on site and increase the efficiency of waste management collection routes, transport distance, collection methods and treatment methods whether the waste is to be recycled or disposed of.
To meet the 4th industrial revolution, construction practitioners whether public or private organizations need to take the first step in initiating effective methods by imitating a few CWM Plan that have been successfully implemented in developed countries. Concerning the construction waste generated on site, the factors that have been discussed previously might give a direction to the government to be detailed in the process of creating a new technology in CWM.

RESEARCH METHODOLOGY

This research begins with the literature review which emphasized sustainable construction waste management evolvement from 2012 until 2018 to explore several initiatives taken and how far it's implementation has been. From the initiatives identified, comparative analysis has been applied in this research by reviewing several factors that have the potential in assisting construction waste management towards the 4th industrial revolution. Furthermore, to initiate an idea of construction waste management in the 4th industrial revolution, this paper has discovered some technologies that have been successfully adopted in developed countries and the technologies reviewed were aligned with the 3R's concept. Through all research mentioned in this paper, a framework has been developed to overview the factors that could potentially assist construction waste management to be aligned with the 4th industrial revolution.

CONCLUSION

The 4th industrial revolution in construction waste management has reviewed sustainable development's 3 keys indicators (environmental, economic and social) to still be perceived as a guidance to ensure the efficiency of technology performance. It has been proven through the functions of each technology proposed throughout 4R's implementation that were aimed to achieve sustainable construction. However, this paper has indicated that there are some challenges to be faced by several developing countries especially in energy intensity, operation cost and skills to implement the new technology. Since the regulatory framework is an approach that can increase the level of usability of technology in construction waste management, the private and public stakeholders need to become partners in taking responsibility to promote the 4th industrial revolution in CWM.

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