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THE UNDERSTANDING AMONG CONTRACTORS IN ADDITIVE MANUFACTURING TECHNOLOGY IN LOCAL CONSTRUCTION INDUSTRY

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Abstract

Additive manufacturing is one of the key elements in industrial revolution 4.0, new to construction industry and have potential to enormously impact the industry due to its ability to disrupt the existing construction supply chain direction and order. The construction players especially the contractors are expected to be the first entity to experience the effect and widely use the technology but up to this stage, the contractors' understanding towards the technology are unknown. At the same time, the Malaysian construction industry suffer lack of responsive towards technology that might one day be left behind if it unable to adopt to the new technology. Therefore, the study is conducted to identify the understanding of local contractors about additive manufacturing in construction industry. The findings can be used to further plan how to overcome challenges in industrial revolution 4.0 environment. A quantitative approach through survey has been engaged and distributed randomly to contractors via emails and by hand. Besides, literature reviews have been conducted to deeply understand the concept of additive manufacturing, its impact and implication as well as the future prospect. The result is analysed based on mean score and able to identify that the contractor does not has the understanding in additive manufacturing technology in local construction industry.

Keywords: Additive manufacturing, construction, Industrial Revolution 4.0, 3D printing.

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1. Introduction

The world that we live today has seen momentous and rapid changes in the industrial sectors. These changes are fuelled by inventions and innovations that give birth to revolutions in industry, progressing over time until the current Industrial Revolution 4.0 (IR4.0). The industrial revolution significantly affects every aspect of human life (Chung & Kim, 2016) and will deeply impact humankind in terms of how they work, live and communicate to one another (Schwab, 2017). Its scale of influence is too big to ignore, global rather than local, unprecedented breadth and depth (WEF, 2017b) and able to manipulate the economy, business, society and individual in both national and international stages (Schwab, 2017). To a further degree, the latest revolution may bring the unthinkable moment that can realised science fictions and illusion which previously beyond reach and impossible to happen. Therefore, considering the massive influence brought by the revolution, it will be appropriate now to study about the revolution sphere, its key drivers and impacts that will shape the humankind in the future.

IR4.0 disrupt the supply chain and transform all end-to-end stages in production and business model in most sectors of the economy (WEF, 2017a). For example, one important component in IR4.0 such as Additive Manufacturing (AM) technology can produce home-grown product that will lead to a world whereby worldwide become domestic, mammoth become miniature, and extensive supply chain will be narrowed down (Ben-Ner & Siemsen, 2017). The ultimate ability of AM to eliminate some chains in the current supply chain raise the eyebrow and shall be handled accordingly.

At some level, the AM technology will reach the construction industry massively and disrupt the conventional construction supply chain. For instance, recent construction scale AM products as shown by few companies around the world such as WinSun in China and MX3D in Netherland proved the construction-scale additive manufacturing whereby concrete residential buildings and stainless-steel pedestrian bridge can be 3D printed respectively. The nature of AM technology and its progresses will subsequently in the future eliminate or reduce the use of construction materials such as woods for formwork, bricks for wall and steel for moulds in the future. As a consequence, it may trigger jobs movement for the disturbed supply chain, similar to report from WEF that stated the IR4.0 will deeply impact the employment market either with significant job creation or job displacement (WEF, 2016b).

Additive Manufacturing (AM), as opposed to traditional formative and subtractive manufacturing, is an advance manufacturing processes that refers to a procedure to assemble materials to create objects from 3-Dimensional (3D) model data, usually layer after layer (ASTM: F2792-10, 2017). AM involve the processes of transforming simulated solid model information into physical models in a fast and easy way (Gibson, Rosen, & Stucker, 2014) and able to print complex form of geometry with the absent of any tools, dies and fixtures (Huang, Liu, Mokasdar, & Hou, 2013; Tay et al., 2017). It also known as direct digital manufacturing, rapid manufacturing, solid freedom fabrication and rapid prototyping, (Fai & Karjanto, 2014). Besides, the AM is widely referred as 3D Printing in general term (Labonnote, Rønnquist, Manum, & Rüther, 2016) although its scope is wider than the 3D Printing. Due to its ability to enable customised material properties and create complex form of geometries, AM has gained significant industry and academic interest (Gao et al., 2015).

In general, the AM processes begin with a modelled 3D design with Computer Aided Design (CAD) software. Then, a layer of printing material is fed into 3D printer which later on printed the shape of 3D

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model. This process will repeat and continue until the selected physical model is accomplished (Ishengoma & Mtaho, 2014). The process is similar to the conventional system of 2-dimensional (2D) paper printer but different in terms of techniques, scale, materials used as the 'ink'. Figure 1 illustrate the processes.

The ink or the materials used and its characteristics for 3D printed property can be different and variety, depending on where it will apply. For example, geopolymer cement can be used as 'ink' to contribute towards sustainable environment due to its characteristic that can be considered as green construction material (Panda, Paul, Hui, Tay, & Tan, 2017). Besides, wide range of raw materials can be used as 'ink' such as plastics, resin, cobalt and nickel-based chromium, titanium, stainless steel, ceramics and polymer (Berman, 2012).

A precedent attempt to utilise cement-based materials was conducted in 1997 in order to investigate potential effectiveness of AM in construction automation (Pegna, 1997). The result was positive as it suggests AM is effective and compatible for small construction such as residential houses (Pegna, 1997). To represent AM in construction, some researcher has termed it as "Additive Construction" which means the method of assembling materials to generate construction by using 3D model data (Labonnote et al., 2016). In 2012, a number of entities exploring 3D printing for construction burst into seemingly-exponential growth, move forward from the previous linear progression (Bos, Wolfs, Ahmed, & Salet, 2016). At the same period of time, there are three available big-scale AM techniques related to construction and architecture namely Contour Crafting, D-Shape (Monolite) and Concrete Printing (Lim et al., 2012). All three techniques were founded by University of Southern California, British Monolite Company and Loughborough University respectively (Ding, Wei, & Che, 2014). As suggested by the researchers, all three processes proven to be appropriate for construction and/ or architecture applications and successful in manufacturing significant size of components (Lim et al., 2012).

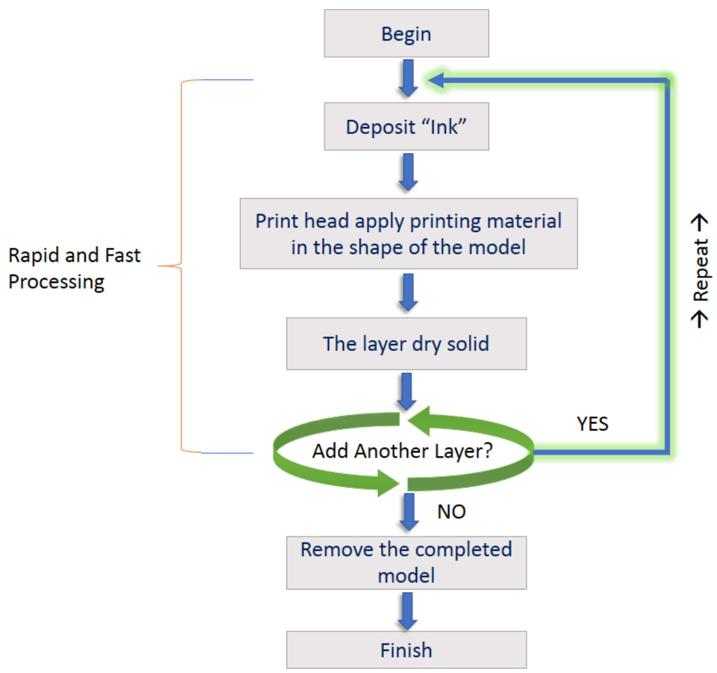

Figure 01. General AM processes

Source: Modify from (Ishengoma & Mtaho, 2014)

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In brief, contour crafting is a technique of layered manufacturing (LM) which utilise ceramic slurry, polymer, cement and a diversity of other materials, mixed together to formed big scale objects with smooth end surface (Khoshnevis, Hwang, Yao, & Yeh, 2006). Meanwhile, D-Shape processes occur through powder deposition and selectively hardened using additive. In this process, each deposit of building materials is placed to the anticipated thickness, compacted and then the outlet nozzles riding on gantry frame dispense the binder where the part is to be solid. Once done, the loose powder bed will be dug out (Lim et al., 2012). Concrete Printing is similar to contour crafting in terms of extrusion of cement mortar but in contrast has low deposition resolution (Lim et al., 2012). Figure 2 demonstrate the Contour Crafting, D-Shape and Concrete Printing product. To enhance and improve the AM, hybrid 3D printing is developed. It is the process to enable the existing 3D printer to integrate with various materials and components such as reinforcement, variety grade of materials and even sensors and actuator for life cycle monitoring (Tay et al., 2017).

Figure 02. Additive manufacturing / 3D printing products (A: Contour Crafting Product; B: D-Shape Product; C: Concrete Printing Product)

Source: Update photos based on (Lim et al., 2012)

The enthusiasm brought by AM development continuously impress the world and endlessly improved from time to time. This statement is supported by real-time application of AM technology to print numerous buildings around the world. It can be printed either off-site then assembled on site or it can be directly printed on-site. To illustrate, WinSun Decoration Design Engineering (WinSun), a company based in Shanghai, China is the world's first entity to print building in 2008 (Aldama, 2017). They also print a villa and 5-storey building in Suzhou, China (AP, 2015). According to a report, the 3D printed villa can decrease production times between 50% to 70%, set aside between 30% to 60% of construction waste, and save costs from 50% to 80% (Starr, 2015). Another example, Apis Cor is a firm that develop moveable construction 3D printer which is capable to print entire buildings on site (Apis Cor, 2017). In March 2017, Apis Cor has printed a 400 square-foot house and took just 24 hours to complete (Marks, 2017). Apart from the stated entities and their projects, there are many more firms around the globe working on AM technology in building construction. Figure 3 show the end product of 3D printed building by WinSun while Figure 4 show the 3D printed building by Apis Cor.

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Figure 03. WinSun 3D printed building. WinSun printed Villa (Left) and printed Apartment (Right) Source: AP (2015).

Figure 04. Apis Cor 3D printed house. (Left: building printed; Right: completed house) Source: ApisCor (2017)

Despite the advance development in 3D printed buildings, the AM technology has extended to build a fully functioning pedestrian stainless-steel bridge. According to the developer, MX3D, the project is expected to complete in year 2018. Figure 5 show the latest design of the bridge.

Figure 05. MXM bridge design (Elevation and Plan view of Pedestrian Bridge developed by MX3D) Source: MX3D (2017)

There are several significant advantages of AM that currently spotted over the globe. These advantages include low cost of customised product and mass customization and soundly shorter duration for construction. For a better understanding, mass customization is the ability to deliver personalised product with near mass production efficiency (Tseng & Hu, 2014). In context of 3D printing, it allows customised goods to be produced at fairly low cost (Berman, 2012). In terms of small manufacturing, it is so economical that some home-improvement shops offer AM devices to their customers for do-it-yourself (DIY) 3D printing (Bohan, 2016). Besides, as suggested by Paoletti (2017), AM enables mass customization in terms of full autonomy in establishing material deposition where the material can be placed only where structural needed and, in that way, granted optimization of construction components.

Furthermore, AM technology bring stimulating prospect of creating advanced and competent structural form to match specific design requirement with the absent of time-consuming in forming and

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assembling processes in traditional way (Ashraf, Gibson, & Rashed, 2018). The nature of AM allows the user to create new product design with the absent of additional cost for new physical tools for the product (Huang, Leu, Mazumder, & Donmez, 2015). Besides, AM can enhanced resource efficiency in both utilization and production stages, extend product lifespan via repair, remanufacture and refurbishment with closer relationship between consumer and producer and reconfigured value chain by shorten and simplify value chain, localised production and innovative distribution and collaboration (Ford & Despeisse, 2016).

Some studies have been conducted to investigate the impact brought by AM technology. For example, Costabile, Fera, Fruggiero, Lambiase, and Pham (2017) stated that different approaches are required in AM's design and operation management. The ability of AM technology that offer freedom of design can further impact the material costs, energy consumption and lifecycle costs during production phases. Furthermore, the implementation of AM together with other advanced manufacturing technologies can create a future whereby it offers significant sustainability benefits, more localised and collaborative and make value chain shorter and smaller (Gebler, Uiterkamp, & Visser, 2014).

Besides, it is interesting to elaborate the AM implication to supply chain. A study by Thomas and Gilbert (2014) illustrated the cost impacts in supply chain in terms of transportation and inventory, close proximity of production to consumers, management of supply chain and supply disruption vulnerability. The traditional way of manufacturing requires much time to produce and too costly for "on demand" parts and once infrequent part is ordered, it generate costly inventory that will consume physical spaces that at the same time require maintenance, insurance and taxes. With AM technology, the parts can be produced on demand and reduced production at multiple locations thus reducing the costs for transportation and inventory. Moreover, AM has the potential to enables localised production and simplified processes that can bring production closer to consumers for some products. In terms of management, AM may reduce the need for supply chain management as it reduces the links in supply chain. Due to reducing links in supply chain, the risk of disruption can be reduced. To further understand, an example is shown in Figure 6.

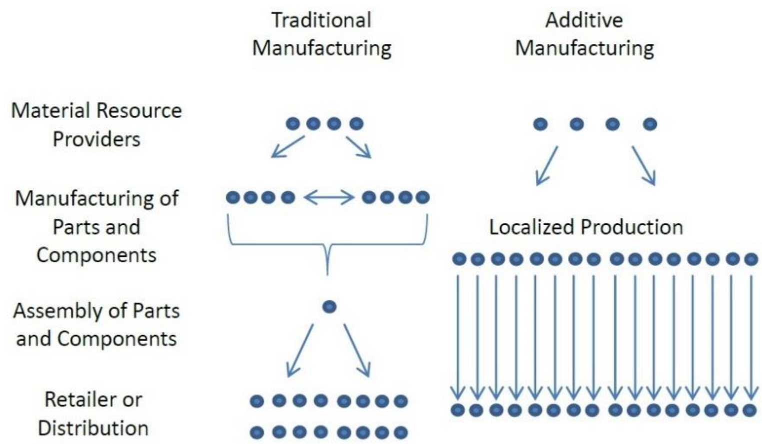

Figure 06. Traditional VS Additive Supply Chain in Manufacturing Perspective.
Source: Thomas & Gilbert (2014).

Finally, a study by Jiang, Kleer, and Piller, (2017) suggested that by year 2030, AM will bring significant effect to few categories such as output, supply chain and localization; competition and business model; market trend and consumer; and policies and intellectual property.

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2. Problem Statement

According to Ibrahim (2017), the Malaysian construction industry itself suffers lack of responsive towards technology. Further illustration to the lack of response to technology can be seen in the utilization of Industrialize Building System (IBS) which was lower than expected although the Government has made huge campaign for it (Kamar, Alshawi, & Hamid, 2009). A survey conducted by Mui, Aziz, Ni, Yee, and Lay (2003) to understand the internet usage in Malaysian Construction Industry suggested that the respondents not fully utilise the advantages of the technology thus denied the very basic element in IR4.0 i.e. Information Technology (IT). Besides, little knowledge of technology, limited resources and poor integration between application and/ or organisation were the causes of lagged behind the other industries (Stewart, Mohamed, & Marosszeky, 2004).

As suggested by Haron, Rahman, and Hanid (2009), the construction industry cannot afford to stay in future business while do today's works with yesterday's methods. The delay to familiarise and adapt technologies will make the industry left behind and become uncompetitive to be in the local and global market as required by the Government. Therefore, it is very important to learn, understand and adapt to the technological revolution to ensure greater development in the future and no one is being left behind.

3. Research Questions

- How far the Contractor in Penang understand about additive manufacturing in construction industry?

4. Purpose of the Study

This research paper is prepared to study the understanding among Contractors in Additive Manufacturing technology in local construction industry.

5. Research Methods

A survey has been conducted to some 214 G7 main contractors in Penang to study about their understanding in AM. The sampling size was determined by using Krejcie and Morgan (1970) method from a total population of 491 contractors provided by CIDB through Centralized Information Management System (CIMS). A set of questionnaires containing statement about AM were designed using Likert scale approach and distributed through online and by-hand submission method. Each statement in the questionnaires tested the respondent's general information about AM, its evolution and the future prospect, its application in construction industry and its impact and implication. The respondents were asked to rate their best perception about all questions between scale 1 which is strongly disagree to scale 5 which is strongly agree. Furthermore, reliability and validity of the questions has been tested during pilot survey which was conducted to some 3 main contractors outside Penang. The result gained from respondent were further analysed using mean score to determine the central tendency of respondents.

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6. Findings

Table 1 illustrate the mean score generated from the survey. General AM information has a mean score of 3.40, AM future prospect gained a mean score of 3.48, AM application in construction industry obtained a mean score of 3.20 and AM impact and implication got a mean score of 3.39. Out of 5 score, all four area of understandings given score between 3 and 4 (between not sure and agree). This show the respondents' tendency more to not understand about AM and suggest the respondent's lack of understanding about AM.

Table 01. Respondent's tendency towards AM

Area of understanding	Mean Score
General AM information	3.40
AM future prospect	3.48
AM application in construction industry	3.20
AM impact and implication	3.39

The general information that were asked to the respondents cover the AM ability to produce any complex form of geometry and need no tools to work. The findings suggested the respondents do not properly understand about general AM information. Despite the general information, AM has its own technical knowledge that more complex to understand. If the respondents unable to understand the basic information, how do they understand the technical information that will open the gate to improve AM.

Besides, the questionnaires about AM's future prospect includes the advance of AM through 4-dimensional (4D) technology which can transform 3D printed form, characteristics and function over time. The questionnaires also cover the statement about continuous improvement conducted in AM technology and its ability to integrate with building information modelling (BIM). Based on the findings, the respondents do not possess sufficient understanding about AM future prospect. This might prevent them to see the true potential of AM in the future and ignore the development of the technology.

Moreover, AM application in construction industry which can build single and multiple storey buildings as well as stainless steel bridge with few techniques were asked to the respondents. Based on the findings, the respondents do not understand that today AM can produce physical structures with few techniques. The AM technology is already in construction industry and happening, but the respondents still do not sure.

For AM impact and implications, the respondents were given statement that AM can give impact in terms of requirement for different approach in management, de-globalization of supply chain, internal production capacity and impact on safety procedures and intellectual property. Based on the findings, the respondents tend to not understand about it. AM bring big impact to the existing construction environment and every respondent should note about the impact and implication in their business.

In short, the respondents who represent the contractors do not understand the AM sufficiently. the calculated average mean score for the survey which is 3.37 enhanced the findings and suggests the respondents' central tendency that do not understand the AM. However, some reason can be assumed why the contractor do not understand the AM technology within the construction industry sphere. The contractors might not understand about AM application in construction industry because it is new

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technology to the industry and the information about AM is not widely available compared to traditional practices. Besides, construction-scale AM projects around the world that highlighted in literature review only represent a very tiny effort of AM advance in construction industry. The study also does not find any huge and large-scale construction project using AM worldwide that can be referred as landmarks and models for future massive development in construction. Therefore, the contractors cannot effectively learn and do not possess sufficient information about AM that enable them to understand its application in construction industry.

Despite some reason that might be provided to cover the lack of understanding in AM technology, the contractors should have equipped and improved themselves with the latest development in construction industry especially in regards of AM technology. This might help them to capture some market share in construction industry in the future.

7. Conclusion

The research outcome suggested that AM will not be implemented and applied in Penang construction industry in near future for at least few more years ahead. This is because the contractors do not understand about AM comprehensively. However, the construction players especially the constructor or the contractors should not ignore AM existence and development because it can bring a massive opportunity for business income in future construction market and will left behind those who cannot change or willing to change and adopt with the changes. It will take a lead times, probably in few years to fully learn and adopt to this technology. Indeed, this is an alarming point to the construction players that require them to respond promptly and properly in order to catch up with the development so when the AM technology for construction really hit the floor and brought into Malaysia and Penang by foreign investors, they will not be left behind and become uncompetitive. Perhaps this is the best time to venture into this technology, become advance and competitive and lead the others in the industry.

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