Adopting Industrialisation in the Construction Environment: Meeting the Requirements of Sustainability

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ABSTRACT

The construction industry should move from conventional construction method and adopt the industrialisation concept, to increase productivity and deliver quality construction end products. Industrialisation is the combination of a large market to divide into fractions the investment in strategies and innovation, in return, of simplifying the production and, therefore, reducing the costs. The introduction of Degree of Industrialisation by Roger-Bruno Richard is critical to the construction industry. The five degrees of industrialisation are prefabrication, mechanisation, automation, robotics and reproduction. Richard's Degree of Industrialisation is in line with the Malaysian government's vision to be a developed nation by 2020, to push forward the use of innovative technologies in most industries including the construction industry. The adoption of industrialisation and innovations in the Malaysian construction industry has the potential to solve the current problems in the construction industry. The problems are the inferior quality of products and processes, a poor site working conditions, low construction productivity, high construction cost, relying on foreign workers and lack of skill labours. The adoption of industrialisation and innovations promote sustainability in the construction environment. The objectives of

the study are to investigate whether the adoption of industrialisation in the construction environment promotes sustainability and to identify the current level of industrialisation of the Malaysian construction industry. The methodologies of the study are semi-structure interview and observation. The Malaysian construction industry is ready to embrace industrialisation in construction environment in limited areas and industrialisation promotes sustainability in the construction environment.

Keywords: *Roger-Bruno Richard's Degree of Industrialisation, industrialisation in the construction environment, Malaysian construction industry, sustainability*

INTRODUCTION

Many factors can affect the Malaysian construction industry which includes the state of the nation's economy and investment environment. Furthermore, the Malaysian construction industry can be affected by the Malaysian government involvement, for example, the privatisation of public services and private finance programme. Population mobility and social trends can affect the Malaysian construction industry. Population mobility and social trends usually report the supply and demand of types of buildings and their locations. The Malaysian construction industry shares 15.9% of the country's Gross Domestic Product (GDP) in the half quarter of 2013. The strength of the construction sector is closely related to the state of the economy and reacts relatively quickly to the economic downturn. The Malaysian construction industry was amongst the first area to suffer during the previous major recession [1].

The Malaysian construction industry is actively constructing residential buildings such as high-end landed properties such as semi-detached houses and bungalows. It includes low and medium cost houses to support the Malaysian government's housing programme. The construction industry has also been supported by the development of infrastructure projects throughout the primary high growth areas of cities and towns [2]. There are new development regions and major infrastructure projects still on-going or recently completed such as the Iskandar Development Region and the

Light Rail Transit (LRT) and Mass Rail Transit (MRT) system connecting key areas and towns in Klang Valley. Under the Economic Transformation Programme (ETP), major projects will be launched and implemented within the next ten years. ETP requires RM1.4 trillion, of which 92 percent is for private investment; and seeks to increase Malaysia's gross national income (GNI) to RM1.7 trillion [3].

A shortage of workforce is one of the factors behind the drive in many countries to industrialise production to increase productivity by replacing workforce with machines [4]. In many developed countries, such as Japan, there has been a change to a more industrialised construction approach. For example, in Japan, automation and robotics technologies are widely used in the construction, including the production of components in factories and the following assembly of the components on-site [5].

Most developing countries have seen an increase in both output construction industry and employment in the over the past three decades. Due to this rapid and long-lasting growth, the Malaysian construction industry demand for workforce could not match the local supply, and dependency on foreign labour, especially from neighbouring such as Indonesia and Myanmar [6]. The distribution of foreign labour in the Malaysian construction industry has continued to increase as Malaysia continues to build [7]. It is within this area that industrialisation in the construction sector can prove to be most useful in term of decreasing labour-intensive work processes and thus reducing the country's over-dependency on foreign workforces.

One of the greatest opportunities for the Malaysian construction industry players is to adopt industrialisation due to the various incentives and encouragement from the Malaysian government for adopting innovative technologies. The introduction of Industrialised Building System (IBS) in the Malaysian construction sector is one of encouragement by the Malaysian government. IBS is a construction process that uses standardised building components mass produced off-site or on-site, transported and assembled into a building structure using appropriate machinery with minimal workers on site with proper planning and integration [8, 9]. The IBS adoption guarantees valuable advantages and benefits such as the reduction of foreign workforces, less wastage, promotes sustainability and construction site cleanliness, better quality control, and others [10, 11].

Industrialising the Construction Environment

Industrialisation in the construction environment has demonstrated the capacity to promote sustainability, reduce costs, improve the quality of products and produce complex products to a large majority of people. Most construction and building material products offered on the market today adopts industrialisation. Roof truss, windows, doors, tiles, curtain walls, precast concrete elements and others are the example of industrialisation in the construction environment. However, so far, industrialisation in the Malaysian construction industry is not applied to the whole building itself. For infrastructure projects, most of the construction components adopt industrialisation such as precast concrete products (box culvert, concrete pipes and others).

Industrialisation

Industrialisation is a modernisation process through the development of innovations, machinery, technologies and modern methods of production. Industrialisation usually requires offsite plant or factory where the work is centrally organised; production operations are mechanised and focused on mass production. Industrialisation is based on quantity. An essential market can justify the investment in strategies and technologies capable, in return, simplify the manufacture of complex goods. The nature of industrialisation: the production of the mass quantity of units divides that investment into small (eventually infinitesimal) fractions. Thus, it will reduce the fixed production costs of a single unit.

For example, producing a handicraft chair does not require a significant investment in equipment and materials: only use wood, paint, glue and a few hand tools. Hours of labour required are about 20 to 24 hours and at RM20 per hour, the cost of the chair will be at least RM400. To supply the market demands of 100,000 chairs, a more productive process needs to be considered to cater to the market demands. Perhaps using plastic injection machine, that represents an essential investment over RM100,000. The machine will produce chairs in a single operation at the rate of one per three minutes that is RM1.00 per chair plus material plus 1/20 of one hour of labour. Buying an injection machine is expensive. There are alternative

solutions such as delegating the production to a subcontractor who operates an injection machine and who amortises it through various projects; do permit this level of industrialisation [12].

The injected plastic chair produced faster a much-reduced cost than the handicraft chair. The plastic chair is as stable and comfortable as the handicraft chair. The plastic chair represents a different image in term of visual and aesthetic. The situation would have been different if the manufacturer had turned to automation and robotics to replace the craftsman: the product would still have a handicraft look. However, the cost of the tools would probably be more expensive as many machinery and operations would be required. Therefore, if producing a chair is the objective, the injection machine can deliver it at a very low cost. However, if the look of the handicraft chair is necessary, the automation is the way to go but at a higher cost compare to the plastic chair produced using the injection machine [12]. The investment provides a more efficient process, although costly at the beginning, but it can generate benefit that increases with the number of units produced once the break- the even point is reached.

Roger-Bruno Richard's Degree of Industrialisation

One of the most significant studies on industrialisation concepts in construction was the work by Roger-Bruno Richard (2005). In his research, Richard stated that the large numbers of components in construction are sub-assemblies; therefore, construction is still forever site-intense handicraft. As an outcome, the degree of industrialisation should be an indicator to measure the level of Industrialisation adoption in construction [12]. The level of industrialisation discussed in Richard's research is illustrated in Figure 1.

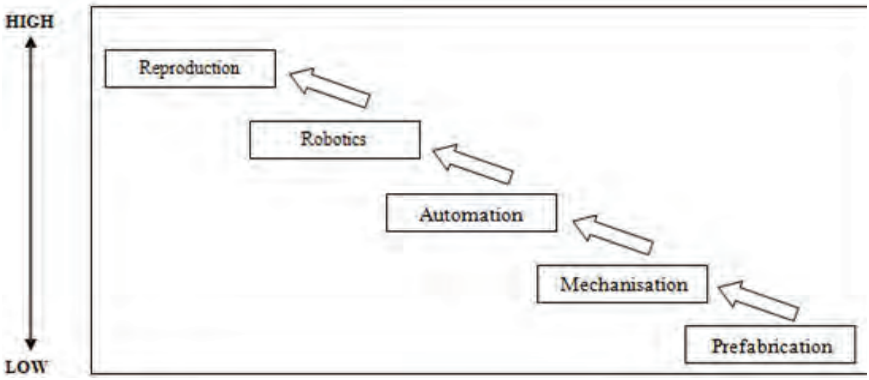

Figure 1: Degree of industrialisation (Richard, 2005) [12]

There are five degrees of industrialisation. The first four are prefabrication, mechanisation, automation and robotics. They duplicate the conventional process in construction, merely transferring the task from human labour to machine. The fifth degree, reproduction, implies research and development of innovative processes truly capable of simplifying the production [13]. The following are the elaborations of the five degrees of industrialisation by Roger-Bruno Richard.

Prefabrication

"Pre" in prefabrication means "before" or "elsewhere". In the construction industry, prefabrication implies building components produced in a factory very similar to the ones done at a traditional construction site (Figure 2), using the same material and the same processes on-site. For example, most modular prefabricated housing manufacturers in US use wood-framed panels using automated devices that quite similar to the ones done at construction site. Prefabrication brings the construction costs down as much as 15% when the factory is producing at full capacity and mass produce [12]. Other benefits of prefabrication are:

- Weather protection (factory control)
- Specialised tooling and handling equipment
- Semi-skill labour
- High-quality control

Figure 2: Prefabrication of precast beams at an off-site yard (Teraju Precast Services Sdn. Bhd., 2015)

Mechanisation

Mechanisation is the term used every time machinery or machine is engaged in the work such as the use of power tools, mobile cranes and other machinery. Usually, prefabrication will be accompanied by mechanisation. For example, to lift the volumetric or 3D modular units, a mobile crane is used to lift the 3D modular units [12]. Figure 3 is an example of mechanisation on-site.

Figure 3: Mechanisation: The use of a mobile crane to lift precast components (Teraju Precast Services Sdn. Bhd., 2015)

Automation

With automation, the tooling is completely taken over the tasks executed by the human worker. A "supervisor" is still around although the industrial engineer and the software or computer technician are essential participant's supervisor. A case study in Sweden, about Swedish wood-framed panels assembled by automation, indicates an economy up to 27% compared to conventional construction methods [12]. Figure 4 is an example of automation at the off-site prefabrication yard, whereby an automated steel formwork is used to produce off-site concrete monolithic or volumetric units.

Figure 4: The use of automated steel formwork machine to produce concrete monolith building system (Green Precast Modular System & Technology, 2015)

Robotics

With robotics, the tooling has the same function as automation and has the multi-axis flexibility to perform by itself to do diversified tasks. The robot is too expensive to be used for nailing wood studs and laying bricks. However, it is still possible and applicable to use the robot for construction works (Figure 5). The future of robotic is related to computer-aided manufacturing (CAM). CAM generates complex forms that are different from one unit to the other, opening the way to individualisation with mass production, opening the path to "mass customisation" [12].

Figure 5: Robotics: Semi-Automated Mason (SAM) is placing a brick (Richard, 2005)

Reproduction

The word "reproduction" is taken from the printing technology. The analogy with printing will serve from now on to extrapolate a methodology bringing productivity and economy in architecture. Reproduction is the introduction of innovative technology able of simplifying the "multiplication" of multipart goods (Figure 6). The purpose of reproduction is to short cut the repetitive linear operations that are the trademarks of the craftsmanship approach, such laying bricks, wall plastering and others [12]. Compare to the other degree of industrialisation, investing straight into machinery; reproduction is more towards research and development for "ideas" to produce a simplified process. Reproduction is not necessarily a downright option; it also can accompany some of the other degrees of industrialisation. The real message of reproduction is to give priority to ideas rather than to machinery. A clear vision of the performance is expected from the product. The ability to imagine a simplified topology and the knowledge of the processes presently available will lead to solutions capable of delivering quality architecture to the mass majority of people.

Figure 6: House Printing-The concept of reproduction in the construction sector (Richard, 2005)

Advantages of Industrialisation in the Construction Environment

The following sub-sections describe the benefits and advantages of industrialisation towards the construction environment.

Reduce the Construction Period

Industrialisation in construction has proven to reduce the construction time. Construction project adopting industrialisation completed faster compare to the traditional construction project. It proved to build faster since on-site and manufacturing activities are parallel. It cut down the duration of work and simplifies the processes by reducing onsite activities and some trades [14]. The usage of machinery speeds up the production of construction products hence increases the speed of the construction period.

Labour Reduction and Solving Lack of Skill Labour

Industrialisation in construction offers important saves in labour and material cost, as the number of labour forces is far lower compared to conventional construction [15]. Furthermore, industrialisation in construction alleviates the issue of skill labours shortage in construction [14]. The usage of specialising machinery or tooling replacing the need for labour forces in the construction process reduce on the relying on labour in the construction sector.

Cost Saving

Cost saving is achievable through mass production and the repetition of the same processes to produce standard products, materials and components. Even though the investment and cost of purchasing machinery are high but once the machinery reached the break-even point, it will benefit the machinery, owners.

Promotes Sustainability

Sustainability involves innovation and the adoption of the modern method of construction through industrialisation. It is centrally organised, mechanised and automated production operations and focuses on mass production [5, 11]. Sustainability can be achieved through industrialisation by reducing wastages and protect the environment due to factory production, and increase human safety on-site and at the factory.

Improve Quality in Construction

Construction products through industrialisation offer an improvement in quality, productivity and efficiency from the use of factory made products. Industrialisation reduces the possibilities of poor workmanship and lack of quality control because of the factory quality control and management. [3]. Factory protects the construction products and materials from the bad weather and reduces the delay due to the bad weather condition.

RESEARCH METHODOLOGY

The objectives of the study are to investigate whether the adoption of industrialisation in the built environment promotes sustainability and to identify the current level of industrialisation of the Malaysian construction industry. Thus, two qualitative approaches were used to achieve the objectives of the study. The methodology used for the first objective is a semi-structured interview and the second goal is observation. The questions in the semi-structured interview were developed based on the second goal and literature review. The selection of respondents for the interview is the appropriate person who is in charge of the operation and industrialisation in the respective organisation. The observation was executed at the interviewee's site or plants. A checklist was developed based on the Roger-

Bruno Richard's degree of industrialisation to guide the observation. Content analysis and cognitive mapping techniques were used for analysing the data supported by the Nvivo 9 software.

Data Collection

There are three respondents selected for the semi-structured interview. The respondents are representative from the selected organisation. The organisations involve in the study are construction material manufacturer, building material manufacturer and civil work contractor. The respondents are interviewed regarding the adoption of industrialisation of their respective organisations. The respondents were also asked about their understanding about Industrialisation, advantages of industrialisation in the construction industry, barriers to the adoption of industrialisation and do industrialisation promote sustainability.

According to respondent A, respondent A's organisation adopts the on-site fabrication and mechanisation on-site. Respondent A's organisation is a construction material manufacturer and had developed an on-site monolithic building system named FASTBUILD. The FASTBUILD monolithic building system adopts on-site fabrication and mechanisation. FASTBUILD monolithic building system is the fastest cast-in-situ reinforced concrete structure construction method in Malaysia. Firstly, the aluminium formwork system is designed according to the building drawings. The combination of bespoke software and experienced design teams ensure the optimum design solution is achieved. A custom made concrete named Agilia concrete is then poured into the formwork once it has been produced, and it is placed at the worksite. When the entire first floor is completed, the formwork panels are easily removed and manually transferred to the subsequent floors where the process is repeated until the whole building is constructed.

The system adopts on-site fabrication using the aluminium formwork that is erected on site to build the building. However, formwork system made from steel, aluminium and composite material is classified as Industrialised Building System (IBS) in Malaysia. Therefore, the formwork system used is considered as a low level of industrialisation but only in the Malaysia context. The mechanisation adopted on-site through the use of trailer mounted boom truck concrete pump, or mobile crane is used to deliver the concrete from the concrete mixer truck to the constructed building used the

FASTBUILD system. The advantages of adopting industrialisation in the respondent A's organisation according to respondent A are well-organised site, cleaner site, increase safety on-site, increase productivity, increase quality, cost saving, labour reduction and promote sustainability. Figure 7 illustrates the on-site fabrication of FASTBUILD monolithic building system with Agilia Concrete. Figure 8 shows the mechanisation using trailer mounted boom truck concrete pump to deliver concrete from concrete mixer to the constructed building used the FASTBULID system.

Figure 7: FASTBUILD monolithic building system using a single cast aluminium formwork system with self-levelling and self-compacting concrete (Agilia) - (Respondent A)

Figure 8: The trailer mounted boom truck concrete pump delivering the concrete to the constructed building (Respondent A)

Respondent B's organisation is a civil work contractor. Respondent B explained that the Respondent B's organisation adopts prefabrication and mechanisation off-site. Meanwhile, on the site, they only used

mechanisation. The prefabrication of the Mass Rail Transit (MRT) precast concrete segments for Respondent B's project is at a yard using large steel formwork. Once the precast concrete segments are completed, the mobile crane (mechanisation) is then used to lift the precast concrete segments onto the transport lorry. It is not suitable to prefabricate the precast concrete segments on-site since it is huge and dangerous to the vehicles and the passer-by. Therefore to ensure safety and productivity of the project, the precast concrete segments are produced off-site. Respondent B's organisation adopts prefabrication and mechanisation off-site.

Respondent B's organisation also adopts mechanisation on-site. The MRT's precast concrete segments are produced off-site and transfer to the site once it is completed. Once the precast concrete segments arrive at the installation location, a gantry launcher will be used to lift the precast concrete segments. The erection of the precast concrete segments is carried during the night to avoid traffic jams and accidents to happen. Respondent B agreed that the adoption of industrialisation promotes sustainability in the project by reducing construction wastage, enhance safety and improve the quality of the end products. Furthermore, the adoption of industrialisation in Respondent B's project enhances productivity, speed up the schedule and reduce the reliance to human labours. Figures 9 and 10 illurate the MRT gantry launcher assembles and lift respectively the precast segments on the site.

Figure 9: The MRT gantry launcher of Package V6 assembles the precast segments on the site (Respondent B)

Figure 10: Gantry launcher used to lift the precast segments on-site (Respondent B)

Respondent C's organisation is a building material manufacturer that produced roof tiles. Respondent C's organisation adopted prefabrication, mechanisation and automation at the factory (off-site). To ensure productivity, safety, quality and to be cost efficient, Respondent C's organisation has opted to used fully automated machinery and equipment to produce the roof tiles (Figure 11). Prefabrication in Respondent B's factory is through the aluminium roof moulds used at the factory. Mechanisation is adopted through the use of forklift at the factory. Automation is implemented through fully automatic machineries such as automated mould oil applicator, mechanical arms machine (Figure 12), roof colour sprayer machine and others.

Mechanisation is adopted on-site and off-site to move or transfer the materials from the factory storage area to the transport lorry and from the lorry to the designated site once the lorry arrived at the site. Machinery used on-site include a crane, forklift or any suitable material lifting and moving machinery. Most of the machinery used are imported oversea since Malaysia does not have the technology and manufacturers to produce the required machinery. According to Respondent C, the adoption of industrialisation in the Respondent C's organisation encourages sustainability by reducing raw material wastage, improving the quality of the roof tiles and since most of the machinery a fully automated, it reduced the used of labours in the factory.

Figure 11: Automated mould oil applicator machine to the roof tile moulds (Respondent C)

Figure 12: Mechanical arms machine to mix the materials to make the roof tiles (Respondent C)

DATA ANALYSIS AND FINDINGS

Table 1 is the coding for three respondents used to analyse the data using Nvivo 9. For the purpose of simplifying the analysis, the three respondents from the interview session will be coded. Respondent A, Respondent B and Respondent C will be coded A, B and C respectively.

Table 1: Assigned code for respondents

Interview Respondents		
Respondent A	Respondent B	Respondent C
A	B	C

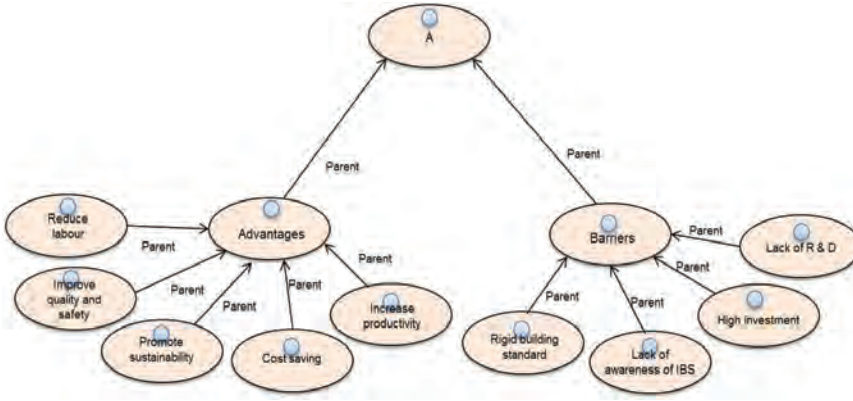

Figure 13: Cognitive mapping of the interview data Respondent A

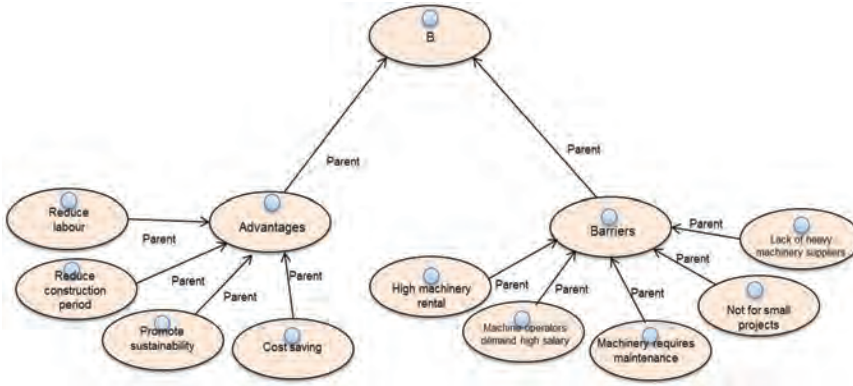

Figure 14: Cognitive mapping of the interview data Respondent B

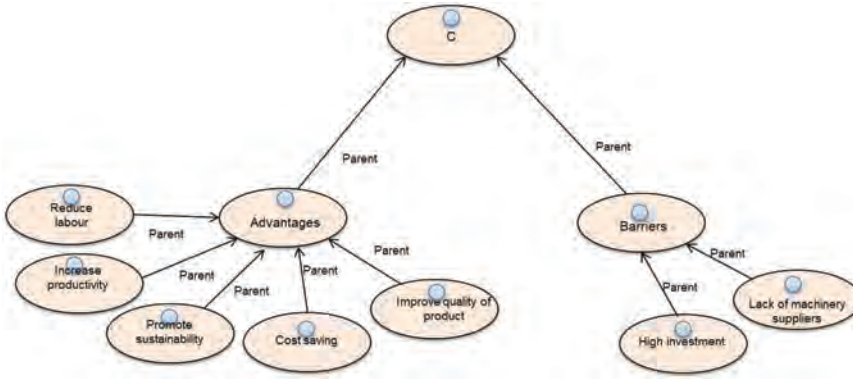

Figure 15: Cognitive mapping of the interview data Respondent C

The following Table 2 and Table 3 are a summary of the data collected from the study.

Table 2: Summary of structure interview from three respondents

	Respondent A	Respondent B	Respondent C
Organisation	Construction material manufacturer	Civil works contractor	Building material manufacturer
Understanding about Industrialisation	Yes	Yes	Yes
Advantages of Industrialisation in the construction environment	-Increase productivity -Cost saving -Promote sustainability -Improve quality of product -Improve safety	-Reduce construction period -Cost saving -Promote sustainability -Labour reduction	-Increase productivity -Cost saving -Promote sustainability -Improve quality of product - Labour reduction
Barriers to the adoption of Industrialisation in the construction environment	-Rigid building standard/ UBBL -Lack of awareness about IBS -High investment and cost to purchase machinery -Lack of R & D culture in the Malaysian construction industry	-High machinery rental/ cost -Machine operators demand high salary -Machinery requires maintenance -Not suitable to be used for small contractors and small projects -from Malaysia	-High investment and cost to setup factory and purchase machinery -Lack of heavy and light machinery suppliers from Malaysia
Does Industrialisation in construction environment promotes sustainability	Yes	Yes	Yes

Table 2 displays the degree of industrialisation adopted by the respondent's organisation. The observation was executed at the interviewee's site or factory.

Table 3: Degree of Industrialisation in the respondent's organisation

	Respondent A's organisation	Respondent B's organisation	Respondent C's organisation
Organisation	Construction material manufacturer	Civil works contractor	Building material manufacturer
Prefabrication	Onsite fabrication (IBS)	Yes (Offsite)	Yes (Offsite)
Mechanisation	Yes (Onsite)	Yes (Onsite and Offsite)	Yes (Onsite and Offsite)
Automation	None	None	Yes (Offsite)
Robotics	None	None	None
Reproduction	None	None	None

From the data collected and analysis, the Malaysian construction industry has adopted the Roger-Bruno Richard's degree of industrialisation that includes prefabrication; mechanisation and automation used on-site and off-site. Mechanisation is essential whereby it is available and used in every organisation involved in the study. The data collected also supported the literature on the advantages of industrialisation in the construction industry. New findings on the benefits and barriers of industrialisation are obtained in the study. Moreover, all the respondents agreed that the adoption industrialisation in the construction sector promotes sustainability by reducing less wastage, enhance the quality of products and improves safety in the construction environment.

CONCLUSION

The Malaysian construction industry is ready, to a certain degree, for embracing the industrialisation in construction environment in limited areas. The areas are on-site and off-site plant prefabrication, mechanisation, automation and assembly in design, planning and costing phases. However, it depends on the capacity and capability of the companies in the Malaysian construction industry, related to size and type of business, existing government incentives and policies. The Malaysian construction industry has a long way to go to industrialising the construction sector. The adoption of industrialisation, innovation, new technologies, machinery, modern method of construction (MMC), prefabrication mechanisation, automation, robotics and reproduction, promotes sustainability in the construction environment and industry. Other benefits of the adopting industrialisation in the construction environment are improving the productivity and safety. Moreover, industrialisation increases the quality of the construction products.

Furthermore, the adoption of industrialisation should be holistic. Innovation towards industrialisation should also include material engineering and innovation (fibre plus cement), improved activities and method (new machine and technology to enhance the construction method) and lastly new product and manufacturing (prefabrication and reproduction).

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