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IDENTIFICATION OF THE HAZARDS/RISKS INVOLVED IN CONSTRUCTION PROCESS FOR SELECTED CONSTRUCTION APPROACHES IN MALAYSIA

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Abstract

The low safety and health performance in the construction industry in Malaysia were proven by the annual accident reports by DOSH and SOCSO. Through these reports, it is evident that the construction industry is among the sectors, which require a high rate of strong improvement in the existing safety of the site. This article discusses the identification and analysis of the hazards/risks involved in several construction approaches, which represent Industrialised Building System (IBS) and traditional construction methods. Case study design was employed, in which the data collection on the activity involved in each construction method and its associated hazards/risks were executed through field observation and interviews. This study involved collecting the data at 2 manufacturing plants and construction sites that represent IBS method, which are precast concrete wall panel system and blockwork system; and 1 construction site that represents conventional method, which is in-situ concrete and masonry method. Furthermore, the hazards/risks are represented as damaging energy, which refers to the energy damage model. It was suggested in this research that the comprehension of risks in various construction process, including IBS, would contribute to new insights for enhanced health and safety of the construction site. After determining the activities and hazards/risks, it was suggested that the risk should be compared in further detail to ensure that the understanding of the risks is enhanced, and a mitigation action is performed before construction works begin.

Keywords: Construction, Industrialised building system, Precast concrete, Safety and health, Safety performance.

1. Introduction

The Malaysian construction industry is crucial for the establishment of the domestic economy in the nation as it strengthens the demands for construction activities [1, 2]. The industry is known for its dangerous physical working conditions that result in significant number of accidents and fatalities [3]. Therefore, the improvement in the health and safety performance of the construction industry in Malaysia is important. Based on the Social Safety Organization (SOCSO) Annual Report, there were excessively high accident statistics in the construction industry in Malaysia [4-6]. Specifically, the most current figures developed by the Department of Occupational Safety and Health (DOSH) showed that 72 from 214 fatality cases were associated with the construction industry in 2019 [7]. Notably, it was proven that this industry is among the sectors requiring a fast rate of significant improvement in the existing safety on the site [8].

Among the measures applied for the improvement in occupational safety and health (OSH) performance, offsite construction (commonly known as Industrialised Building System or IBS in Malaysia) was proposed as an alternative to the traditional construction approaches [9]. The Malaysian government is strongly supporting the implementation of IBS and a paradigm shift in construction through the conventional and industrialised method. This support is presented by the declaration of the Construction Industry Master Plan (CIMP) 2006 - 2015 [10], which particularly highlights IBS and the employment of it using IBS Roadmaps. Additionally, the significance of IBS is presented in the Construction Industry Transformation Plan (CITP) 2016 - 2020 [11].

The industrialisation of building or ‘system building’ is a term in the building industry indicating the industrialised process, in which the elements of a building are organised, created, delivered, and built on the site [12, 13]. The classification of IBS is categorised into six types, namely precast concrete framing, wall and box system; formwork system; blockwork system; prefabricated steel framing system; prefabricated timber framing system; and innovative. In regard to the construction phase, a slight difference is present between the IBS construction phase and the conventional systems as the construction requires the production of the components or products in a factory or site, as depicted in Fig. 1. Specifically, traditional construction requires the on-site construction of the building using the materials and components (fixtures and fittings), while IBS involves the construction of building elements in a factory or on-site through specific materials and components, which are then delivered and installed on-site. Additionally, several sub-activities are present within these constructions. It was suggested in some studies that IBS offered higher safety compared to the conventional method as the working area could be transported to the lower hazard environment [14, 15]. This shift was also performed from the field to the factory to improve the management of the hazards [15, 16].

The previous suggestion was in line with McKay’s [17] study, which reported that offsite could lead to a significant reduction in OSH risks in traditional construction. Furthermore, Gangolells et al. [18] found that the safety risk level of designing an in situ concrete structure was twice the safety risk level of designing a precast (IBS) structure. In Malaysia, although the IBS implementation was not the main initiative to improve the construction of OSH, it was presumed to directly lead to the higher safety of construction sites after the reduction of site workers, construction waste, materials [19], and clean site environment [20]. Substantial effort and capital have been invested by the government and other construction players to promote IBS. However, whether the true improvement in safety could be delivered to the industry remains unknown due to the insufficient existing studies on hazard identification for IBS construction process.

McKay [17] postulated that there is ongoing need to address the lack of knowledge regarding offsite or IBS and its effects. In Malaysia, there is not much study regarding the identification of the occupational safety and health risks throughout the IBS construction process, including in the manufacturing facility. Amin et al. [21] in their study investigated the hazards and risks involved in the manufacturing, delivery and installation of two IBS methods, which are prefabricated steel framing system and prefabricated timber framing system. The major hazards and risks were identified, which are mainly due to exposure to sun and musculoskeletal disorders (MSDs) from manual handling work. Further, Amin et al. [22] analysed the effect of prefabricated steel framing system method towards occupational safety and health by comparing it with the traditional construction method. Their study contributed to knowledge by describing the hazards or risks removed by the use of IBS, the changes of risks, the activities with similar risks or hazards and additional risks incurred from the use of IBS.

However, there is still gap of knowledge in existing study in which other types of IBS are not covered. Therefore, this study aims to identify the hazards and risks of several construction approaches indicating the IBS and traditional construction methods, which are precast concrete wall panel system and blockwork system; and compare them with in-situ concrete and masonry method. In this study, the hazards/risks were represented as the damaging energy, which refers to an energy damage model developed by Viner [23].

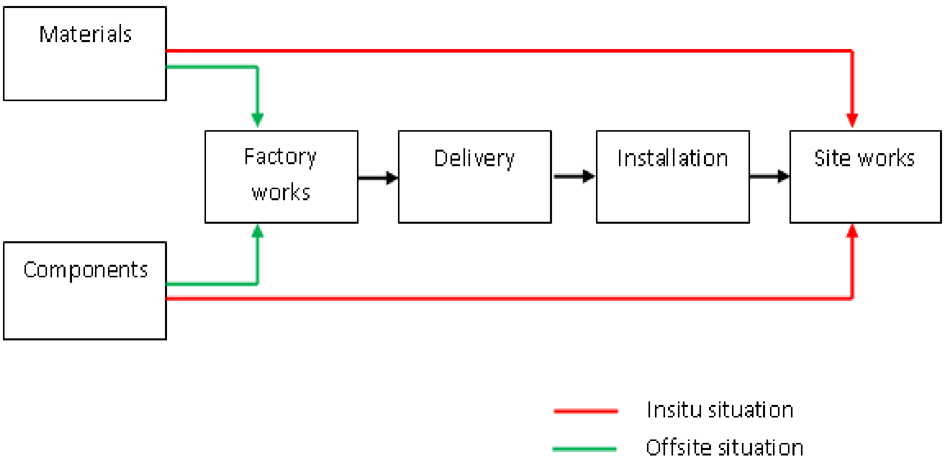

Fig. 1. Conventional and IBS processes - Adapted from McKay [17].

1.1. Safety, health, and IBS

McKay [17] discussed the effect of offsite construction (IBS) on OSH based on the research by Gibb [16] and Court et al. [24]. According to Gibb [16], offsite fabrication will reduce, or completely remove, the need for on-site work at height, which is a hazardous operation. Therefore, through the offsite techniques, including the decrease in on-site hours, site labour, and the omission of certain hazards, safety performance is enhanced [17].

According to McKay [17], offsite approaches involve a management discipline, which contributes to improved safety and health. Specifically, the increased planning involved in off-site fabrication provides an opportunity for appropriate risk assessments to be completed. Increased management input is usually associated with the installation of off-site fabricated units, which also indicates that the agreed method statements are more likely to be adhered to. These factors should reduce the risk of health and safety in installation activities 16.

It was proposed by some scholars that the safety of IBS is higher than that of the traditional approach as the worksite could be changed into the less harmful environment [15]. This shift could also take place from the field to the factory, which improves hazard management [15, 16]. Notably, the factory environment provides easy access to the collection, collaboration, and adjustment of work at an efficient orientation and height [17]. Besides, offsite construction could eliminate the common transient nature of the construction workforce and the influence of weather on operations [16].

Gibb [16] proposes that developing a project-wide strategy at an early stage would be essential for successful offsite implementation. Consideration of offsite fabrication should be done from an overall project perspective rather than on the element-by-element basis that is commonly adopted. This strategy is essential in achieving health and safety benefits from offsite construction where the project management team could organise the whole project to minimise risk and maximise efficiency [17]. This supports Szymberski's [25] assertion that there is a greater influence on safety the earlier it is considered in a project.

1.2. Energy damage model

This study used Viner's [23] energy damage model to describe the hazards/risks involved in the construction process. In this model, hazard is defined as a source of potentially damaging energy, whereas risk is defined as the loss of control of the energy when there is a failure of the hazard control mechanism. These mechanisms may include physical or structural containment, barriers, processes and procedures. The space transfer mechanism is the means by which the energy and the recipient are brought together assuming that they are initially remote from each other. The recipient boundary is the surface that is exposed and susceptible to the energy [21].

This model suggests the identification and control of possibly hazardous energy to diminish or manage the unseen states of the unsafe individual as the operation takes place in a risky location. Provided that the issue may be present despite the absence of harm from the energy, the model is underpinned by an unsolicited transfer of hazardous energy source, which is not predicted (in terms of force, speed, time, or type) by an individual. According to this model, hazards appear in the form of vibration and noise, radiation, and pressure, and it could also exhibit the psychosocial, biomechanical, microbiological, thermal, gravitational, mechanical, electrical, and chemical forms [26], as described in Table 1. Notably, the identification of hazardous energy allows the technological management of minimisation and removal, which functions as the physical environment instead of the workers' behaviour.

Table 1. Description of damaging energies [26].

Damaging energies	Description
Gravitational	• Found wherever objects could fall from a height onto a person or where a person could fall from a height, slip or trip on the same level or fall to a level below; • Consequences may range from lacerations to death.
Noise and vibration	• Found wherever people are exposed to noise or vibration; • Consequences may range from whole body vibration, 'white finger' to noise induced hearing loss.
Chemical	• Found wherever people could inhale, ingest or absorb a range of liquids, dusts, fumes, or gases, or substances react to cause damage such as fire, explosion or corrosion; • Consequences range from acute to chronic, may have a long latency and could result in death.
Electrical	• Found wherever electricity is used to operate equipment; • Consequences range from burns to death.
Mechanical	• Found in machinery where there are movi there may be ejection of parts; • Consequences range from lacerations, amputations, to death.
Radiation	• Found wherever there are x rays, UV radiation, microwaves, lasers or welders; • Consequences range from burns to death.
Body muscle (ergonomic related-risk)	• Found wherever a job that can cause biomechanical stress on the employee, such as highly repetitive tasks, awkward postures, forceful exertions, static postures and localized pressure into the body part. • Examples of consequence are Musculoskeletal disorder (MSDs), tendonitis, strain injury (RSI), etc.

As such, the learning guide for Contribute to the Implementation of Strategies to Control OHS Risk [27] indicates that the opportunities for intervention can be identified as depicted in Fig. 2. From the figure, it is apparent that high reliability controls, which act closest to the source of energy, are chosen when the foreseeable outcome may be death or serious injury. Low reliability controls such as personal protection can prevent personal damage from the energy, and this control should be a last resort. The probability for injury or damage intervention ties in with the Hierarchy of Controls, which is one of the principles of risk management. It could also be seen that 'elimination' or 'reduction' of the risk (represented by technological controls) are better approaches compared to protecting a person through individual or behavioural controls.

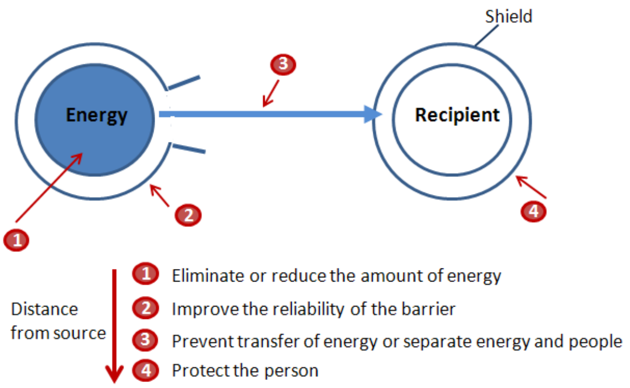

Fig. 2. Opportunities for injury or damage intervention [27].

2. Methods

The case study design was implemented in this study through the integration of field observations, interviews and document analysis. Data was collected on on-going construction projects, which used the selected construction approaches in order to observe the process involved and to identify the associated OHS risks. For this research study, a comparative type was undertaken, where the focus was on the knowledge acquisition on different construction approaches of building envelopes and structure, at multiple case study organisations, involving several participants. It is to be noted that the 'case' for this study is defined as the construction approaches involved in residential building construction, whereas the participants are the case study organisations which implemented the particular construction approaches in their building construction projects.

This study follows Yin [28] proposition in the selection of case study organisation, which are relevance, feasibility, access and application. The selected case study organisations were suitable since they were executing residential construction projects using IBS and traditional approaches. All of these case studies were readily accessible via visits or electronic communication, which helps researcher if there is information required in future. During the execution of the case studies, the researcher received adequate managerial and operational support from the participant organizations to ensure successful completion of the project. One of the concerns for the conduct of the research is that the full co-operation of the organisations should be secured for the duration of the research [28]. For this study, the researcher had applied for ethics approval to conduct research which required all the participating organizations to agree to participate and permit the researcher access to their operational facilities. In addition, the case study organisations were well known to the author and a good relationship had been developed.

Three case studies were chosen for this study, in which two of them were in IBS/offsite and one in traditional construction. These numbers, which represent different construction methods were a convenient sample and enough to compare the difference of the processes and the effect of IBS on construction safety and health. The author was also aware of the practical consideration of time and resources available to execute the research. As there is no ideal number to address the number of cases stated in the literature [17], the number of cases employed for this study was deemed sufficient to achieve the objectives of the study. Similar number of cases was employed by McKay [17] who investigated the associated risks involved in 3 offsite construction methods and their effects on traditional construction in the United Kingdom.

Table 2 presents the research participants (organisations) in the case study research. Overall, this study involved a discussion with the managerial staff, operatives, and supervisors, including the observation and documentation of operations. Data collection was performed on the currently on-going construction projects, in which each project represented different construction approaches.

Table 2. Details of case studies.

Case study description	Case study project description	Location/Source
Case study 1 In situ concrete and masonry method (Traditional construction)	Construction of 3-storey semi-detached house using conventional method	Kuala Lumpur, Malaysia
Case study 2 Precast column-wall panel system (IBS)	Construction of 4-storey hostel using precast column-wall panel system. The precast panel acted as a load bearing wall	Precast concrete manufacturer and contractor Selangor, Malaysia (precast factory and batching plant); *and* Melaka, Malaysia (construction site)
Case study 3 Blockwork system (IBS)	Construction of 2-storey academic block using blockwork system. This system uses interlocking CMU to build the structure and envelope of the building where the CMU itself acts as a load bearing structure	Blockwork system manufacturer and contractor Selangor, Malaysia (factory); *and* Johor, Malaysia (construction site)

During the field observation, a significant amount of time was spent directly observing the activities and process operations of each case. Site visits were undertaken to directly observe and document the identified tasks, workstations, equipment and tools in use. The site visits were guided by construction personnel. In addition, photographs were taken for documenting purposes.

Interviews were conducted in conjunction with the field observation. For the purpose of this research, semi-structured interviews were used which offer open responses from participants to specific questions. The interviews were digitally recorded to secure an accurate account of the conversations and avoid losing data since not everything can be written down during the interview. For interviews, purposive sampling was used for this study as a sampling strategy. The respondents of the interviews were determined by the participating organizations based on their job responsibilities, position and involvement of the subject studied; and could provide the necessary information for the research. Numbering and labelling of the interview were performed on the interviewees' names (coded) and interview date. The participants for the interview were selected by the organisation management based on the ability of the participants to represent the organisations in areas of the research questions. The participants also had a commitment to the research project, including reliability and experience in a particular field. Table 3 presents the details regarding the participants.

Table 3. Interviewees.

Case study	Name	Role/ experience
1	A	• Assistant project manager • Responsible for planning and monitoring construction scheduling • 6 years' experience in traditional residential construction
	B	• Site supervisor • Experience in construction process
	C	• Safety and health supervisor • Responsible for health and safety issues
2	D	• Production manager responsible for health and safety • Experience in production operations and IBS construction
	E	• Project manager responsible for health and safety • Experience in production operations and IBS construction
	F	• Site supervisor • Responsible in monitoring production process
3	I	• Factory manager responsible for health and safety • Experience in production operations
	J	• Construction manager responsible for health and safety • Experience in construction process
	K	• Site supervisor responsible for monitoring construction process

Meanwhile, document analysis involved collecting the documentary sources during data gathering activities. These included case study organizations' corporate publications, and documents and records pertaining to the construction process observed were analysed. This documentary evidence acts as a method to cross-validate information gathered from interviews and observations and also provides guidelines in assisting the author with the inquiry during interview. The corroboration of multiple qualitative techniques for these case studies enhances the validity and reliability of findings.

3. Results and Discussion

3.1. Case study 1

The construction of the 3-story semi-detached house, which was performed using conventional construction methods, took place in Kuala Lumpur**.** Established in 1990, the company for this project is known as the main contractor for building low to medium-rise residential buildings, factories, and infrastructure works. The selected case study was a part of a project to develop residential housing located in Cheras, Kuala Lumpur. The contract period for the development project was one and a half year, with a total contract sum of RM 53 million. Figure 3 shows photographs of the project.

Fig. 3. The project under construction.

3.1.1. Reasons for choice of construction method

In response to the question regarding the reason for a company to select a particular method for construction, Interviewee A stated, "this company is experienced in the use of the conventional method for building construction." The projects managed by the company were commonly large-scale projects, which involved the construction of residential developments. Furthermore, 'cost' was perceived as the barrier to the implementation of IBS methods due to the large capital investments required to operate the manufacture of components (Interviewee A). However, the cost of purchasing IBS components from a manufacturer or supplier was considered pricy. Interviewees A and B also stated that compared to the construction of building through an IBS method, the traditional construction method was perceived to be beneficial for transportation, site arrangement, and formwork disposal.

The structure and walls were constructed using conventional methods for housing development. The sub- and super-structure of the building were constructed from reinforced concrete, while the walls and partitions were formed of bricks with a plaster finish. The materials of building construction (cement, sand, aggregate, and bricks) were delivered from the manufacturing facilities/quarry to the construction site. Following that, the concrete was poured in situ. The formwork was stripped out when the concrete was cured, and bricks were laid to form the walls.

3.1.2. Process and associated risks in the 'delivery' works

This stage involved delivery of construction materials to site, such as bricks, cement, sand and aggregate. The activities involved in the delivery phase for the 'in situ concrete and masonry' method is described include load materials onto truck; transport and deliver materials; off-load materials on-site; and storage (Interviewees A and B). The main risks were associated with the transport of materials to the construction site, for example, road traffic, site access, site conditions and the stability of materials. In addition, mobile plant risks during loading and off-loading were also highlighted. The risks were then categorized into damaging energies for evaluation. Table A-1 (*Appendix A*) provides a clearer view of the damaging energies involved in each activity.

3.1.3. Process and associated risks involved in the 'in situ' works

The main in situ site activities and OSH risks for this conventional in situ concrete and masonry method are site preparation; ground slab construction, e.g., mix concrete, concreting and vibrating, checking starter bars and pipe positions; column construction, e.g., fix rebar/steel bar, formwork for column, mix concrete, pour concrete into formwork and vibrate, curing; bricklaying, e.g., transport brick, carriage of bricks to workplace, erection of work platform, mix mortar, cut bricks, laying mortar, laying of each course of bricks; place damp proof course; fix wall ties; fix mesh reinforcement; place lintels; plastering; and painting and finishing.

The main OSH risks were claimed to be those associated with dermatitis, and the repetitive tasks of carrying of bricks, which can cause manual handling injury and MSDs. In addition, the risk of falling bricks, working at height, craneage risk, trips and falls and exposure to ultraviolet (UV) light from working in sunlight were also noted (Interviewee C). These risks were categorized into damaging energies for evaluation. The damaging energies involved in each activity is shown in Table A-1 (*Appendix A*).

3.2. Case study 2

A construction of 4-story hostel, which was located in Melaka and used the precast wall system, was selected as the case study. The project was a charity with a contract worth RM 2 million. Provided that the project involved the manufacture of a building component at the factory, the data collection process was also performed at the precast factory and batching plant in Selangor. The system for the construction of the building was an unconventional 'wall panel system', in which the column was integrated with the wall. In this system, the precast column-wall panel functioned as a load-bearing wall, where the column formed a part of the structure. The connection system used for this project was an integration of wet-joint, grouting, and welding joint. Photographs from the project are shown in Figs. 4(a) and (b).

(a) **(b)**

Fig. 4. (a) Production yard for the integrated wall/column panels, (b) Construction site of the hostel.

3.2.1. Reasons for choice of construction method

In response to the question regarding the organisation selection of a particular construction method, Interviewee D stated that the selection was according to the client's request.' Furthermore, although the 'column-wall panel' system was deemed as 'overly used', the company used it as a marketing opportunity to introduce an uncommon panel system for this charity project. The incorporation of the columns for the panel formation was performed to add architectural features of the building. It was proven from this system use that the precast concrete wall panel system is not restricted to box-shapes, but it could also easily incorporate architectural features of various shapes, such as arches. Additionally, interviewee D elaborated that the selection of the wall panel system was mainly according to the repetitive nature of the building structure.

In regard to the difference between the manufacturing process of this system and the ordinary 'wall panel' and 'frame system' (precast beam, precast column), interviewee D stated, 'the manufacturing process is the same, however, the cost is different.' To illustrate, the cost for the system fabrication was more expensive due to the higher complexity of the mould set, the longer time required for fabrication, and a different configuration of the steel reinforcement bar. The interviewee also explained that to create competitiveness within the wall panel systems in terms of cost, a minimum of 200 units should be fabricated to absorb the cost of the mould.

In the case of this project, although the number of units used was lower than 200, the project was continued due to the client's request and their willingness to bear the cost. However, it was stated by interviewee D that Malaysian architects remained unwilling to specify IBS in their designs. Furthermore, architects frequently presented drawings featuring the traditional systems of construction, which led structural engineer into converting the drawings. As a result, the precast system to was returned to the architect for approval. In summary, the construction process for this IBS precast column-wall panel system consisted of the manufacturing of the components, including the delivery of the components to the site, on-site panel installation, and in situ works.

3.2.2. Process and associated risks in the 'manufacturing' works

From field observation and interview, the activities involved in the manufacturing of precast wall panel include bar cutting; bar bending; cage inspection; mould setting; cleaning of mould and oiling; placing reinforcement in cages and setting embedded items into mould; tying bar; positioning the mixer truck; concreting, vibrating and surface finishing; dismantling moulds; finishing using skim coat; and transferring the components to storage.

The OSH risks highlighted were mainly associated with the craneage of large moulds and components, ergonomic-related risks, and exposure to UV. The assembly of steel bars included RSI, electrical shock from the electrical equipment used. The setting of the mould also involved heat from the use of cylinder gas torches and RSI due to screwing works. The use of chemicals was identified in the activities of cleaning and oiling the moulds, and also the finishing of components using a skim coat. In vibrating and compacting concrete, the main OSH risks highlighted were dermatitis, HAVs, craneage risk (from the overhead concrete bucket attached to the overhead crane) and manual handling. Positioning of the mixer truck included the risks of mobile plant (vehicle injury), whereas dismantling of moulds involves risk of MSDs. Mechanical handling and craneage risks were identified in moving and storing the panels, in addition to the mobile plant risks (Interviewees D and F). The damaging energies associated with the activities are depicted in Table A-2 (*Appendix A*).

3.2.3. Process and associated risks involved in the 'delivery' works

The activities involved in the delivery phase for the column-wall panel system were identified as similar to the traditional system. Delivery of the panel components to the site are listed in Table A-2 (*Appendix A*). The main risks were associated with the transport of panels to the site: road traffic, site access, site conditions and the stability of materials. In addition, the craneage risks from the use of crane, mobile plant risk and manual handling during loading and off-loading were also highlighted (Interviewee D).

3.2.4. Process and associated risks involved in the 'component installation' works

The activities involved in the delivery phase for the column-wall panel system were identified as similar to the traditional system. Delivery of the panel components to the site are listed in Table A-2 (*Appendix A*). The main risks were associated with the transport of panels to the site: road traffic, site access, site conditions and the stability of materials. In addition, the craneage risks from the use of crane, mobile plant risk and manual handling during loading and off-loading were also highlighted (Interviewee D).

3.3. Case study 3

The selected project was a construction of a 2-storey hostel block, which implemented the blockwork system. The project site was located in Johor, while the factory was located in Selangor. The selected case study was a part of the construction of a school building, which consisted of an academic block, hostel, and other facilities. Considered by the Malaysian CIDB as an IBS method, this system used the interlocking concrete masonry units (CMU), which functioned as the load-bearing structure and assisted in building the structure and envelope of the building. The interlocking blocks (CMU) were different from conventional bricks as spreading mortar was not required when the bricks were laid. Therefore, the speed of building wall process increased, and lower number of skilled labours was required as the blocks were laid and arranged on a dry surface [29].

Load bearing blocks eliminated the use of columns and beams as structural members. To strengthen the block and enable load-bearing, the reinforcing steel was placed inside the cavity and filled with concrete. It was said that the rates for cost saving from the reduction of the beam and reinforcing the column steel used for this approach were up to 75% [29] compared to the conventional methods, while the speed of the construction of walls, columns, and beams was three times faster. Furthermore, the internal finishing, which used a skim coat, saved labour in external plastering. This method also resulted in minimum material waste, which reduced on-site cleaning. It also contributed to all-weather use, which indicated that no important construction was delayed as a result of weather issues and insufficient manpower. Good quality management was also achieved, which was represented through the accurate delivery of construction speed and job site by the manufacturer. Additionally, the product was environmentally friendly and energy-efficient and offered excellent heat insulation. Photographs from the project are shown in Figs. 5 (a) and (b).

(a) **(b)**

Fig. 5. (a) Production facility of the CMU blocks, (b) Construction site.

3.3.1. Reasons for choice of construction method

Upon the question regarding the factors of the organisation selection of a particular construction approach, interviewee I stated that it was due to the competitive market in other IBS methods, such as the precast and formwork system. As a system used for buildings with less than five storeys, the blockwork system was a preferred solution in rural projects, which were challenged with the mobilisation of machinery and equipment for installing other IBS systems (e.g., precast concrete and formwork systems). Besides the ability to enable future renovation, the use of this system was comparatively inexpensive, with less labour intensity and shorter project completion time.

The process took place in the construction of the building envelope, which implemented the IBS blockwork system, consisted of material delivery and in situ works. This approach was distinguished from the traditional method (Case study 1) due to the use of interlocking blocks, which eliminated the use of mortar to attach the blocks altogether.

3.3.2. Process and associated risks in the 'manufacturing' works

In the manufacturing works for the construction of the blockwork, the following activities were identified: transferring raw material to weighing hopper machine;

delivering pallets; checking product dimension; stacking of interlocking blocks; curing; packing; delivering product for factory storage; and storage. The process of making the interlocking blocks was largely automated therefore requires minimal labour. The OSH risks highlighted were mainly associated with 'struck by moving elements', such as the forklift. Manual handling, which could cause RSI, was identified in the packing activity. In cutting the board, the OSH risks highlighted were cuts, excessive noise and electrical shock. In stacking of finished blocks, the main OSH risk was falling objects due to inappropriate stacking. Table A-2 (*Appendix A*) lists the damaging energies involved in each activity.

3.3.3. Process and associated risks involved in the 'delivery' works

The activities involved in the delivery phase for the blockwork system were identified as follows: loading materials onto truck; transporting and delivering materials; off-loading materials on-site; and storage. Table A-3 (*Appendix A*) summarizes the activities, the damaging energies and the associated OSH risks involved in each activity.

3.3.4. Process and associated risks involved in the 'component installation' works

From field observation and interviews, the main in situ site works activities and OSH risks for blockwork system were discussed and the following activities were highlighted: transporting blocks; carrying blocks to workplace; erecting work platform; installing blocks; placing rebar; grouting; installing of electrical services; and filling gaps between blocks. The main OSH risks were claimed to be those associated with dermatitis, and the repetitive task of carrying blocks, which it was claimed can cause manual handling injury and MSDs (Interviewee K). In addition, the risk of falling blocks, working at height, craneage risk, trips and falls and exposure to ultraviolet (UV) light from working in sunlight were also noted. Table A-3 (*Appendix A*) provides a clearer view of the damaging energies involved in each activity.

3.3.5. Process and associate risks involved in 'in situ' works

The activities involved in the in-situ works were plastering and finishing. The OSH risks associated with the activity include skin burn and inhalation due to the use of chemicals, working at height, RSI and exposure to UV. Table A-3 (*Appendix A*)) provides the description of damaging energies involved in this set of activities (Interviewees J and K).

4. Discussion

The information of activities and their associated risks for every stage of construction (e.g., manufacturing, delivery of component, installation of the component, and in situ works) are tabulated, as shown in the appendix. It could be seen from the table that the 'delivery' phase presents the similarities between the procedures of most construction methods, including in situ concrete and masonry method, precast column-wall panel system and blockwork system. Although this similarity led to the generalisability of the processes, the methods might be different in terms of 'element'. This element could be either the materials, lightweight panels, blocks, bricks, or precast element.

The findings revealed that traditional in-situ concrete and masonry method involved massive on-site manual works, labour-intensive, and exposed workers to many damaging energies. Although the two IBS approaches also consist of several damaging energies, the exposure to those energies is lesser as less time is required on-site for component erection and minor in-situ works. When compared to the traditional method, the precast column-wall panel is deemed to contribute lesser risk, followed by the blockwork system, due to the less on-site activities involved during on-site works. The findings are in in-line with McKay's [17] study that the risks were more controllable and of a less serious nature in the transition from traditional in-situ method to IBS. IBS approaches also offer less trade overlap and a more controlled factory environment with moulds orientated to suit ease of installation [17].

The following paragraphs describe how the selection of different construction approaches could affect the OSH risks involved in construction processes, using the hierarchy of control based on the energy damage model proposition (see Fig. 3). The discussion on how the risks change from traditional in-situ and masonry method to IBS approaches with selected activities providing examples are presented. Particularly, the benefits of IBS in improving safety and health can be described as the amount of damaging energy eliminated or reduced through the use of IBS approaches. For damaging energies that cannot be eliminated or reduced, they can be contained from injuring the recipient (workers) through improving the reliability of the barrier, or preventing the transfer of energy to the worker, and protect the workers by providing appropriate and adequate PPE.

4.1. Elimination or reduction of the amount of energy

In the manufacturing stage, several energies can be reduced with full-mechanization instead of semi-automation, which still requires manual works. For example, in precast column-wall panel system, vibration energy during concreting can be reduced by using vibrating tables. This can also reduce chemical energy where the activities of pouring concrete and vibrating are done by mechanization - concrete is poured into the mould from the attached overhead concrete bucket and vibrating is done by self-vibrating tables, thus eliminating the risk of potential chemical energy exposure to workers. Similarly, in blockwork system, using automation can eliminate kinetic, body muscle and gravitational energies, where all activities can be done through mechanisation without the use of labour.

In regard to delivery phase, the contrast between the elements was present through the method of executing the procedures and the heavier or lighter physical characteristics of the component, which would lead to diverse risk ratings. To illustrate, the method of loading the element into the truck varied between different construction approaches. The precast column-wall panel must be lifted by a crane, although crane lifting was not necessarily required for the blockwork and bricks. In this case, the blocks and bricks can be transferred from factory storage to the truck together with the transport racks using a forklift. The lifting and transportation of precast column-wall panel are also riskier than other approaches if surrounding conditions such as ground surface, vehicle access, lighting and environmental factors are not adequate or bad. Also, manoeuvring the precast panels are more difficult compared to stacked bricks and blocks. Therefore, a lower impact on the kinetic, gravitational, and body muscle energy was observed for the in-situ concrete and masonry method and blockwork system during the delivery phase. However, according to Gibb et al. [30], even though precast concrete wall panel system has higher potential consequence risks, but the risks are much less likely to occur as they tend to be easier to be identified and controlled.

In regard to the in situ works, the elimination or reduction of gravitational energy could be achieved through the use of a precast column-wall panel, in which the risk was not present. Gravitational energy is likely to be involved during working at height, especially within the activity of bricklaying/blockwork and finishing, particularly in the traditional in situ concrete and masonry method and blockwork system. Despite the presence of gravitational energy during the painting at the end of the in situ works for column-wall panel system, the amount of energy could be reduced if the painting were performed in the factory or at the ground level before being lifted.

The use of IBS methods could eliminate and reduce several damaging energies in the traditional method. For example, the chemical energy was controlled through i) reduction of the use of concrete; and ii) reduction of the exposure to cement or concrete. This could be seen within activities that involved chemical substances such as concrete and mortar. To illustrate, the precast column-wall panel does not require concreting at the site as the panel can just be erected to its position. Although the blockwork system still requires concrete during on-site activity, only a small amount is needed. Additionally, the duration of worker's exposure is lesser than the traditional method as the blocks is bigger in size than common bricks, thus reduce the construction time.

Other damaging energies, which could be eliminated or reduced through the use of IBS methods (i.e. precast column-wall panel system and blockwork system) included body muscle (reduction of manual works and time spent for laying blocks), vibration (during concreting), radiation (reduction of the time spent on-site), mechanical power (no work related to cutting bricks in both IBS methods), and noise (fewer machines and equipment are used). For the in-situ concrete and masonry method, the use of self-consolidating concrete could reduce the amount of chemical, vibration, and body muscle energy.

4.2. Improvement in the reliability of the barrier

For energies that could not be eliminated, improving the reliability of the energy barrier could reduce the energy transfer to the recipient. To illustrate, the use of engineering or design controls such as ‘providing and maintaining the edge protection’ during working at height could reduce the gravitational energy during ‘plastering and painting’ in in-situ concrete and masonry method and blockwork system. Moreover, the condition of the barriers, such as the safety net for scaffolding works, should be checked and assessed before its use.

4.3. Prevention of the transfer of energy to people

Energy transfer to the recipient could be prevented by separating the damaging energies from the workers. To illustrate, the prevention of electrical energy requires the work to be performed in a dry area. Furthermore, the radiation energy could be prevented through the use of canopy or shading for activities involved in the manufacture, which are often performed in open areas instead of a closed factory. Noise energy could be prevented through temporary noise barriers when a work involving excessive noise exposure is performed, such as cutting steel bars and bricks.

4.4. Protect the person

The last resort to mitigating the amount of energy transfer to the recipient is the use of personal protective equipment (PPE). Therefore, the workers should be fully equipped with PPE to avoid the damage of energies or at a minimum, reduce the volume of energy threshold. For example, the use of safety harness is a must for working at height activity (along with safety shoes, helmet and vest) to reduce the impact of injury for gravitational energy. Meanwhile, the use of an anti-vibration glove can reduce the impact of vibration energy on the workers, whereas the use of an earmuff and earplug can reduce the impact of noise energy. Workers must be given safety vests to reduce the potential of being hit by vehicles at the construction site (kinetic energy). However, it could be seen in Fig. 3 that this control was considered the least reliable method as it is the last line of defence in the hierarchy of control. Besides, provided that this control relies heavily on the worker's behaviour, the workers would be exposed to dangerous zone due to their human nature, which is susceptible to error [31]. Apart from that, other forms of protecting the person can be done through continuous and targeted training such as correct working posture to reduce potential ergonomic energy.

5. Conclusions

This article presents the results and analysis of the activities and risks involved in the construction of building envelope and structure, which range from manufacturing to in situ works using different construction approaches. The risks/hazards involved in each activity were categorised into several types of damaging energies. Based on the energy damage model propositions, the possible contribution of a particular construction approach towards improved OHS outcomes instead of alternatives is also highlighted.

This study has developed additional contributions to the understanding of IBS construction risks. Despite the contribution of previous study to the same area of understanding (offsite in the UK), this study performed an analysis of the risks related to building envelope and structure within the IBS scope in Malaysia. As a result, the types of risks associated with the IBS construction process were presented in detail. However, several types of damaging energy were not highlighted, such as body muscle energy and psychological energy as this study essentially focused on the major accident types in the construction industry. To illustrate, the top four most common accidents reported by DOSH were the falling of an individual (gravitational), caught-between objects (kinetic), strike from falling objects (gravitational) and stepping on object (kinetic).

This study has determined the OHS hazards/risks in activities related to IBS and traditional construction. Therefore, it is recommended the risks should be investigated and compared in further detail to develop a better understanding of the hazards and mitigation measures are performed before the construction.

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Appendix A

Table A-1. The activities involved in traditional construction process and the associated damaging energies, risks and hazards.

Activities	Damaging energies	Risks/ Hazards description
Delivery		
Loading materials onto truck	Kinetic Body muscle Gravitational	Mobile plant risks (vehicle injury) Musculoskeletal Disorder (MSD), Repetitive Strain Injury (RSI) Mobile plant risks
Transport materials to site	Kinetic Gravitational	Road traffic risks Instability of materials
Off-loading materials at site	Kinetic Body muscle Gravitational	Mobile plant risks (vehicle injury) MSD, RSI Mobile plant risks
Storage/stacking of blocks at site	Gravitational	Collapse of elements/materials
In-situ works		
Mix concrete	Chemical Body muscle Radiation	Dermatitis due to contact with concrete MSD Exposure to UV
Concreting and vibrating	Body muscle Chemical Vibration Radiation	MSD, RSI Dermatitis Hand-arm vibration (HAVs) Exposure to UV
Fix rebar/steel bar for column	Body muscle Radiation	RSI, cuts Exposure to UV
Install column formwork, propping	Body muscle	MSD
Pour concrete into formwork & vibrating	Chemical Vibration Radiation	Dermatitis HAVs Exposure to UV
Curing compound	Chemical	Exposure to chemical compound
Formwork removal	Body muscle	MSD
Prepare for bricklaying (wall)	-	-
Transport bricks (from storage to working areas	Body muscle Kinetic Gravitational Radiation	MSD, RSI Mobile plant risks (vehicle injury), overturning due to unstable ground Mobile plant risks, lifting equipment risks Exposure to UV
Carriage/moving bricks to workface	Body muscle	MSD
Erecting work platforms	Body muscle Gravitational	MSD, overhead work Working at height
Mix mortar	Chemical Body muscle Radiation	Dermatitis RSI Exposure to UV
Cut bricks	Electrical Noise Mechanical power Chemical	Electrical shock Excessive noise from cutting machine Struck by cut brick from saw Dust contamination
Laying mortar	Chemical Body muscle Gravitational Radiation	Dermatitis MSD, RSI Working at height Exposure to UV
Laying of each course of bricks	Gravitational Body muscle Chemical energy Radiation	Working at height MSD, RSI Dermatitis from cleaning mortar Exposure to UV
	Body muscle	MSD, RSI

Fix wall ties; fix mesh reinforcement; place lintels and DPC	Gravitational	Working at height
Painting	Gravitational	Working at height
Plastering/finishing	Chemical Gravitational Body muscle Radiation	Exposure to chemical compound Working at height MSD, RSI Exposure to UV

Table A-2. The activities involved in precast column-wall panel system construction process and the associated damaging energies, risks and hazards.

Activities	**Damaging energies**	**Risks/ Hazards description**
Manufacturing		
Bar cutting	Body muscle Electrical Mechanical power Thermal Noise Radiation	RSI Electrical shock Cuts Exposure to sparks causing burns, exposure to cylinder gas Excessive noise from cutting machine Exposure to UV
Bar bending	Body muscle Electrical energy Noise Radiation	RSI Electrical shock Excessive noise from bending machine Exposure to UV
Cage inspection	-	-
Mould setting	Body muscle Electrical Noise Thermal Radiation Mechanical power	MSDs, RSI Electrical shock from welding, screw bolts Excessive noise due to screwing Exposure to cylinder gas (holes) Exposure to UV due to welding Mechanical handling of machines
Cleaning mould and oiling	Chemical Radiation	Exposure to chemical compound Exposure to UV
Put reinforcement in cages & set embedded items in mould	Gravitational Body muscle Kinetic Radiation	Craneage risk MSD Mobile plant risk Exposure to UV
Tying bar	Body muscle Muscle Radiation	RSI Cuts Exposure to UV
Positioning mixer truck	Kinetic	Vehicle injury risk (mobile plant)
Concreting, vibrating and surface finishing	Gravitational Body muscle Chemical Vibration Radiation	Overhead bucket MSD, RSI Dermatitis HAVs Exposure to UV
Mould dismantles	Body muscle Radiation	MSD Exposure to UV
Finishing (skim coat)	Chemical Radiation	Exposure to chemical compound Exposure to UV
Transfer to storage (component lifting & stacking)	Gravitational Kinetic Mechanical power Body muscle Radiation energy	Craneage risks Mobile plant (crane) risks Mechanical handling RSI Exposure to UV
Delivery		
Prepare for transportation	-	-
Loading precast wall panel onto truck	Kinetic Body muscle Gravitational	Craneage risk MSD, RSI Craneage risk
	Kinetic	Road traffic risks

Transport and deliver wall panel to site	Gravitational	Stability of materials
Off-loading wall panel at site	Kinetic Body muscle Gravitational	Craneage risk MSD, RSI Craneage risk
Storage of wall panel at site	Gravitational	Inappropriate stacking of materials
Component's installation		
Prepare site for panels/column	-	-
Lifting component	Gravitational Kinetic Body muscle Noise Radiation	Craneage risks, working at height Vehicle injury (mobile plant) risks MSD, hand injury Excessive noise from mobile plant Exposure to UV
Adjust component to required position	Gravitational Kinetic Body muscle Radiation	Craneage risks, working at height Vehicle injury (mobile plant risks) MSD, hand injury Exposure to UV
Installation of bracing or propping	Vibration Electrical Noise Gravitational Radiation	HAVs Electrical shock From machine Due to inappropriate propping Exposure to UV
Sealing of gap at the bottom of component	Chemical Radiation	Dermatitis Exposure to UV
Jointing panels	Gravitational Radiation	 Exposure to UV
Checking alignment	-	-
Grouting for in situ wall joint	Chemical (grouting) Gravitational Body muscle Radiation	Dermatitis Due to inappropriate propping MSD (Formwork set-up and removal) Exposure to UV
Sealing for facade wall	Chemical Radiation	Exposure to chemical compound i.e. sealant Exposure to UV
In-situ works		
Finishing	Chemical	Exposure to chemical compound

Table A-3. The activities involved in blockwork system construction process and the associated damaging energies, risks and hazards.

Activities	Damaging energies	Risks/Hazards description
Manufacturing		
Transfer raw material to weighting hopper	Kinetic Vibration	Vehicle injury Whole-body vibration
Transfer hopper	-	-
Mixer	-	-
Delivery of pallet	Kinetic	Mobile plant risks
Pressed machine	-	-
Product checking	-	-
Stacking	-	-
Curing	-	-
Packing	Body muscle	RSI
Deliver product for storage	Kinetic	Mobile plant risks
Storage	Gravitational	Inappropriate stacking
Delivery		
Loading blocks onto truck	Kinetic Body muscle Gravitational	Mobile plant risks MSD, RSI Mobile plant risks
Transport blocks to site	Kinetic Gravitational	Road traffic risks Stability of materials
Off-loading blocks at site	Kinetic Body muscle Gravitational	Mobile plant risks MSD, RSI Mobile plant risks

Storage/stacking of blocks at site	Gravitational	Collapse of materials
Component's installation		
Prepare the site for foundation casting		
Mix concrete	Chemical Body muscle Radiation	Dermatitis MSD Exposure to UV
Concreting and vibrating	Body muscle Chemical Vibration Radiation	MSD, RSI Dermatitis HAVs Exposure to UV
Transport blocks to worksite	Body muscle Kinetic Radiation	MSD, RSI, unstable ground Mobile plant risk (forklift) Exposure to UV
Carriage/moving blocks to workface	Body muscle	MSD
Erecting work platform	Body muscle Gravitational	MSD, overhead work Working at height
Installation of blocks	Gravitational Body muscle Chemical Radiation	Working at height MSD, RSI Dermatitis (cleaning mortar) Exposure to UV
Mix mortar	Chemical Body muscle Radiation	Dermatitis MSD Exposure to UV
Place rebar/reinforcement (vertical reinforcement every 1m; horizontal reinforcement for lintels; column and stiffener; bond beam)	Body muscle	Cuts
Grouting (for the above activities)	Chemical	Dermatitis
Installation of electrical services	Electrical	Electrical shock
Filling gaps between blocks	Chemical Gravitational Radiation	Exposure to chemical Working at height Exposure to UV
In-situ works		
Plastering and finishing	Chemical Gravitational Body muscle Radiation	Exposure to chemical compound (Chemical inhalation from painting) Working at height RSI Exposure to UV