Development of a fast and effective solution for on-site building envelope installation

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Abstract –

Purpose: building cladding installation process is one of the most important tasks in the construction phase. This paper will focus on the development of a fast and effective method for assembly precast concrete exterior wall panel in high-rise building. The existing method can be described as inefficient, time consuming, expensive and labor intensive. There are various parameters has to take in to consideration when planning and execute the precast concrete wall panel installation task. For instance the size, orientation, weight of the panel, then the ground and weather condition of the site yet the transportation sequence of the panel all need to be carefully planned to ensure smooth operation on-site. Method: the proposed method will investigate the existing procedure from the following aspects; designing, logistical, assembly and management and then provide an alternative lean construction method. The proposed approach will introduce an innovative installation technology that consists of a ground level loading bay, vertical transportation system, positioning system and intergraded management system. The innovative solution requires minimal alteration of an existing constriction tower crane hence with less additional changes of on-site equipments the cost of such system will remain affordable. Results & Discussion: the proposed solution will impose a fast and effective installation method for installing precast concrete panel in high-rise building. It requires further implementation and pilot project in the future to verify the effectiveness and practicality of the system under on-site operation.

Keywords –

Assembly; Construction sequence; Logistics; Continuous flow

1 Introduction

There are many types of cladding systems applied in the construction of high-rise buildings. Usually cladding systems are non-load bearing but structurally sounds itself. Such system can be removed from the structural frame of the building without affecting the structural performance of the building. Precast concrete exterior wall panels are commonly used for cladding multi-storey or high-rise buildings around the world. Yet it has shown many constraints throughout its assembly process. Those constraints often include following aspects; technology availability, tower crane usage, vertical transportation, site labor moment, site management, time, cost, weather, location of the site and the design of the building. Assembly task of the wall panel often marks the completion of the building envelope. With aforementioned constraints this task becomes rather tricky and unpredictable. Therefore, solving problems associated with on-site assembly technique of precast concrete exterior wall panel is essential.

Technology availability varies between different parts of the world. Many developed countries have accomplished standardization, industrialization and some even automation in the construction sector. However, in many developing countries this is still out of reach. For example, in developed countries such as Germany its industrialisation of building production can be traced back into the 1920's and 1930's Bauhaus period. Nowadays, there is profound evidence that European industrialising process in building is widespread and matured. This is not only referring to the technology used in the construction process but also its concept, manufacturing equipment, management and other services are more advanced comparing to many developing countries. Currently, in China the government is urgently promoting the concept of construction industrialization. Stress is given to the improvement and extension of applications of existing industrialized building systems. In the meantime, to find the suitable method to improve work efficiency, engineering quality and save investment become apparent challenge. [1]

Tower crane is one of the most commonly used construction equipment. However there are many drawbacks during the installation of precast concrete exterior wall panel process. When the tower crane is in operation there is only a single lifting task can be executed. Other work station may redundant due to the crane is occupied. Therefore down-time of crane usage can cause unnecessary delay in work schedule. The lifting task requires a high degree of skill and organized planning. Yet weather condition could make this task even more formidable. Heavy wind will cause the hoist cable and the panel to swing. It may cause damage of the panel and the structural frame of the building. In the worst scenario, if the hoist cable snaps it may result injury or casualty of on-site personal.

In many construction sites, the manoeuvre of labor and machinery is often disorganized or even random. This could result unnecessary moment of labor, poor work efficiency on-site and increased health and safety risks.

The building component and the structural frame of the building have to be developed with the consideration of the choice of assembly tools and sequence will be deployed during the on-site assembly process. The size, weight, and logistical strategy have to be compatible with each other to ensure the assembly tasks to be carried out smoothly. [2]

This paper will focus on solving those aforementioned issues and develop a fast, effective method for assembly precast concrete exterior wall panel in high-rise building. The proposed system will be developed with regard of lean construction, design for assembly (DFA) principles. Thoroughly investigates issues that appeared in the conventional method and find the appropriate solution. More detailed description of the proposed system will be mentioned in the paper.

2 Existing method

The conventional installation method of precast concrete exterior wall panel in high-rise building it is not a straightforward process. It is complex, dangerous, time consuming task which requires careful planning and team work among all personals involved.

The overall installation process can be briefly described as follow:

Access route of the building must carefully arranged and the ground condition must capable of taking the live load to ensure safety operation during delivery of the wall panels. Ensure there is adequate height for mobility of machinery and the positioning of the panel in the assembly area.

Centre point of the steel frame structure need to be measured and the position of loading bays are assigned.

Precast wall panel will be lifted from the delivery vehicle or from the stacking area to the assigned loading bay. The lifting clutches will be attached on to the embedded lifting inserts.

Tower crane will lift the wall panel to position gently to avoid swing. Then lift wall panel to assembly location and align the connection joint with the bracket on the steel frame work. Slowly lower and adjusting the wall panel into position.

Tighten the connection bolts and ensure the panel is align both vertically and horizontally. Finally apply joint sealant to the wall panel joints.

There are many challenges exposed during the existing installation process. Initially, the wall panels are off-loaded from the on-site stock yard or directly from the delivery vehicle by tower crane then lifted to the job floor where the panel will be installed into position. This task could be problematic as the tower crane can only lift one piece of panel at a time. While the tower crane is lifting the panel, the delivery vehicle has to remain stable on-site. This can cause two potential issues, first, Down-time of tower crane time and second congestion on-site. [3] The design of the connection joints between the wall panel and the steel building frame can also determine the duration of the assembly time. The movement of the wall panel caused by swinging lifting hoist can make alignment and joining between the wall panel and the steel structural elements extremely difficult. Furthermore, damage on wall panel during assembly process can increase project cost and time delay dramatically. Mechanization during the assembly process is relatively low. Most of the assembly task is conducted by human labor. Dealing with heavy building element while exposed in the environment will inevitably increase safety hazard or cause unpredictable delay. In addition to those challenges, there is an increasing trend in many countries which is aging work force. Demographic change and aging society will have directly impact on the construction sector. Shortage in skilled labor, increased wages and less young population is willing to engage in such physical demanding industry. One of the feasible solution is to increase the degree of mechanization and semi-mechanization with manual operation will flexibly cope with varies conditions and be adopted easily with minimal system development and alteration cost. [2]

2.1 Related work

In the late 1980s, a shortage of skilled labor, as well as an aging society has been a major concern in the Japanese construction industry. Single-task robots have been developed to address this issue while also trying to attract young workers to get involved in the industry.

The example below will demonstrate a multi-purpose material-handling robot developed by Kajima called “Mighty Hand”. (Figure 1)

Wall panel installation work is physically demanding as it involves heavy lifting in an enclosed space where it is impossible to use cranes or other heavy lifting devices. Traditionally, workers need to work as a team to lift heavy loads. The task is dirty, dangerous and repetitive. The main goals of this development were to increase productivity and relieve workers from heavy physical exertion. The vertical material lift moves the material to the desired position with little manual assistance. Once in position the material can be attached by hand tools. Preparation material-handling are: transportation of the robot, inspection of the floor surface, accessibility of the floor area, identification of any obstacles, preparation of material for picking up and set-up of the robot. The manipulator commonly has five degrees of freedom: rotating, tilting, shifting, lifting and retraction. The robot is controlled remotely from a small control bow light enough to be carried by a worker. The worker will be responsible for directing the moment of the robot and off-load and position of the building materials.

The robot has increased productivity on-site, reduced manual material handling and the control box can easily carried by humans. Even though interchangeable end effectors allow the robot to perform multi-task jobs, a trained worker must follow the robot at all times, and is responsible for placing materials. Preparation time is long therefore increasing total operation time and total cost. [4]

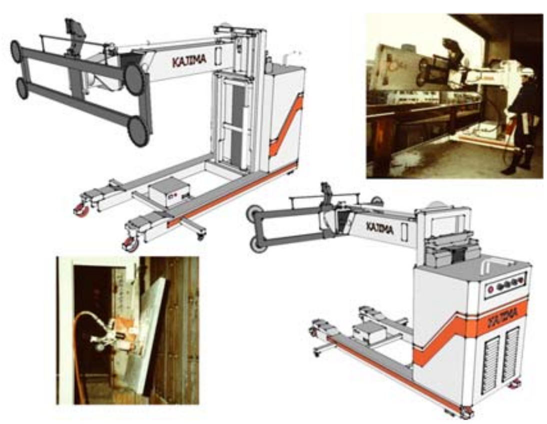

Figure 1: Kajima "Mighty hand" material-handling robot

3 Proposed Method

The proposed system BFIS stands for Building Facade Installation System. The principle design concept is aim to reduce initial R&D cost and manufacturing of the system by utilising existing applied technology in the construction industry or other industrial field. Develop a flexible integrated assembly system that will satisfy vast range of end users demand. BFIS will focus on the design of its on-site logistic, installation, lifting coordination and management technique to solve the aforementioned issues regards to on-site assembly of precast concrete exterior wall panel in high-rise building. The system aim to generate a continuing work flow, reduce down-time in every work station and necessary waste. In terms of design, the degree of automation in the system is carefully applied to be able to achieve reduction in R&D cost. Semi-mechanization combined with manual operation will be able cope varies conditions and be appropriately adopted in many countries. Therefore, the goal of to save investment, reduces expenses, improve the engineering quality and accelerate the overall construction process. [5]

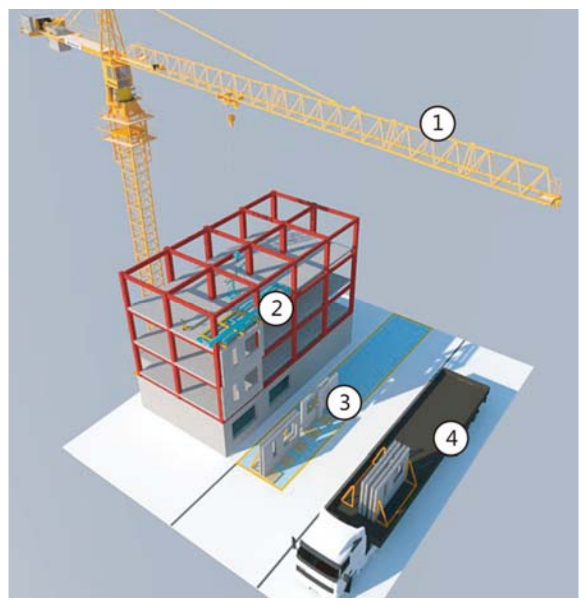

Figure 2: Components of BFIS

3.1 Components of BFIS

The proposed system is designed to be highly modular that the main component of the system consists of three main modules: (Figure 2)

- Number one is the tower crane system. The module is similar to conventional tower crane system, but it equipped with on-board camera, it will connects with the hoist systems and lifts wall panels from the delivery vehicle and unload them to the loading bay. The hoist system will then connects with the BFIS hoist system for final wall panel lifting task while monitor and execute final assembly adjustment.

- Number two is the assembly system module. This is also the key module of the BFIS, it provides support to the wall panel during the assembly process as well as allocation and fine-tuning of the wall panel before it connect with the building structural frame. The assemble module consists of several sub-systems and it will be introduced in detail later in the paper.
- Number three is the loading bay. The wall panel is placed on the loading area by a tower crane from the delivery vehicle. The system will be following a pre-programmed order generated by the construction schedule. A programmable logic controller (PLC) is used for the control of the logistic system. At the prefabrication factory each wall panel is issued a RFID tag. When they arrive on-site, the tag will be scanned and the information read will show the exact assembly sequence and assembly position of each wall component. The control system can be controlled remotely allowing workers to operate the system in case of emergency. [6]
- Number four is the delivery bay. The delivery vehicle will dock into the correct bay following the assembly order generated by the PLC. To adopt just-in-time (JIT) Just-in-sequence (JIS) principle in the construction process will enhance overall productivity on-site.

The assembly system module is the key design feature of the entire system as shown in (Figure 3). The system offers an integrated assembly approach, which include positioning, fine-tuning and fitting of the wall panel. It also provides a self-adjustable approach that allows the system to move along the assembly position. The system can be divided into six modules; main hoist module, tuning hoist module, travel support platform, tuning support module, mobile crane and a trolley system. The system is designed to provide efficient vertical and horizontal transfers of the wall panel. Especially in this high-rise building project, efficient planning for different types of lifting tasks is essential. [7]

The main hoist module connects with the tower crane and the tuning hoist module. It provides vertical lift of the wall panel along with the tuning hoist module. It will lift a set of wall panel with tuning hoist module from the loading bay. Once the tuning hoist module reaches the docking position and securely connected with the turning support arm, the main hoist will be manually detached from the tuning hoist module. The stop damper is designed to minimize the damage may accrue during the lifting of the wall panel. There is an on-board camera will monitor the entire sequence.

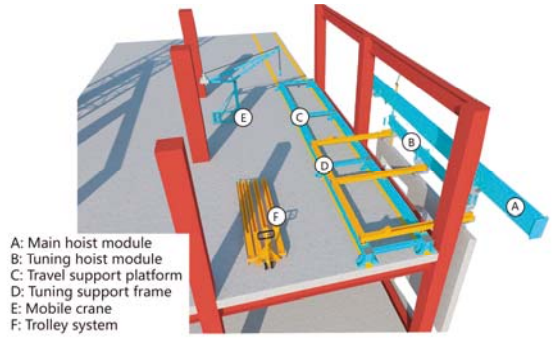

Figure 3: The assembly system module

Once the main hoist module is detached from the tuning hoist module, it will repeat the sequence again.

The tuning hoist module manually operated controlled by assembly operator by a joystick controller. Once it detached from the main hoist module while the wall panel is connected with the tuning hoist supported by the tuning support frame. The hydraulic legs will be inserted into the docking guide on top of the sliding rail. It offers vertical adjustment of the wall panel. The hydraulic legs can be removed from the tuning hoist module and reattached to the correct position based on the size of the wall panel to be assembled. (Figure 4)

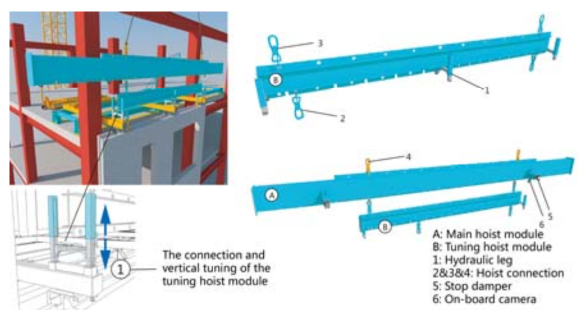

Figure 4: Main and tuning hoist module

There is a motor located in the arm body that will pull and push the docking guide back and forth along the sliding rail. It offers horizontal adjustment of the wall panel. The tuning support adjusting frame will allows the tuning support arm to be fitted in correct position according to the size of the panel. (Figure 7) The tuning support frame is connected with the travel support platform which is linked with the building floor. Both the travel support platform and the tuning support frame are designed as flexible modular components that suitable for on-site assembly and disassembly and easy for transportation across the building site. The mobile crane is for lifting tuning support frame parts and travel platform parts during wall assembly process. The spare parts are temporarily stored on the trolley system.

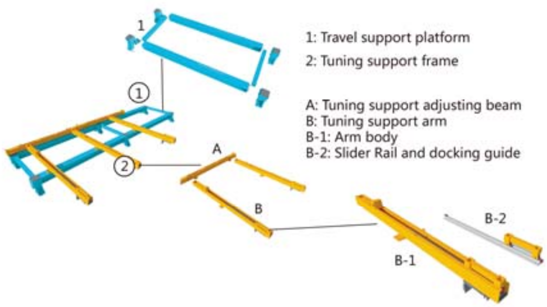

Figure 5: Travel support platform and tuning support frame

3.2 Work flow of BFIS

The wall panels are arrived on-site and to be unloaded from the delivery vehicle on to the loading bay. The tuning hoist module will be connected with the correct wall panel ready to be lifted by the main hoist module that attached on the tower crane. At the same time, on the assembly floor level, the travel support platform and the tuning support module is adjusted and positioned. The panel will be lifted and securely positioned on the tuning support frame along with the tuning hoist module. At this point, the main hoist module will be disconnected from the tuning hoist module and return back to the loading bay for the next load. At the assembly floor level the wall panel is fine-tuned and finely assembled to position by the operators. As shown on (Figure 6) the operators will arrange the assembly tasks of the next section of the travel support platform and the tuning support frame based on the evolution of the assembly process. Those tasks are overlapping according to the installation plan ensures continuous work flow. [8]

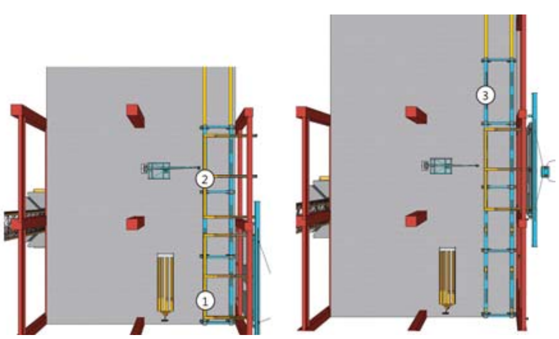

Figure 6: Work set-up of BFIS

Figure 7: Different ranges of hoisting capacity

4 Discussion

In comparison with the conventional installation process, BFIS reflects some advantages as well as limitation.

The advantages are listed as below:

- Time saving –The system is specially designed for the specific task. Due to each task is carefully planned and the overall composition of the system is closely guided by the work flow to ensure work is executed in a parallel fashion. The overall duration of the wall panel assembly process will be reduced.
- Improved on-site logistic – The proposed system enables the detail of the wall panel to be traced from the factory to its final assembly position of the building. On the other hand, the availability of each station and personal is also traceable. This feature will enhance the coordination of work force on-site.
- Stability – The wall panel will be positioned on a static support frame before final assembly. This design will eliminate any swing caused by wind or other external force.
- Cost effective – Semi-mechanization combined with manual operation enable the system to save considerable amount of R&D cost. Most of the system components are available on the existing market and require minimal alteration to achieve the concept specification.

The system limitation and challenges in later implementation stage can be surmised as below:

- Handing variety weight and sizes of the wall panels –The assembly system module is supported by the floor of the building therefore the system weight plus the weight of the wall panel must be considered. Lifting heavy wall panel may cause structural damage of the building. Even through the tuning support adjusting frame and allows the tuning support arm to be fitted in various positions to accommodate different sizes of wall panels. However, because most of dismantle work will be carried out by operators, therefore it will increase overall assembly time.
- Operation Safety – There is not any similar

assembly system available on the market for operators to train or compare. This will increase the potential risk when unfamiliar situation occurs during the assembly process. In addition, the system requires the operators to work closely with the machinery that will increase potential injury caused by malfunction of the machine or misconduct by human error. Therefore, additional training is necessary for all personnel who will be working with the system. An expected learning curve will occur, hence when planning out assembly schedule this period of time should be considered.

- Manufacturing – Even through most of the component can be found on the existing market, however, reconfigure the systems to preform functions as a new system can impose some difficulties. Each party might from a different industry yet has to share each other's technological know-how and expertise. Strong understanding and collaboration between various industries is an essential factor for the success of the proposed concept.

5 Future development

Generally the BFIS still at its concept development stage, the system provides a huge potential for solving issues in assembly of precast concrete exterior wall panel in high-rise building. However, it also faces many changes in terms of system integration, safety and management. Development of such system and improve the assembly processes will face cross disciplinary tasks between the manufacturers, building designers, property investors, and construction contractors. As mentioned earlier, the most optimized working relationships of developing the system would be increased collaboration between all stakeholders. The system has potential to be upgraded with more degree of automation depends on the budgets of the end-user.

6 Conclusion

This paper has given an overview of the concept of the Building Facade Installation System. The concept will impose a fast and cost-effective installation method for installing precast concrete panel in high-rise building. It has demonstrated an innovative approach in reform the assembly process and also has potential to reduce construction time and save overall project investment cost. However, it still requires further research, implementation and pilot project in the future to verify the effectiveness and practicality of the system under on-site operation.

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