COMPARATIVE STUDY OF IPS & PPVC PRECAST SYSTEM- A CASE STUDY OF PUBLIC HOUSING BUILDINGS PROJECT IN SINGAPORE

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ABSTRACT

A key means of upgrading the construction industry in Singapore is to improve the existing industry techniques and practices that affect construction productivity and cost efficiency, in addition to reviewing the management practices of the industry. Precast technology is not new to the industry, but its use in the local context is still limited for many reasons. The purpose of this paper is to study the construction techniques and compare the performances of the Individual Panel System (IPS) & Prefabricated Prefinished Volumetric Construction (PPVC) precast system through a case study that has been adopted in a high rise public building project in Singapore. From the drawings, specifications, method statements and site documents, it was observed that all the precast components except House Hold Shelter (HHS) were fabricated and installed as an IPS system. Only HHS was used as a PPVC system. The research result indicates that IPS is less productive than PPVC system. Therefore, it could be recommended to introduce PPVC system for the upcoming project that will reduce construction time, cost, waste, site safety hazard, noise, and dust. On the other hand, it will enhance the productivity with better quality of workmanship.

Keywords: *Precast concrete, modular construction, productivity, PPVC, quality*

1. INTRODUCTION

In Singapore, mandatory requirements for prefabrication are enforced indirectly through statutory compliance with ‘‘build ability’’ provisions in the building control system. Singapore is the first country to formulate guidelines for quantifying ‘‘build ability’’ and making the assessment mandatory for building developments under its Buildable Design Appraisal System (BDAS). With a scoring system, the Building Construction Authority requires building designs to achieve minimum build ability scores under building regulations(Chiang, Chan, & Lok, 2006). The mandatory requirements do pose new contractual and legal burdens on developers and consultants(Pheng & Chan, 2001). However, empirical studies have demonstrated a positive correlation between build ability, quality and productivity(Pheng Low, 2001).Precast construction method plays an important role in the modern construction industry; it refers to the making of parts in an offsite precast yard prior to the installation at the site. “The primary purpose of precast construction is to produce building components in an efficient work environment with accesses to specialized skills and equipment in order to reduce cost and time expenditures on the site while enhancing quality and consistency(Anderson & Anderson, 2007).

The precast concrete system is cost-effective than cast in place concrete system. But, the main limitation of use of precast concrete construction is the transportation of precast members from precast yard to the construction site because the cost of transportation is considerably high(Turai & Waghmare, 2015).Precast technologies are not only helping contractors and builders to get their buildings faster but also made easier to perform non-destructive testing

(NDT) if the need arises, In addition, Precast is a smart way to achieve the sustainability objectives of Green Building (Jain, Kumar, & Patterson, 2016).A review of the seismic performance and behavior of precast concrete structures indicates that the buildings designed and constructed by incorporating seismic design concepts performed remarkably well(Khare, Maniyar, Uma, & Bidwai, 2011).Despite a lot of advantages from the precast system, many countries do not want to implement this system because there is a major shortage of expert personnel capable of designing and organizing precast building projects(Arditi, Ergin, & Günhan, 2000).

In order to promote building and construction industries embarking towards sustainability and higher productivity, the Singapore Building and Construction Authority (BCA) had introduced an advanced, leading-edge modular construction technology to promote off-site manufacturing for onsite assembly, namely Prefabricated Prefinished Volumetric Construction (PPVC).The PPVC is defined as a construction method whereby free-standing volumetric modules complete with finishes for walls, floors, and ceilings are constructed and assembled outside the premises of the building works and installed at those premises for the purposes of those building works (Rui & Yahya).Design for Manufacturing and Assembly (DfMA) is a new concept in the construction sector. The principle of DfMA concept is planning more works offsite; manpower and time needed to construct buildings are reduced while ensuring work sites are safe, conducive and have minimal impact on the surrounding living environment. Therefore, PPVC system supports the DfMA concept. However, In Singapore until 2016 it was used only at bathroom and HHS. Most of the builders in Singapore are not keen to be first movers to PPVC due to lack of expert and experience.

Modular construction comprises prefabricated room-sized volumetric units that are normally fully fitted out in the manufacture and are installed on-site as load-bearing “building blocks(Lawson, Ogden, & Bergin, 2011).A module is characterized as a three-dimensional object, which, by its size, is able to provide utility space. Each module consists of a frame, floor, ceiling, walls, and other accessories(Kyjaková & Bašková, 2016).Modular construction is essentially a construction method where individual modules or volumes are constructed offsite, stand-alone, transported to the site and are then assembled together onsite to make up a larger structure(Velamati, 2012).Modular construction is saved about half the time with compared to conventional construction method, meaning the property can be leased faster and added revenue can be created that would not be possible using traditional construction system(i.e. cast-in-place). Modular construction also provides consistent and better quality increases workers skills and reduces errors in construction(Ganiron Jr & Almarwae, 2014).Precast concrete system becoming a very popular technique in order to fulfill the rapid demand of infrastructure. But, most of the country in Asia like Singapore, Malaysia, Thailand and HongKong practicing individual panel system (IPS).But IPS had some limitation such as less productive than PPVC, lots of onsite activity still needed for example Mechanical and Electrical services works, skim coat on precast elements. In order to overcome the limitations of IPS, a sophisticated Prefabricated Prefinished Volumetric Construction (PPVC) method has been recommended in this paper throughout the whole project.

2. ABOUT THE PROJECT

Housing is the basic need of every human being. Due to the faster-growing population, and to fulfill the tremendous housing demand, a more reliable, faster, sustainable method of construction is deemed necessary by the Singapore Housing Authority so-called Housing Development Board (HDB). The concept of “Built to Order (BTO)” in the most economical way has not changed since the beginning; however, new technologies have been developed to suit the modern world construction. One such solution is precast concrete construction technology. The project comprises of 10 blocks of the 16-story residential building with 6 story height car-park. The project is located East part of Singapore namely Sengkang Neighborhood area. The developer of the project is Housing Development Board (HDB).The case study is based on drawing, the method of statement, specification and site installation. To avoid complicated details of a precast column/wall at level 1, conventional cast-in-situ construction was adopted at level 1.Except HHS, rest of the precast elements were used as an IPS system. Moreover, using the precast system started from level 2 to the roof. The location plan, site plan, and typical unit layout plan were shown in figure 1, 2& 3 respectively. In addition, some others basic information about the project shown in Table 1.

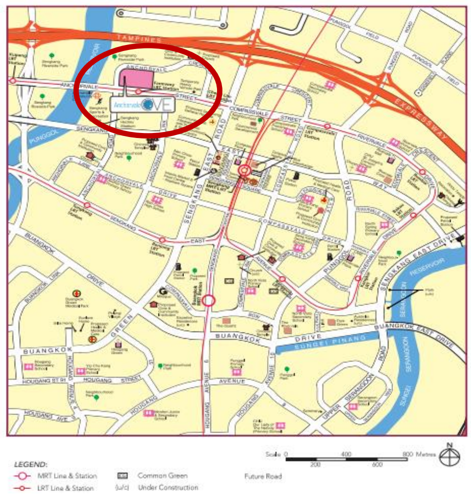


Figure 1: Location plan of the project

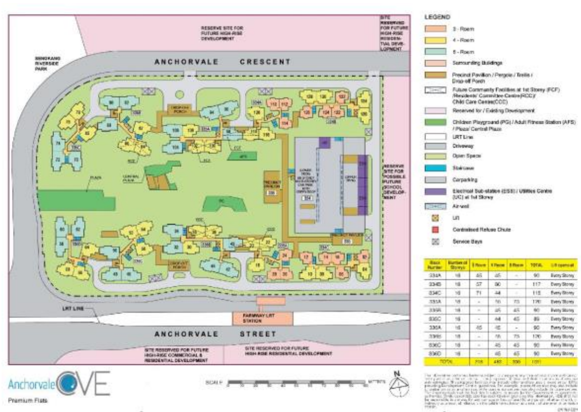


Figure 2: Site plan

Figure 3: Typical floor plan

Table 1: Basic information of the project

Project Name	Anchor vale Cove
Total nos. of building blocks	10 nos. of 16 story residential building with one multi storey carpark.
Total nos. of residential units	1011
Amount precast used	90% of total build up area (10% cast in situ)
Structural system (sub-structure)	Bored pile
Structural system (super-structure)	Precast beam, column, wall and slab.
Basement	2 basement at multi storey car park
Residential unit type	3,4 & 5 bed room platinum flat

3. METHOD OF CONSTRUCTION

One of the biggest challenges in the precast system is connection details. Connections are needed not only to transfer loads but also to provide continuity and overall monolithic behavior of the entire structure. A complete system of precast units can be integrated to form a structure that behaves monolithically with sufficient strength, stiffness & durability to resist seismic & other dynamic loadings. The connections act as bridging links between the components(Bommi, Somaraju, Senou, & Barde).Structural precast elements can largely be classified into two categories based on their production methodology, namely vertical and horizontal. For a typical residential unit construction, the major elements are columns, wall, household shelter, beams, canopy, facade, balcony, staircase, slabs etc. Out of these columns, wall, facade, household shelter are vertical and slabs, beam, balcony, AC ledge are horizontal elements. The common area of a building has many other precast elements such as lift core, boundary walls, and curbstones. However, the installation techniques for some of the key precast elements that have been implemented in this project were discussed below:

3.1 Method of installation of column/Wall

The type of precast column/wall that had been used in this project was IPS. And the installation of precast column/wall started from level 2 to upward. Starter bars from bottom slab are protruding out with a specified length and another starter bar came down from the precast column. Both starter bars are connected by the spiral connector. After checking the verticality, the recess in the precast column is cast back by pressure grouting. Figure 4 to 7 shown precast wall/column connection details and installation procedure.

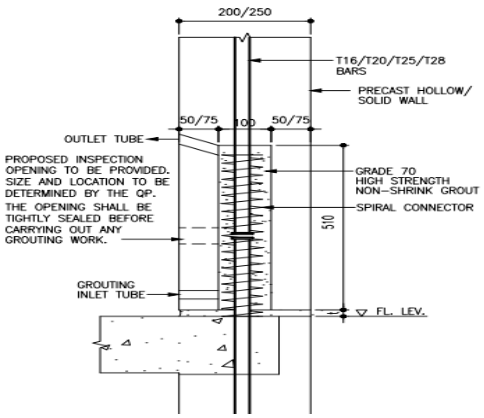


Figure 4: Typical column connection details

Figure 5: Spiral connector for column or wall connection

Figure 6: Bedding preparation for column or wall connection

Figure 7: Column after installation of column

3.2 Method of installation of facade

Precast façade panels are monolithically cast with the beam on top of facade. It was an IPS system as well. The thickness of façade panels were100 and 120 mm. Before installing the facade panels on site, waterproofing strips are placed on the RC curb and then just placed the façade panel on the curb. Both ends of a façade panels had recess with the exposed link. Another exposed link came out from adjacent columns or walls. Both exposed links were connected with U shape link. Finally, the recess cast back with non-shrink grout. Figure 8 to 11 shown typical connection details and installation procedure of precast facade panels.

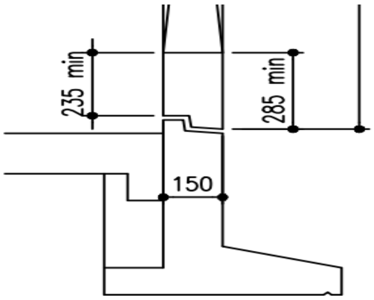


Figure 8: Typical bottom connection of façade panels

Figure 9: Bedding preparation for façade installation

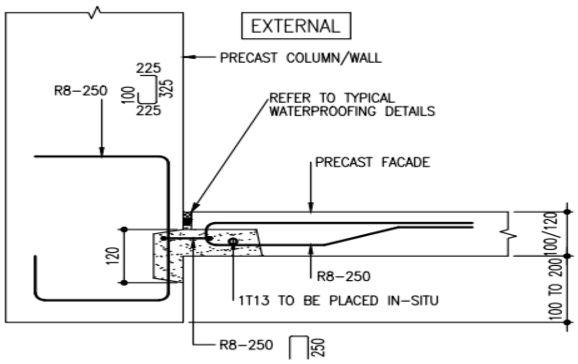


Figure 10: Typical Façade connection details

Figure11: Façade panel being installed

3.3 Method of installation of slab

Precast slab system consists of precast pre-stressing planks and that is why it is possible to achieve larger unsupported span. Typical thickness of planks was70,90 and 110mm.These planks were cast offsite as per approved shop drawing and then delivered to the site. The planks were placed in position using tower cranes. The bottom layer of rebar placed in the precast planks and the top layer of rebar placed on site at top of planks.PVC conduit for M&E services placed just below of the top mesh and then top up with 80 to 90 mm in-situ concrete. Figure 12 to 15 shown the typical connection details of the precast slab as well as installation procedure.

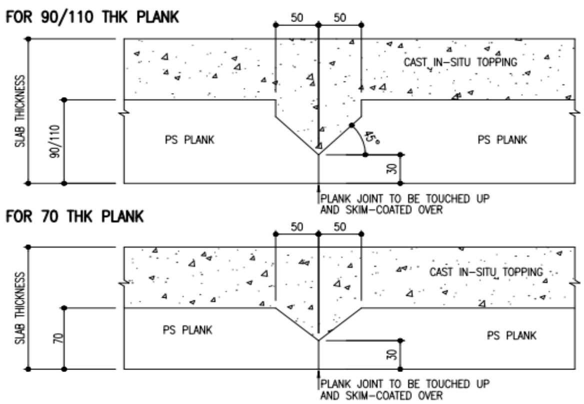


Figure 12: Typical precast slab system

Figure 13: Preparation for precast plank placement

Figure 14: Placing of precast plank

Figure 15:Top layer of rebar placed and slab is ready for casting

3.4 Method of Installation of Household Shelter (HHS)

The precast house hold shelter is a PPVC (modular compartment) module that was used in this project. But, the percentage was very little with compared to total precast elements. It has the hollow core at every side of the wall. The starter bar comes from below slab and passes through the hollow core. The core then cast back with cast-in-situ concrete. Figure 16 to 19 show the connection details and installation procedure of the precast house hold shelter. From this single PPVC element it was found that total installation time for HHS was reduced 75% with compared to IPS system.

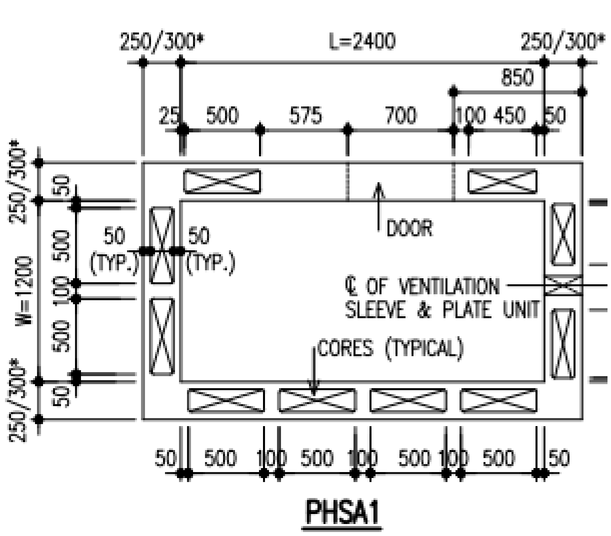


Figure 16: Typical shop drawing for house hold shelter

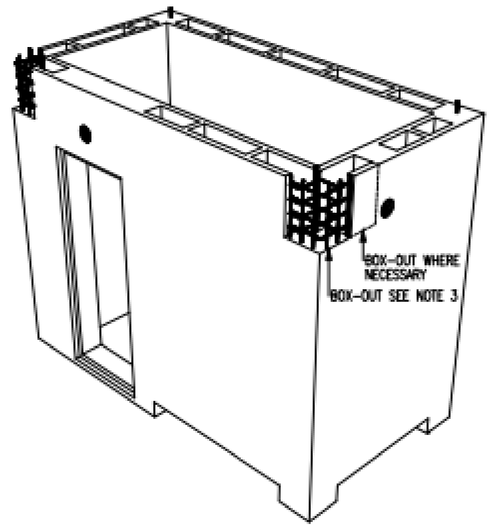


Figure 17:Typical 3D view of household shelter

Figure 18:Installation of household shelter in progress

Figure 19:After installation of household shelter

4. CHALLENGES EXPERIENCED

Initially**,** the main contractor appointed one precast supplier but they failed to deliver the precast components on time, as a result, the project was delayed and this experienced similar to previous research finding(Ali, Hammad, Sweis, & Samhouri, 2009). After that, the main contractor deployed two precast suppliers and they managed to catch the delay. Concrete supply was another challenge. Initially, the builder engaged one concrete supplier, but they could not cope with the site demand. As a result, later on, added one more supplier in order to avoid delay. Manpower was a serious issue because Singapore construction industry mainly depends on foreign manpower. The Ministry of Manpower continuously changes immigration policy that greatly affects the quota of firms. The main reason behind the above challenge was adoption of IPS system because lots of onsite activity was required in IPS system. That can be reduced significantly by adopting PPVC system within the whole project. But transportation and hoisting for PPVC system was a big challenge that has to be carefully considered during the design phase. Nevertheless, the challenges that experienced from this particular project will be the learning curve for future projects.

5. BENEFITS OF PPVC SYSTEM OVER IPS SYSTEM

In IPS system still lots of onsite activity needed for example slab topping-up, Mechanical Electrical & Plumbing (MEP) services installation, skim coating. On the other handin PPVC system, very minimum on-site works required like grouting at joint area only. Manpower saving with compare to in-situ construction for the IPS & PPVC system was presented in table 2.

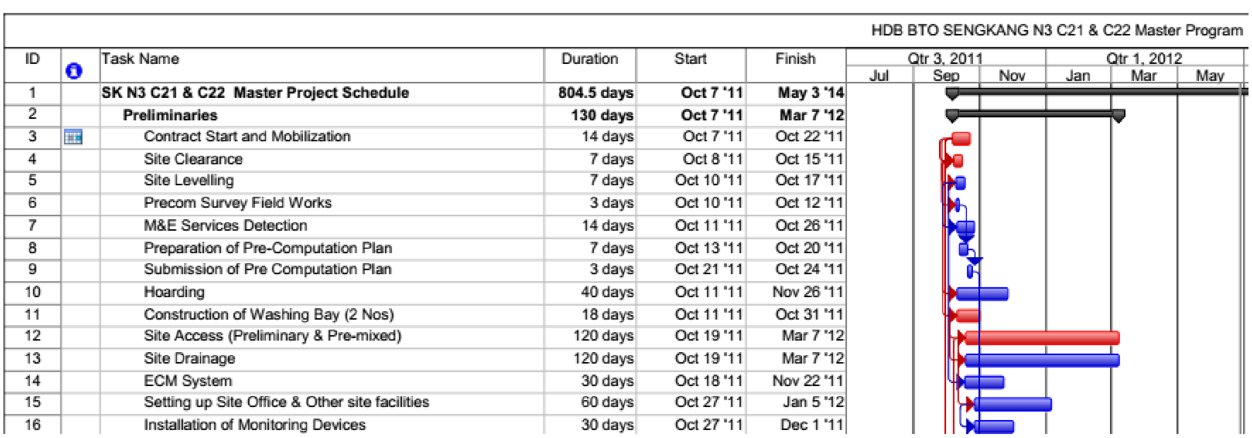
Table 2:Comparison of manpower requirement

Trade	Precast system	Manpower saving
Structural (project level)	IPS	10%
	PPVC	40%
Architectural (Trade level)	IPS	30%
	PPVC	70%
MEP (Trade level)	IPS	30%
	PPVC	70%

6. RESULTS AND DISCUSSION

6.1 Total construction period

The as-built master program that has been followed in this project shown in figure 20.From the program it has been found that the whole project that means10 building blocks of 16 stories comprise 1011 units and one 6 story car-park completed by 28months. It was possible by adoption of the IPS precast system. As PPVC system was used only in HHS and it was very small percentage with respect to the whole project, the separate master program for the project was not prepared. However, the total construction period can be reduced to 19 months.

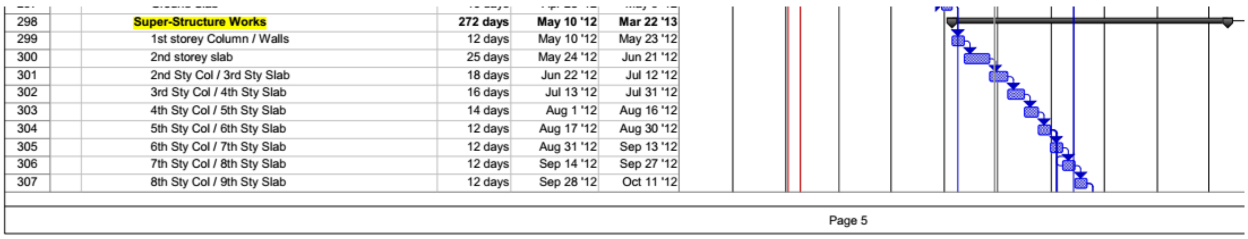

HDB BTO SENGKANG N3 C21 & C22 Master Program

ID	Task Name	Duration	Start	Finish
1	**SK N3 C21 & C22 Master Project Schedule**	**804.5 days**	**Oct 7 '11**	**May 3 '14**
2	**Preliminaries**	**130 days**	**Oct 7 '11**	**Mar 7 '12**
3	Contract Start and Mobilization	14 days	Oct 7 '11	Oct 22 '11
4	Site Clearance	7 days	Oct 8 '11	Oct 15 '11
5	Site Levelling	7 days	Oct 10 '11	Oct 17 '11
6	Precom Survey Field Works	3 days	Oct 10 '11	Oct 12 '11
7	M&E Services Detection	14 days	Oct 11 '11	Oct 26 '11
8	Preparation of Pre-Computation Plan	7 days	Oct 13 '11	Oct 20 '11
9	Submission of Pre Computation Plan	3 days	Oct 21 '11	Oct 24 '11
10	Hoarding	40 days	Oct 11 '11	Nov 26 '11
11	Construction of Washing Bay (2 Nos)	18 days	Oct 11 '11	Oct 31 '11
12	Site Access (Preliminary & Pre-mixed)	120 days	Oct 19 '11	Mar 7 '12
13	Site Drainage	120 days	Oct 19 '11	Mar 7 '12
14	ECM System	30 days	Oct 18 '11	Nov 22 '11
15	Setting up Site Office & Other site facilities	60 days	Oct 27 '11	Jan 5 '12
16	Installation of Monitoring Devices	30 days	Oct 27 '11	Dec 1 '11

Figure 20: As built master program for the study project

6.2 Casting Cycle

The as built master program for super-structure has represented in figure 21.From the result it has been found that achieved slab casting cycle of 12-14days. It can be reduced to 6 days cycle by adopting PPVC system.



298	**Super-Structure Works**	**272 days**	**May 10 '12**	**Mar 22 '13**
299	1st storey Column / Walls	12 days	May 10 '12	May 23 '12
300	2nd storey slab	25 days	May 24 '12	Jun 21 '12
301	2nd Sty Col / 3rd Sty Slab	18 days	Jun 22 '12	Jul 12 '12
302	3rd Sty Col / 4th Sty Slab	16 days	Jul 13 '12	Jul 31 '12
303	4th Sty Col / 5th Sty Slab	14 days	Aug 1 '12	Aug 16 '12
304	5th Sty Col / 6th Sty Slab	12 days	Aug 17 '12	Aug 30 '12
305	6th Sty Col / 7th Sty Slab	12 days	Aug 31 '12	Sep 13 '12
306	7th Sty Col / 8th Sty Slab	12 days	Sep 14 '12	Sep 27 '12
307	8th Sty Col / 9th Sty Slab	12 days	Sep 28 '12	Oct 11 '12

Page 5

Figure 21: As built master program for super-structure

6.3 Quality of Workmanship

From the figure 22, it was found that by implementing IPS precast system high quality-finishing workmanship was achieved by doing only skim coat directly on the precast elements. No plaster works were needed for IPS system. On the other hand, no onsite plaster as well as skim coat required for PPVC system but achieved very high quality finishing compared to IPS system that has been shown in figure 23.

Figure 22: Quality of workmanship using IPS

Figure 23: High quality workmanship using PPVC

6.4 Other Achievements

Some others astonishing results along with learning experiences achieved through this landmark project which is noted as follows:

- Cost and time optimization.
- Eliminated brickworks and plasterwork on precast wall, column & facade.
- Overall cost required for constructing the building using IPS system is reduced by 20% when compared to conventional method. It can be possible to reduced 40% by adopting PPVC system.

- The IPS precast system saved form work requirement 75%, scaffolding requirement 75% to 90%, and wet concrete requirement 90%.On the other hand, it can be reduced to 95 % by adopting PPVC system.

7. CONCLUSIONS

The precast system represents an efficient method of building construction. Design for Manufacturing and Assembly (DfMA) concept was developed to enhance the construction speed significantly. Prefabricated Prefinished Volumetric Construction (PPVC) is one of the game-changing technologies that support theDfMA approach. By adopting IPS precast technique, the construction period was reduced by over 50%; construction waste was reduced by 70% relative to the site-intensive building. Precast wall panel system was lead to a more economical design as well. The productivity of IPS precast system is not sufficient enough to meet the industry demand because the client wanted to complete the project within 19 months that was not possible by IPS system. Therefore, to overcome the limitations of the IPS system that has been addressed in this study, the PPVC system (modular system) has proposed to implement in the upcoming whole project as a pilot project. A high-rise residential project that takes three years to complete can potentially save nine months if the PPVC is used. However, the transportation and hoisting factor for the PPVC system need to be carefully considered prior to the design of PPVC module.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the support of the below organizations

- Housing and Development Board (HDB),Singapore
- Axis Architects Planners Pte Ltd, Singapore.
- Mainhardt (Singapore) Pte Ltd., Singapore
- KayLim Construction and Trading Pte Ltd., Singapore

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