The Productivity Rate of Prefabricated Pre-Finished Volumetric Construction (PPVC)

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Abstract. Prefabricated Pre-finished Volumetric Construction (PPVC) is the new, advanced modular construction technology introduced by Singapore Building and Construction Authority (BCA) to promote construction industries towards higher productivity. This paper aims to study the installation procedure of this leading edge construction technology in the construction site. The hindrance and problems encountered throughout the erection of PPVC and the mitigation measures taken to minimize the impact are investigated. Lastly, the study also establishes the productivity of PPVC during the installation process, and also the delivery and unloading process of PPVC modules at the construction site as a reference for future project implementation.

Introduction

In the early ages, buildings and structures were constructed using perishable materials, such as leaves and branches. Later, natural materials such as clay, stone and timbers were utilized. Homes and shelters were all built using bare hands and human muscle power. The birth of modern science on the seventeenth century had made a major breakthrough in the construction industry as the rule of thumb and the use of scale modeling were applied in structures. Stronger building materials and new innovative construction technologies were slowly developed to allow higher precision in designs and ensure the quality and efficiency during the execution process in construction stage.

Today, a huge leap in technology had leaded the Building and Construction industries around the globe embarking towards sustainability and higher productivity. In consonance with this, the Singapore Building and Construction Authority (BCA) had been encouraging the local corporates to adopt and implement a leading-edge construction technology to promote off-site manufacturing for on-site assembly, namely Prefabricated Prefinished Volumetric Construction (PPVC). PPVC technology also known as Modular Construction technology had been well-applicable in constructing commercial buildings around the world for decades. Modular technology significantly speeds up construction, improves productivity in terms of manpower and time savings. In a nutshell, lower costs and shorter construction period with better quality are the core values implemented in every construction projects.

Problem Statement Conventional construction methods whereby the structural members are casted on site using wet concrete are still till the preferable method among the contractors as labor is abundance and the cost is still cheap. There is still lack of references on PPVC in Malaysia construction industry due to challenges and other external factors faced in adopting new construction technology. Contractors are required to allocate additional expenses in hiring experts and high skilled workers, providing training classes, purchasing new software and facilities. High invest in capital and high risks made builders become reluctant to implement new leading edge construction technology.

Aim and Objectives The aim of this study is to establish the productivity rate of execution of PPVC system. The objective of study is to:

1. Determine the installation procedure of PPVC;
2. Identify the problems encountered throughout the launching of PPVC and the appropriate measures taken to minimize the impact to the project; and
3. Calculate the productivity rate of PPVC on unloading and installation.

Scope of Study The scope of study is listed as below:

1. The study involved only execution phase of PPVC technology in the construction site. The manufacturing and transportation stages are not included in the study.
2. The study is focusing on the execution system of PPVC technology which includes the installation procedures and design specifications. The management in adopting PPVC such as coordination, resources and waste control, planning and monitoring are not covered in the study.
3. The productivity rate of PPVC is established based on 1st and 2nd storey only.

Research Significance Through this research, the students hope to introduce PPVC, the new leading edge to construction industry. Installation procedures, details, problem encountered and measures taken during the construction will be recorded and analysed. In addition, throughout the study of PPVC, the student hopes to establish the productivity rate of PPVC system to be references for the future projects.

In regard to urban natural gas pipeline accidents, corrosion is one of the major causes [1]. This underground pipeline is prone to external corrosion rather than internal. Model of external corrosion specifically designed for buried pipeline improves its reliability [2]. Pipeline failure due to corrosion attack can cause hazards involving multiple fatalities, serious financial loss, bad economic implications, and significant environmental damage [3]. These failures definitely contribute to undesirable costly consequences that will be borne by pipeline operators, resulting in the reduction of annual profit margins. Therefore, the need for awareness among operators to assess the overall consequences in order to forecast the total cost of a pipeline failure event has increased dramatically. Human loss, production loss, asset loss, environmental loss, and reputation loss are the types of losses considered in the consequence assessment, which could exhibit a new methodology of assessing the monetary loss of a pipeline failure event due to corrosion. Hence, the prediction of the total failure cost of an event can be accurately assessed. It could assist pipeline operators in making the right decisions in future pipeline inspections and maintenance program to protect their valuable assets.

The total cost of failure is known as risk. Risk can be defined as the product of an event's probability of failure (POF) and the consequence of failure (COF). Various industries practice risk assessment to evaluate risk. The consequences of a pipeline accident are commonly assessed based on human loss, environmental loss, asset loss, and production loss. Reputation loss can be included, too, because a pipeline accident event due to corrosion certainly makes a significant impact on the operator's reputation. Reputation is an intangible asset that can contribute tangible or monetary losses to the pipeline operator. For example, on September 9, 2010, an explosion of a natural gas pipeline in San Bruno, California, owned by Pacific Gas and Electric Company (PG&E), killed eight people, injured 58 others, destroyed 38 houses, and damaged 70 more in a residential neighborhood [4]. The company spent approximately $2.7 billion dollars of shareholders' money to pay fines and penalties charged by California regulators for the blast as reported in March 2014, almost four years after the event date. Recently, PG&E is reported to have been charged for diverting millions of dollar from pipeline safety allocations to executive bonuses for years prior to the accident. This integrity violation might create a negative perception among stakeholders. It is a sign of reputation decline because reputation is measured by stakeholders' perceptions [5].

A 20-inch-diameter buried natural gas pipeline owned and operated by Columbia Gas Transmission Corporation ruptured near a sparsely populated area in Sissonville, West Virginia, on December 11, 2012. Fortunately, there were no fatalities or serious injuries. However, three houses were destroyed, and the fire ignited approximately 76 million standard cubic feet of high-pressure natural gas, which was released and burned an area 820 feet wide and 1,100 feet along the pipeline right-of-way. The operator spent about $8.4 million for pipeline repair and inspection, and they lost almost $285,000 in released gas. The investigation found that pipeline corrosion was the main source of the accident. Furthermore, there had been no inspection done on the pipeline since 1988 [4]. The integrity of the employee responsible for pipeline inspection and maintenance was questionable and capable of influencing the perception of the stakeholders. Hence, the operator's good reputation was endangered.

Previous research regarding consequence assessment of pipeline failures has commonly considered the monetary loss of an accident, while reputation loss has been neglected because the data is difficult to quantify [6, 7]. Tangible human, environmental, and asset losses are calculated at the time of the event. On the other hand, reputation loss is time-dependent and it relies on the critical to the event [8, 9]. An effort to measure reputation loss for a pipeline accident is done based on the coverage range the event receives [10] and the level of public concern. However, this method does not portray the actual perceptions of stakeholders, and the definition of reputation is the beliefs of the stakeholders towards a company and its attributes [5]. Reputation is measured using an index-based method and vital to most organizations [11] because it affects company's profit margin [12].

This paper will discuss the factors that contribute to the loss of pipeline operator reputation due to accidents caused by corrosion. Six pipeline operator experts were interviewed, and questionnaires were answered. The multiple decision-making criteria of the analytical hierarchy process (AHP) with a weighting method were implemented to process the information received.

Previous Studies

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 on-site assembly, namely Prefabricated Prefinished Volumetric Construction (PPVC). 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 [1]. A construction project should cover at least 65% coverage area of unit PPVC modules of total super-structural area except carpark and roof. The PPVC modules shall comply with the following requirements shown in table below.

Table 1: Requirement in PPVC [1]

Element	Minimum level of completion off-site
Floor finishes	80%, only prefinished timber floor allowed for on-site installation
Wall finishes	100%
Painting	100% base coat, only final coat is allowed on-site
Windows frame	100%, only glazing allowed for on-site installation
Door frame	100%, only door leaves allowed for onsite installation
Wardrobe and Cabinets	100%, only wardrobe and cabinet doors allowed for on-site installation
M&E including water and gas piping, wiring, ducting	100%, only equipment and fixtures to allowed for on-site installation
Air-conditioning drain pipe	100%, only air-conditioning Fan Coil Units (FCU) and condenser unit allowed for on-site installation.
Electrical sockets and light switches	100%, only light fittings allowed for onsite installation

As the majority of on-site activities are replaced by more efficient, faster factory processes, construction time can be shorten with the increased labour productivity [2]. It also provides a safe and clean worksite with fewer restraints, on-site noise and disruption [3]. Besides, precise inspections are conducted during the manufacturing stages to eliminate variability and ensure the quality and performance of products. Controlled materials wastage [4] and reduced labour requirements also help to reduce the overall cost of project [5].

Huge investment is needed to adopt new technology, such as setting up facilities and also maintenance of equipment [6] and machineries [7]. Besides, contractors are still to switch to mechanized based system as they are already familiar with conventional system [8] Furthermore, lack of knowledge and exposure to the technology, can lead to poor structural analysis and design which eventually causes difficulties to the on-site installation and also various serviceability issues and defects such as leakage [9]. Without a rigid, standardized system, inflexible for changes for design will discourage clients in prefabrication adoption [10].

In order to establish a rigid and feasible modular construction system, standardization should be integrated in designing the system which can reduce the cost of manufacturing, eliminate errors in production and erection due to variability, improve product's quality and increase the ease of manufacturing [9]. A good planning on the construction activities is necessary for modular projects as delays may cause quality deficiency products and incurred more cost [11]. In addition, a construction project is fragmented in nature, diverse and normally involves various stakeholders.

Hence, it requires integrated participation of the entire team [6]. Lastly, improvement in IT capacity and capability can be the greatest driver of change in the building and construction industry as it covers wide extensive of process which eventually helps to promote standardization.

Construction project is generally diverse as it involves numerous stakeholders and players in a team. The entire operations can be broken down into different stages of works and activities to be completed in specified time upon completion of project. However, there are many factors which may affects constructability of a building from of initial stage to the final stage of the project operation. Ehsan (2013) highlighted that there were eight critical factors that influence structures constructability, namely financial, construction time, labour's issues, safety, construction waste, materials, weather and climate conditions. His study had concluded that financial and time are the major concerns to the major stakeholders.

Retrieved from [3] the modular construction project in Wolverhampton involves three blocks of 8 to 25 stories buildings. There are a total of 824 modules installed in the project. The total floor area of the project is 20730 m2 and the modules installed cover 79 % of the total floor area. The maximum size of the module was 37 m2 with the average size of 21 m2. The total project duration was 59 weeks (July 2008 – August 2009).

Figure 1: 25-story modular building in Wolverhampton [3]

Table 2: Construction data [3]

Module Weight	10000 – 25000 kg
Installation Duration	32 weeks
Installation Team	10 people (8 workers + 2 site supervisor)
Average Installation Rate	7 modules per day
Maximum Installation Rate	15 modules per day
Productivity Rate	7.5 man-hours/ m^2
Waste Generated	5 % of overall construction
Waste Recycled	43 %

Methodology

The study fully utilized the qualitative research methodology. The instrument used to collect the data was through on-site case study on PPVC. The data for the case study are collected via different sources, including field survey, reviewing reports and also archival records. The prevalent environment that entails the sphere of uncertainty in the launching of and the first hand information from the construction site can be obtained, studied and analyzed.

The processes for the research methodology used to conduct the study are divided into four phases, as shown in Figure 2 below.

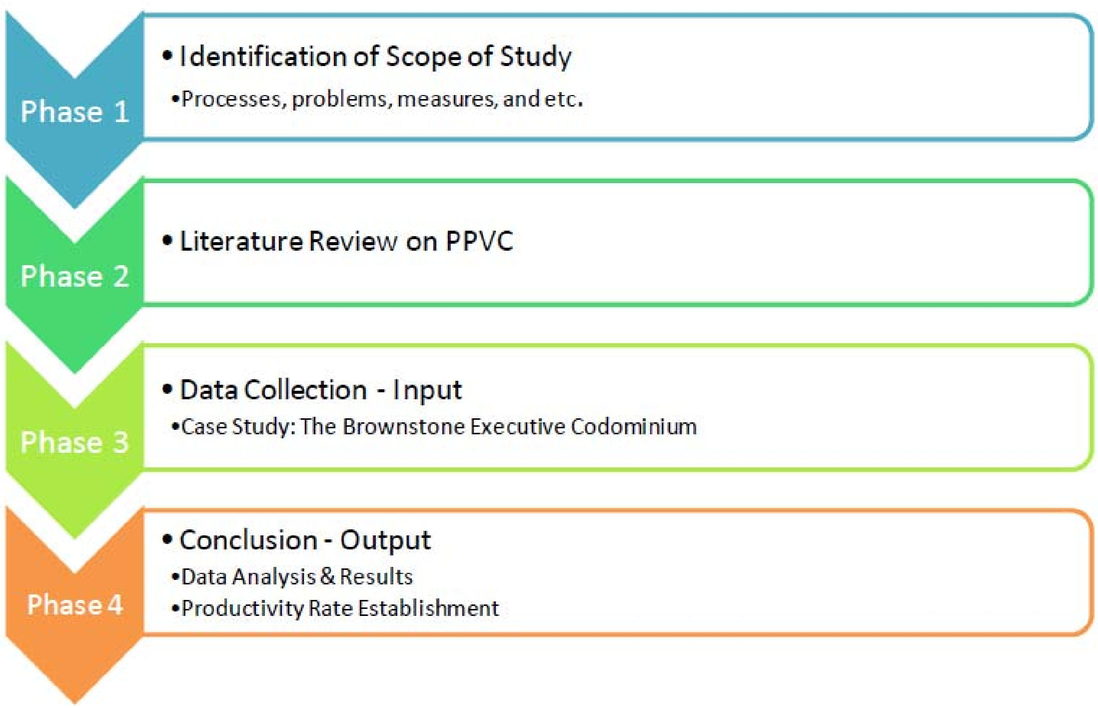

Figure 2: Flow Chart of Research Methodology

Phase 1: Identification of Scope of Study The first phase of the study methodology was to understand the research topic of PPVC and eventually identify the scope of study to be conducted. The study will focus on the understandings of PPVC which includes the processes, problems encountered, mitigation measures taken and etc.

Phase 2: Literature Review A literature review is long process which involves intensive study of what has been published on a topic by accredited scholars and researchers. It highlights the relevant information, outlines the gap in previous researches and provides a better understanding on the field of the study. By writing up literatures, researches are able to refine, refocus and improvise on the scope of research to be conducted.

Phase 3: Data Collection In this study, The Brownstone Executive Condominium project handled by Teambuild Construction Group, Singapore was selected as a case study. The selection was due to the initiative of implementing PPVC technology in the project. The Brownstone EC is located in North Region of Singapore with a vast land site area of 307446 ft2 of land, bounded by Sembawang Road, Canberra Drive and Canberra Link. The residential development comprises of 8 blocks, vary between 10 and 12 storeys high with a total of 638 units of residential apartments.

Coordination meetings has been held with the respective project managers to understand the scope of the study and other relevant details of the project which include exact date for the launching of PPVC construction, the available time slot and etc. so that issues can be highlighted earlier to ensure the study went on smoothly. Accurate and reliable information are vital to ensure that the study conducted is valid. Primary data were collected via field study on the daily construction activities. On the other hand, secondary data were obtained through approved documentations reviews. The methodology implemented is summarized in Table 3 below.

Table 3: Data collection methodology respective to different objectives

Objective	Method	Instruments	Analysis
Objective 1	Field Study Documents Review	Cameras Reports, meeting minutes, archival records	Content Analysis
Objective 2	Field Study Documents Review	Cameras Reports, meeting minutes, archival records	Content Analysis
Objective 3	Field Study	Pre-structured spreadsheet	(i) Establish productivity rate and analyze trend through bar chart and graph illustrations (ii) Comparing with previous case study

Phase 4: Data Analysis Out of 8 blocks in The Brownstone EC project, Block 3 is selected to conduct the study. Daily construction activities on the installation of PPVC modules of Block 3 are recorded down which include the problems encountered during the erection process and the appropriate measure taken to minimize the impact on project.

Besides, the time and duration taken in delivering, unloading and installing each PPVC modules are also recorded based on the following equations [13] to calculate the productivity rate for PPVC technology and analyze the trend of the productivity.

$$\text{Productivity Rate} = \frac{\text{Output}}{\text{Work hour}} = \frac{\text{Area Coverage of PPVC Module } (\text{m}^2)}{\text{Number of workers x duration (hour)}}$$

Data Analysis

This section illustrates the results and discussion of the research. Installation procedures of PPVC, the problems encountered during erection and their respective mitigation measures, and also the productivity rate of PPVC are included in the section.

PPVC Installation The installation procedures consist of three different phases, which are the pre-installation, installation and the post-installation phase.

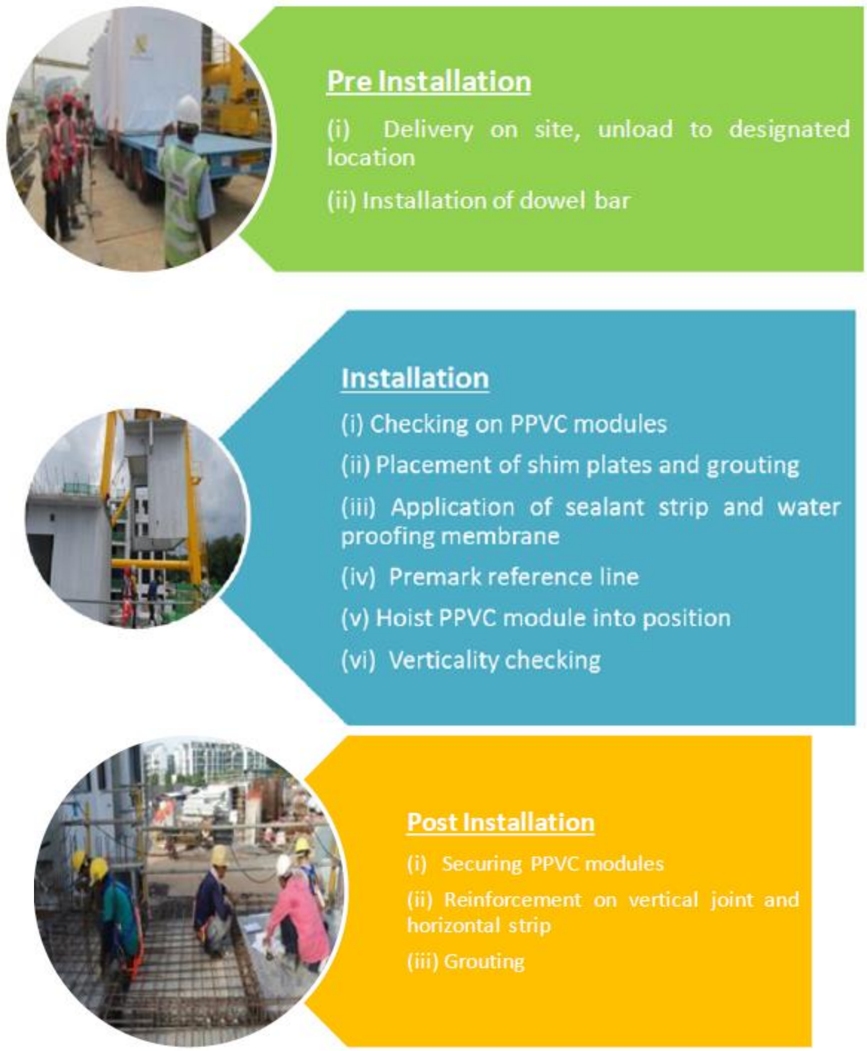

Figure 3: Summary of installation procedure of PPVC

Problems and Mitigation Measures During the installation process, it's common to encounter problems due to various uncertainties. Hence it is vital to take immediate action to rectify the problems and minimize the damages and delay caused to a project.

Table 4: Summary of PPVC installation problems and the respective mitigation measures taken.

PPVC Installation Problem		**Mitigation Measures**
Dimensional deviation in PPVC modules	Excess width/dimension Insufficient depth for dowel bar location	On site Rectification
PPVC modules connection	Level checking Verticality checking	
Defects to PPVC modules	Cracks Concrete chip off Skim coat chip off Damage to internal Unit	

External Factors	Unexpected weather conditions Machinery defects	Coordination for back-up plan

Productivity Rate of PPVC out of 8 blocks in The Brownstone EC project, Block 3 is selected to conduct the study. The time and duration taken in delivering, unloading and installing each PPVC modules daily are also recorded into the pre-structured spreadsheet. The PPVC productivity rate is summarized in Table 5 below.

Table 5: Summary of PPVC Productivity Rate

Project Title:				**Brownstone EC @ Canberra Drive**			
A	B	C	D	E	F	G	H
S/N	Information			Productivity Calculation for Delivery and Unloading		Productivity Calculation for Hoisting and Installation	
Sample	Apartment unit type	Nos. of PPVC modules installed	Total Floor Area of PPVC modules installed (m2)	Total manhours taken	Trade Productivity (m2 / manhour)	Total manhours taken	Trade Productivity (m2 / manhour)
1	Blk 3 1st Storey	33	416.51	124.75	8.26	164.17	**2.54**
2	Blk 3 2nd Storey	46	589.34			374.58	**1.57**
TOTAL		79	1005.85	124.75	**8.26**	538.75	**1.87**

The productivity rate established for delivery and unloading a total of 79 modules the PPVC modules is 8.26 m2 / manhour. On the other hand, the productivity rate calculated for installation of PPVC modules for Block 3 1st and 2nd storeys are 2.54 m2 / manhour and 1.57 m2 / manhour respectively. The average productivity rate of PPVC installation is 1.87 m2 / manhour.

Productivity Rate Performance Evaluation. Out of 79 PPVC modules, there are a total 30 sets of identical modules involved in the execution of Block 3 1st and 2nd storeys.

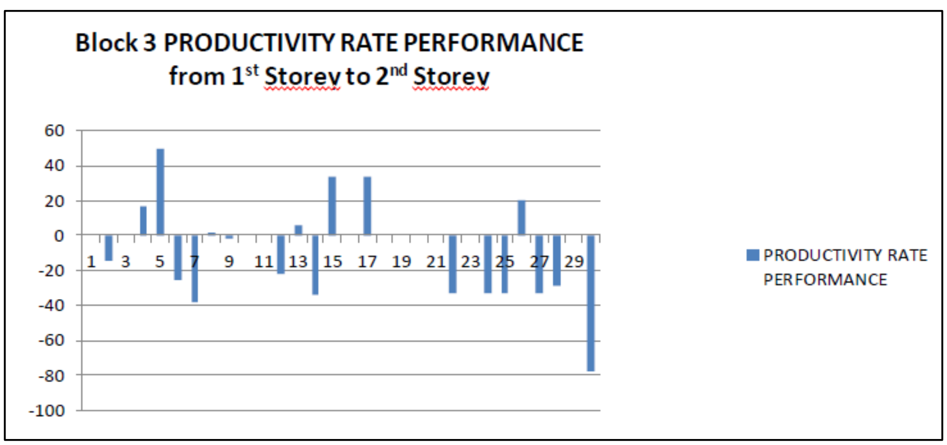

Figure 4(a): Evaluation on the productivity rate performance of Block 3 PPVC installation from 1st storey to 2nd storey.

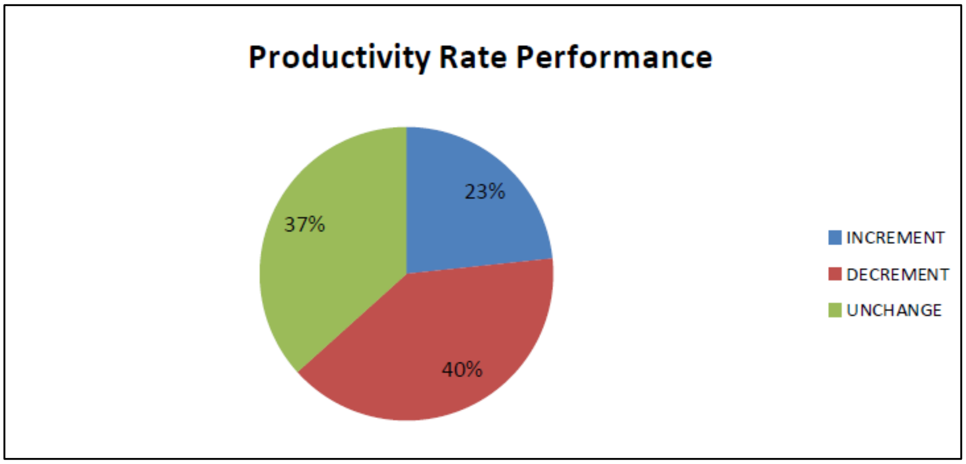

Figure 4(b): Summary of productivity rate performance from Figure 4(a).

From the figure above, 7 PPVC modules (23%) show increment in productivity rate while 11 PPVC modules (37%) show decrement in productivity rate. The productivity rate for the remaining 12 modules (40%) remains unchanged. Hence, the result had shown a decreasing trend. However, taking the average productivity rate for PPVC installation, 1.87 m2 / manhour as baseline, the productivity rate on PPVC installation of Block 3 2nd storey is higher than the baseline value.

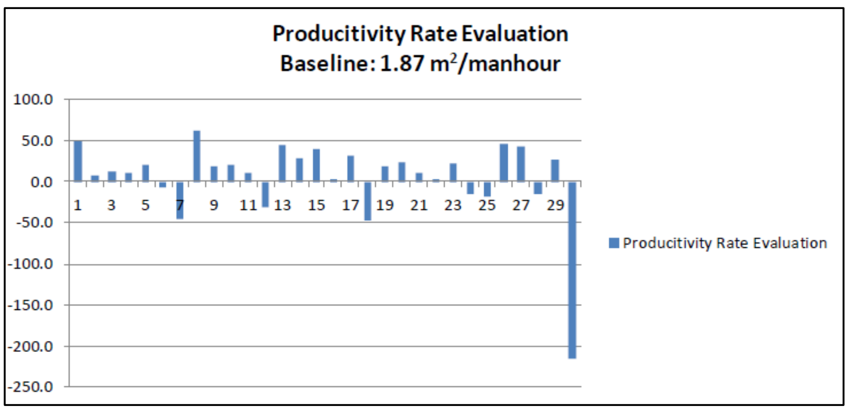

Figure 5(a): Comparison of productivity rate (Baseline: 1.87 m2 / manhour).

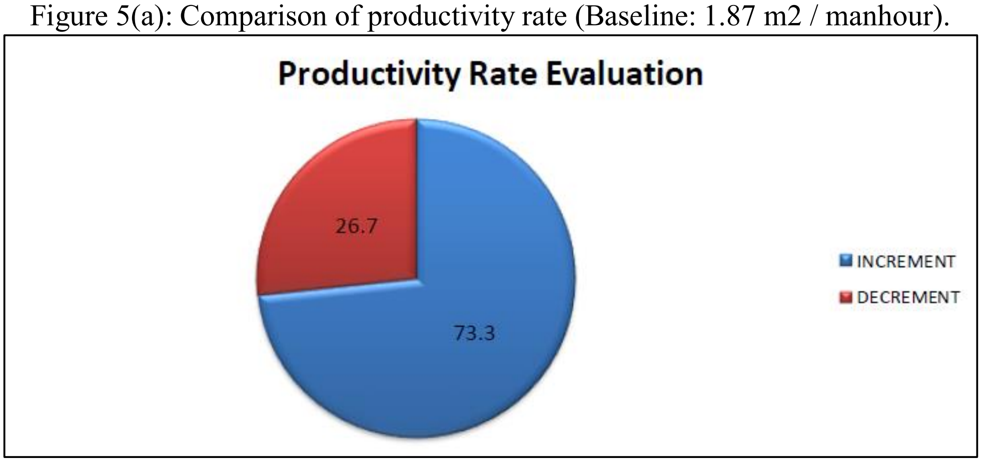

Figure 5(b): Summary of productivity rate performance from Figure 5(a).

22 PPVC modules of 30 (73.3%) show increment in productivity rate while the productivity rate for the remaining 8 modules (26.7%) decreases. Theoretically, the productivity rate increases as the

construction proceeds to the upper floors. Therefore, the data gathered from two storeys of Block 3 are not consistent and insufficient to illustrate the trend of PPVC system.

Construction Data Comparison. The productivity rate of PPVC installation in Canberra Executive Condominium is higher compared to the modular building in Wolverhampton. This can be caused by various factors such as advanced in technology, workers' skill and etc.

Table 6: Construction data comparison

Project	25-storey modular building, Wolverhampton	Canberra EC, Singapore
Installation Team	10 people (8 workers + 2 site manager)	5 people (4 workers + 1 machine operator)
Average Installation Rate	7 modules per day	4 modules per day
Maximum Installation Rate	15 modules per day	7 modules per day
Productivity Rate	0.13 m^2 / manhour	1.87 m^2/ manhour

Conclusion

There are a total of three phases involved in PPVC installation; namely pre-installation, installation and post installation. During pre-installation phase, the dowel bars were installed on the PPVC modules after they are delivered and unloaded to the construction site. At the installation stage, several preparation works such as checking on modules, applications of waterproofing membrane and sealants are carried. A 1 m reference line is pre-marked before the PPVC module is hoist onto position and the verticality is later checked. After the installation, the modules are secured via tying the reinforcements and grouting.

During the installation of PPVC, there are a few problems encountered such as dimensional deviation in PPVC modules, the connections issues and defects. Immediate on site remedies are conducted which include trimming, hacking and cutting works to minimize delay in project. External factors such as unexpected weather conditions and machineries defect may also lead to issue. Hence, the project team should coordinate well for back-up plan to ensure the project progress is not interrupted.

Lastly, the productivity rate for delivery and unloading of PPVC modules to the construction site is 8.26 m2 / manhour while the PPVC installation productivity is 1.87 m2 / manhour.

Recommendations This study has established the productivity rate as a reference for future PPVC projects in Asia. However, these findings are not applicable for every PPVC projects as the productivity rate is established from two storeys of one block in the project as the study is only conducted for one month. The PPVC technology is also considered a new implemented construction method and hence it is still in an immature stage whereby limitations are yet to be discovered for further improvement.

Based on the findings and conclusion of the research, here are the several recommendations need to be considered:

(i) The study can be conducted in a larger scale and durations, whereby all blocks are monitored from the 1st storey until completion so that the productivity rate established is more accurate and reliable.

(ii) Similar study with a difference scope can be conducted in future such as waste generations, environment impact assessment, the productions of PPVC modules and etc. This helps researchers and the construction industry to explore more ideas to improve and enhance the implementations of PPVC in future.

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