# A STUDY ON THE PRODUCTIVITY EVALUATION OF BUILDING INFORMATION MODELLING (BIM) BASED PREFABRICATED PREFINISHED VOLUMETRIC CONSTRUCTION (PPVC) PROJECT

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**Abstract**

In line with the Building and Construction Authority's (BCA) target to improve construction productivity, the industry is currently moving towards more productive technologies that will achieve higher productivity gains. Of these productive technologies, BIM and PPVC were identified by the authority to be of high potential to achieve productivity gains. BIM is a technology and a process. BIM as a technology enables users to better visualise their development in a simulated environment by generating a 3D model. As part of a process, BIM carries the project modelling further via BIM supported methodologies which will aid in other areas of construction management such as construction cost control and facilities management. PPVC, on the other hand is a type of modular construction. Modules are first manufactured offsite then transported to the site for installation. As such, allowing the construction process at the site to be efficient.

Together, BIM and PPVC technologies are believed to have a significant impact on the construction industry in terms of improving productivity. There are many instances of BIM based PPVC developments globally that have been found to be effective in improving productivity. BIM based PPVC developments are still new in Singapore and therefore, more study needs to be done to evaluate the extent of productivity gains and the potential problems it brings about locally. This report aims to study current BIM based PPVC developments locally; the challenges faced, the benefits that should be retained and the possibilities for improvements. This is so that we may work towards a smoother sailing project development in future and also to further enhance productivity of the construction industry as a whole.

There are currently three PPVC developments in Singapore and of the three, only one is BIM based. This BIM based development is the new hostel development in NTU and it will be used as a case study in this paper. Present workflow of a BIM based PPVC development will be evaluated and representatives from the industry will be interviewed to gain insights on the current benefits and challenges faced.

Findings have shown that current BIM based PPVC development is experiencing challenges such as resistance to move away from conventional methods and interoperability issues between BIM software. Furthermore current BIM based PPVC development is not using BIM to its maximum potential. Henceforth, a new workflow is proposed to attempt to mitigate these challenges for further BIM based developments. This workflow will include a refinement of the current workflow and the necessary changes to ensure that both technologies are exploited to its maximum capabilities in gaining productivity.

## Acknowledgements

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P & T Consultants Private Limited

Santarli- Zheng Keng Joint Venture

Sunhuan Construction Private Limited

**Table of Contents**

**List of Figures**

**Chapter 1: Introduction**

1.1 Background

Globally, there has been a shift in the construction industry towards the use of more productive technologies. Such technologies include the Prefabricated Prefinished Volumetric Construction (PPVC) (also known as modular construction) and the use of Building Information Modelling (BIM). The PPVC technology has proven to be cheaper (Generalova et al., 2016) while BIM has allowed for better coordination and visualisation for industry users. (Czmocha & Pekala, 2014)

Likewise, the construction industry in Singapore is also moving towards such productivity enhancing technologies to reduce reliance on manpower and to be cost efficient. In recent years, the Building and Construction Authority has been actively encouraging the use of game- changing technologies to enhance productivity at the worksite. Under the Construction Productivity Roadmap, the Construction Productivity and Capability Fund (CPCF) was set up to promote the use of more productive technologies by supporting such projects through grants. Under this CPCF, the Productivity Innovation Projects (PIP) scheme supports the use of large- scale productive technologies like PPVC. (BCA, 2015) The BIM fund, also under the CPCF is given out to firms to help defray the additional costs incurred while transiting to BIM. ("BIM Fund", n.d.) Since January 2010, authorities have been accepting BIM submissions in phases to encourage the use of BIM. From 1st July 2015, all submissions are to be made by BIM. ("Singapore BIM Roadmap", 2012)

Currently, Singapore has three PPVC pilot projects- Crowne Plaza Changi Airport Hotel extension, Brownstone Executive Condominium and a cluster of hostel residences development at the Nanyang Technological University (NTU). (BCA, 2015) Of the three PPVC pilot projects, only the NTU PPVC hostel development is BIM based.

1.2 Objective and Scope

Given than PPVC projects are relatively new locally and that we are currently in the transition phase of using BIM, more research needs to be done to study the potential benefits and problems that have arose or may arise through the usage of such technologies and henceforth, recommend the necessary solutions that counter the negativity and to further enhance construction productivity.

This paper aims to study the productivity improvements led by BIM and PPVC by studying BIM based PPVC developments through qualitative analysis by gathering feedback from current industry practitioners to evaluate the challenges faced, the benefits that are worth retaining and the possibilities for future improvements. Following current project procedures will be reviewed and the necessary changes to the current workflow will be recommended to further improve productivity. This research will focus solely on the NTU hostel development as a case study and only its stakeholders will be interviewed.

# Chapter 2: Literature Review

## 2.1 Prefabricated Prefinished Volumetric Construction (PPVC)

PPVC is a specific type of modular construction. According to the Modular Building Institute, an industry trade group modular construction is a process in which a building is constructed off-site, under controlled plant conditions, using the same materials and designing to the same codes and standards as conventionally built facilities – but in about half the time. The difference between a PPVC module and a generic module for modular construction is that a PPVC module is not just prefabricated offsite, its' interiors are also prefinished offsite before being transported to the site for installation.

PPVC has been found to be a more productive way of construction given its benefits. The following summarizes the benefits of using the PPVC technology. (Generalova et al., 2016; Lu, 2007; Ngigi, 2016; Schoenborn, 2012)

- Reduce in construction time and cost
- Efficient scheduling due to parallel production activities
- Reduce in manpower needed with the increase in labour productivity
- Increased in quality and craftsmanship of building works since the modules are prefabricated in a weather protected environment
- Increased in construction safety with minimized danger from heights
- Minimal environmental impact such as reduced air and noise pollution surrounding the development

The use of PPVC technology can be classified into four stages- design, manufacturing, transportation and installation of modules. At the design stage, the module is deliberately designed with many repetitions to reduce time wastage on differences so as to achieve higher productivity. At the manufacturing stage, the PPVC modules are fabricated in bulk in the factory. Bulk fabrication allows for economies of scale to be exploited. As such, manufacturing costs decreases and overall construction cost would decrease as well. After which, quality checks will be done before shipping the PPVC module from overseas to the holding yard where more finishing works will be done. Following the modules will be transported via a trailer to the construction site for on-site installation. On-site installation is done by hoisting and releasing the modules through a tower crane. (Ng, 2015)

A more detailed explanation of the stages of PPVC will be explained in Chapter 2.3 Case Study on NTU PPVC 2 where PPVC stages are explained in the context of a local development.

However, there are also disadvantages of modular construction. Some constraints of using prefabricated components include the inconvenience of transporting the modules and the inflexibility for changes to be made during the construction process. (Lu, 2007) The former is especially significant in Singapore as the Land Transport Authority (LTA) has strict regulations regarding the transportation of heavy and massive objects on the roads. If the PPVC modules used is too massive or heavy, relevant permits need to be seek before they can be transported on the road. In certain cases, police escort may also be required. Should a police escort be needed, the transportation of such modules will be done in the night to reduce traffic hindrance. As such, transportation of the modules to the site will be held up and eventually affect the construction process.

In general, the advantages of modular construction would supersede the disadvantages (Schoenborn, 2012) since most of the disadvantages are avoidable if great consideration is taken to avoid them. Hence the usage of PPVC technology is worth considering and encouraging.

## 2.2 Building Information Modelling (BIM)

Building Information Modelling, BIM is both a technology and also a process. BIM technology is recognized for its usefulness towards 3D visualization of the building in a simulated environment to help identify downstream risks such as design faults. Figure 1 shows an example of a BIM model used for visualization.

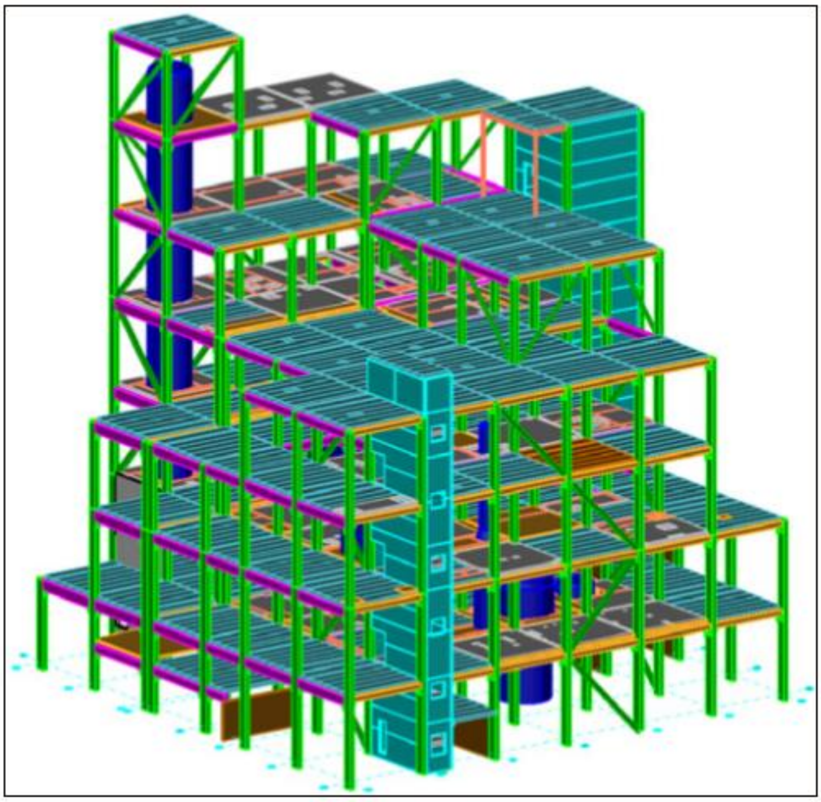

Figure 1: A sample of a 3D BIM model

In addition, BIM as part of a process helps enable close collaboration between the stakeholders of the project. This can be done via Virtual Design and Construction (VDC) methodologies where the BIM model uses such methodologies as a platform that allows different levels of project details to be viewed, from construction costs to facilities management. (Czmocha et al., 2014) Figure 2 shows how BIM can be a part of a building process.

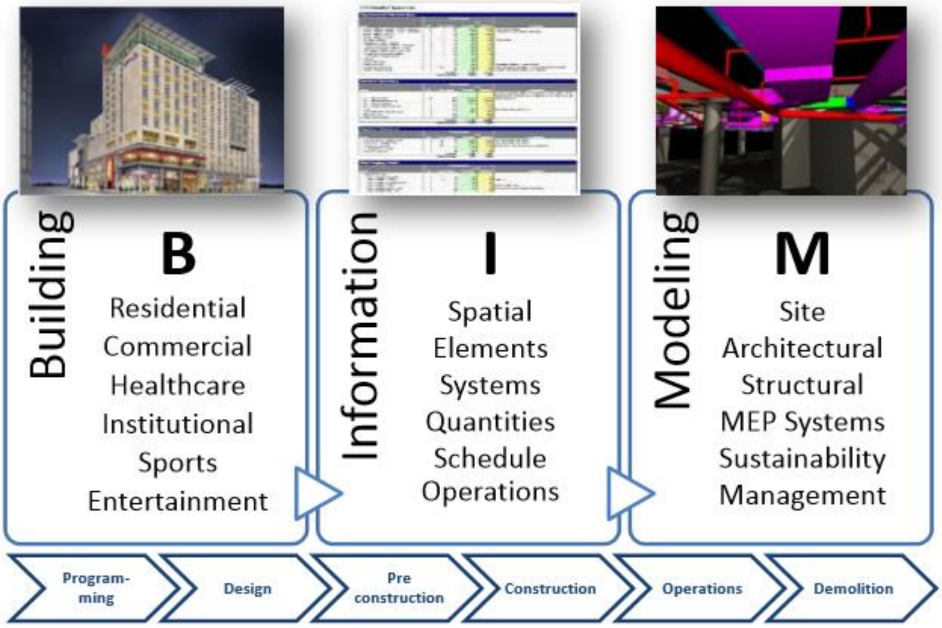


Figure 2: BIM as part of a building process

The success of BIM however relies heavily on collaboration and communication in the project. Without them, the benefits of BIM cannot be exploited. BIM also requires the early involvement of stakeholders in the project. This early involvement would in turn result in an optimum maximization of quality, constructability, affordability and timeliness of the design produced. (Azhar, S et al., 2012) since it encourages a more holistic planning of the development right from the start of the project

2.2.1 Parametric Design in BIM

Parametric design technique enables shapes to be modeled using independent parameters that are regarded as constraints and where object combinations are automatically updated when the parameters are modified which can result in active response to the design change. (Yoo B. et al., 2016)

A parametric design library is where parametric designs are stored based on specifics and users' purposes. This greatly reduces the time needed to redesign an object. Users can choose from an array of parametric designs from the library and load them into their projects. Furthermore, should they need to amend the design they only need to do it once.

As such, parametric design in BIM is ideal for a PPVC development since it requires a repetitive design of PPVC modules. Figure 3 shows an example of a parametric library in a BIM software, Revit while Figure 4 shows an example of an column predesigned in the parametric library.

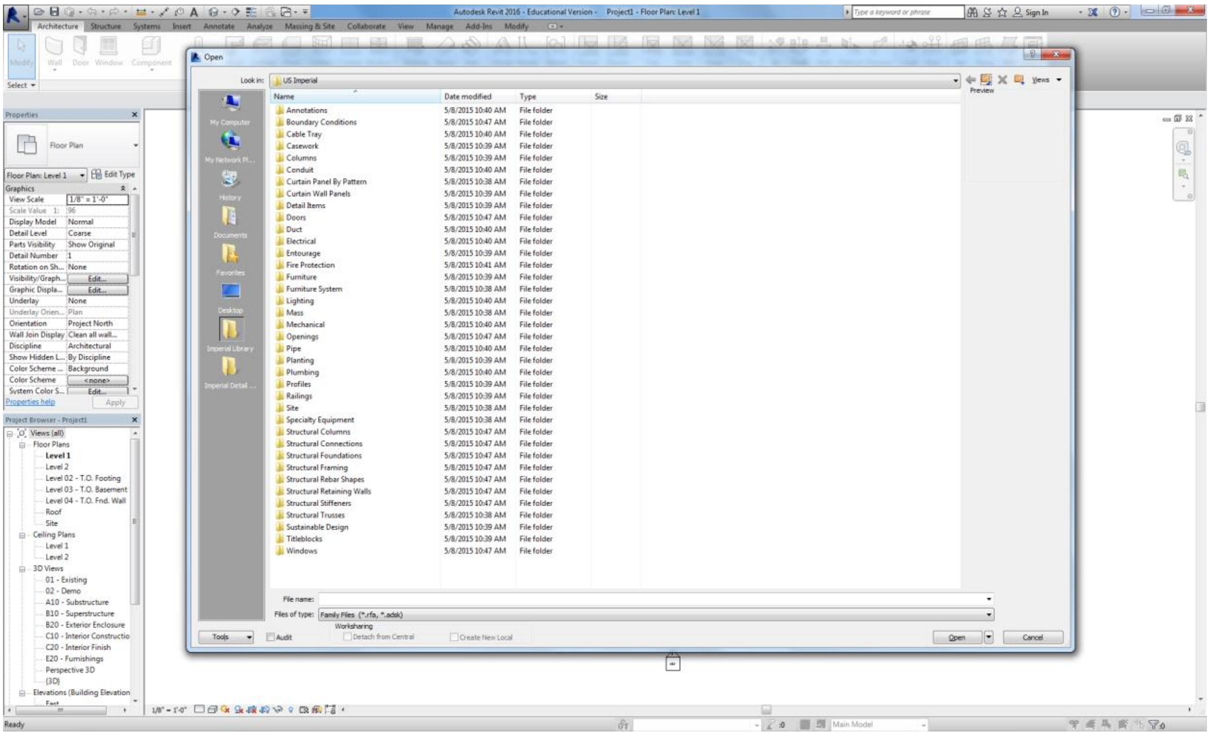


Figure 3: Parametric library in Revit

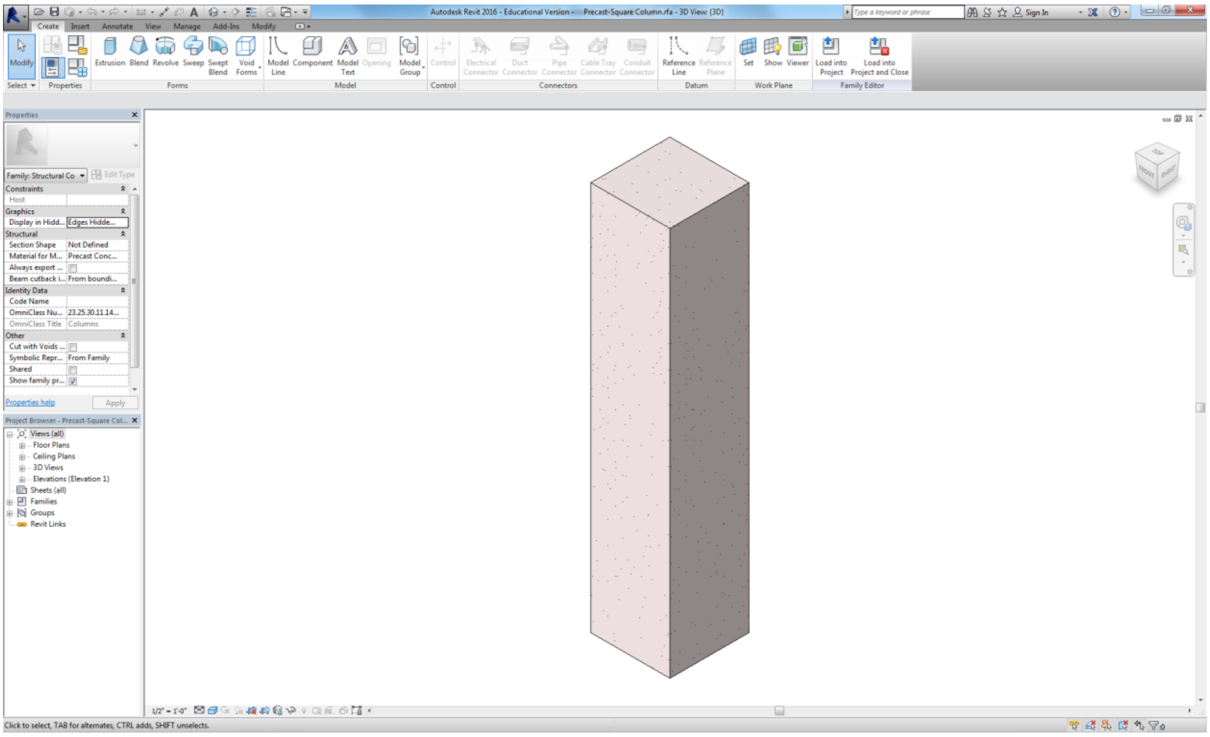


Figure 4: A column found in the parametric library in Revit

## 2.3 Case Study on a BIM Based PPVC Project- NTU PPVC 2 Hostel Development

In recent years, NTU has been building hostel residences. To support newer technologies, the recent NTU hostel development has been built using the BIM and PPVC technologies. The NTU hostel development has been divided into two different developments- NTU PPVC 1 and NTU PPVC 2. The NTU PPVC 1 hostel has been completed and opened for used while the NTU PPVC 2 is still undergoing construction. Previous research has already evaluated the NTU PPVC 1 development as a case study. Hence, in this paper NTU PPVC 2 will be used for analyses. This case study will be explained through the stages of PPVC.

The NTU PPVC 2 hostel is the second phase development of the new NTU hostel consisting of 1233 single occupancy rooms and 294 double occupancy rooms. This development has a Gross Floor Area (GFA) of 4950$m^2$.

Figure 5: Artist impression of the NTU PPVC 2 Hostel

This is a BIM based PPVC development where Revit, a BIM software was used at the design stage. It is a 24- month contract and was originally designed to be constructed via the conventional way. Then, NTU decided to have it to be built with PPVC. The main contractors redesigned the structural parts for PPVC. Design and approval from the authorities took approximately 5 months and the manufacturing of the PPVC modules in China started right after the approvals were given.

The following details were taken through site visits and discussions with the consultants and the main contractors of this development.

### 2.3.1 Design Stage

BIM (Revit) was a tool that the architects used to design and visualised the project. According to the consultants BIM had allowed for the reduction of man-hours by about 20-30% at the design stage. It was especially helpful in checking areas like Temporary Occupation Permit (TOP) compliances. It reduced conflict that was not obvious to the eye and this minimized downstream risk. This is especially important as PPVC has zero tolerance for downstream risks like failure to comply with design standards. Any downstream amendment would incur a high costs.

For this development, BIM plans were non-contractually passed to the contractors from the consultants. However, it was not made compulsory for the contractors to use the plans. To facilitate collaborative communication, NTU had a Google Drive that allowed the different collaborators to gain access to the files of information via a common platform.

Parametric designs were also used in less structural design like windows and doors. PPVC was not used as a parametric design as there were 8 varying types of modules out of the 676 of them. Some modules were used to contain two bedrooms while some were dissected into triangular modules in areas with irregularities. Therefore, in this development parametric design for a PPVC module was not ideal due to the high variation of modules needed.

Figure 6 shows the structural details of the buildings. The first 3 storeys (podium) were built with conventional RC construction. Following, a transfer slab is then placed over the podium. PPVC modules are then stacked on top of the transfer slab. In this way, the loading of the PPVC modules will then be able transferred into the ground. A bondeck slab is then constructed at the roof at the top of the last floor of PPVC modules to further ensure the structural stability of the PPVC modules.

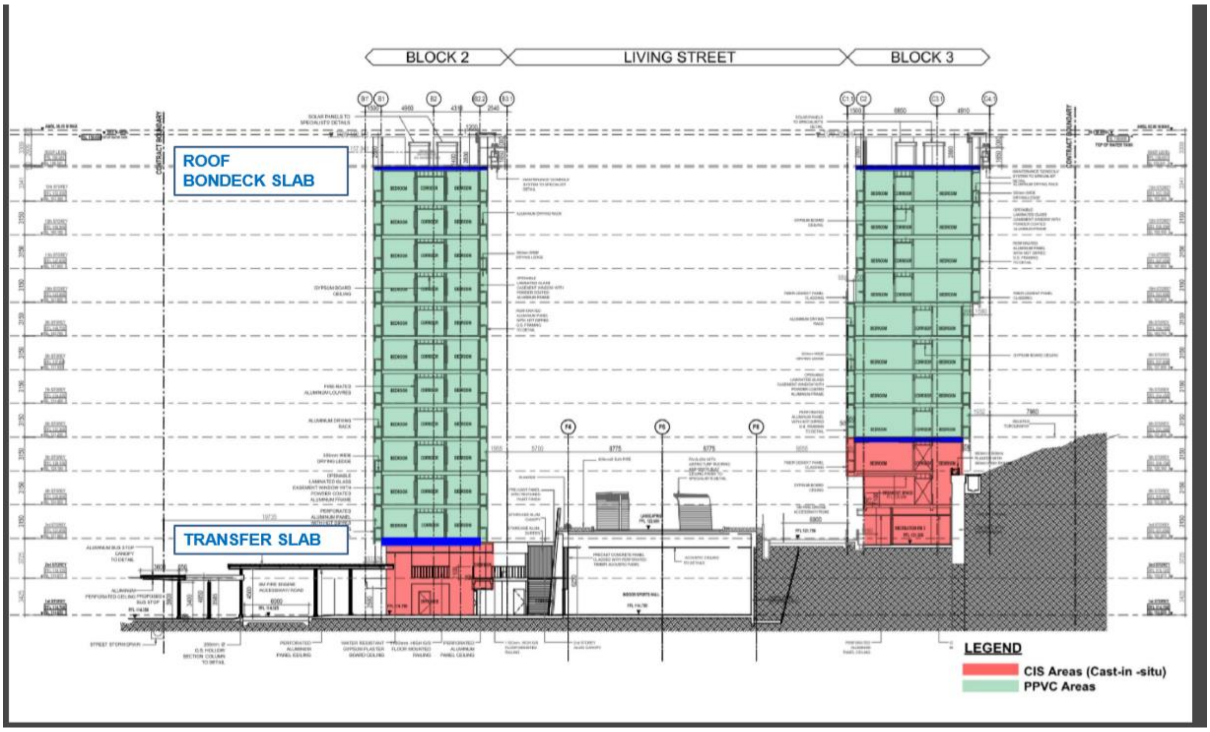


Figure 6: Structural details of NTU PPVC 2 Hostel

Due to architectural design, some of the modules were required to be staggered as seen in Figure 7.As such, stiffeners were needed to be place at some parts to further strengthen the buildings.

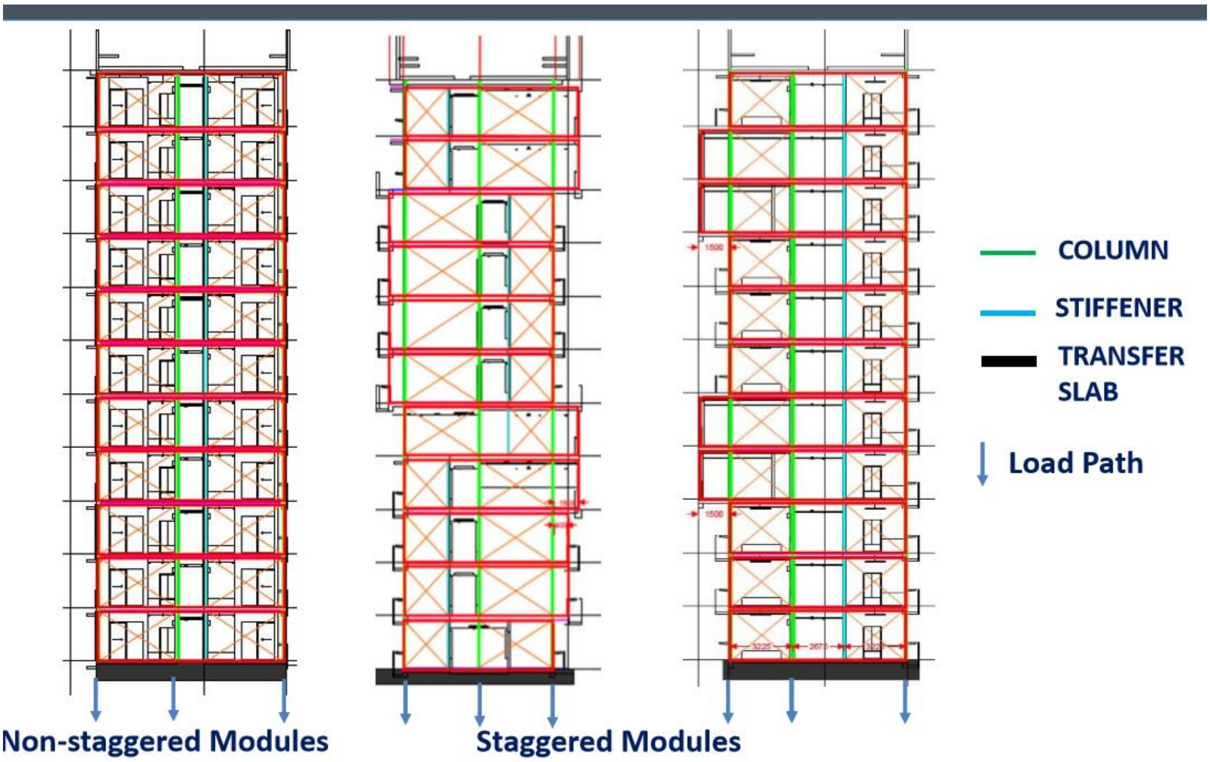


Figure 7: Architectural details of NTU PPVC 2 Hostel

Figure 8, 9 and 10 shows a sample both the architectural and structural detailing of one type of PPVC module.

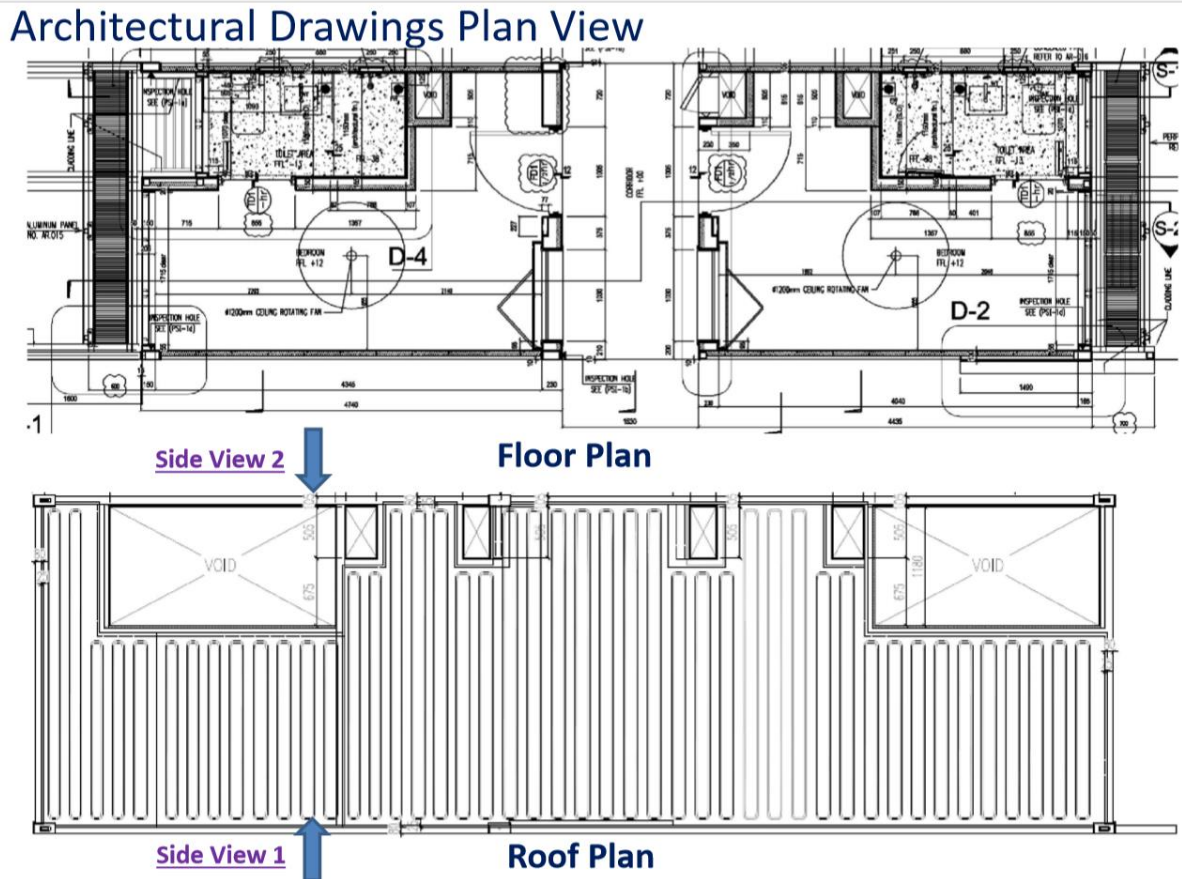


Figure 8: PPVC architectural plan view

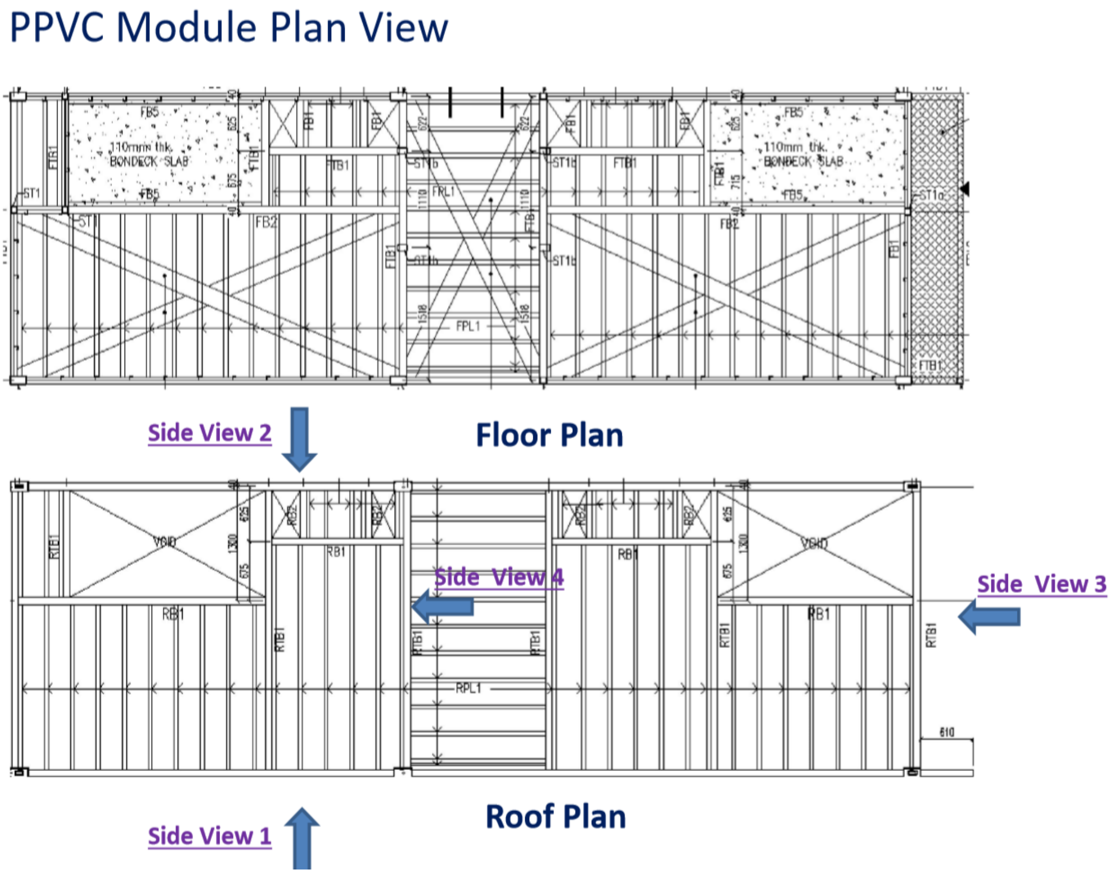


Figure 9: PPVC Module Plan View

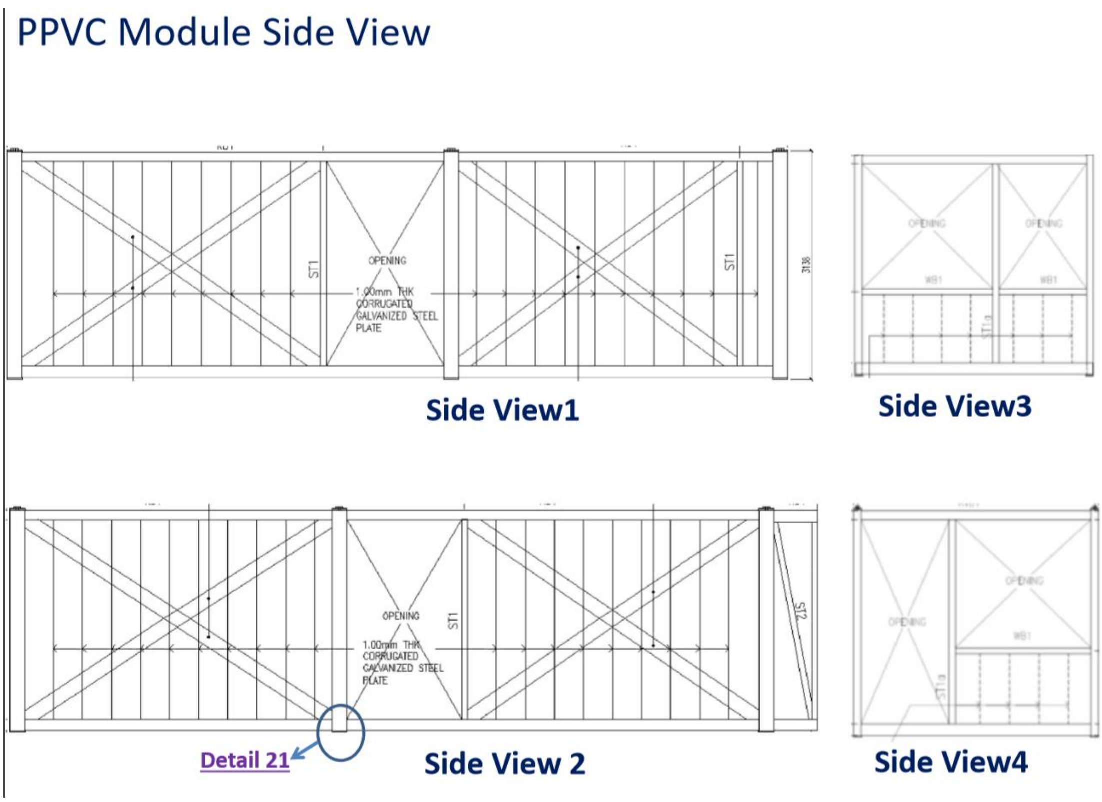


Figure 10: PPVC module side view

### 2.3.2 Manufacturing Stage

Figure 11 shows the manufacturing process of PPVC module. Construction of PPVC modules begins in Zhangjiagang in China where the structural steel frame is built. At the factory, materials used for the construction of PPVC will first be inspected before preparing them for assembly for 3D frame preparation. After which, there will be an inspection on this steel frame structure.

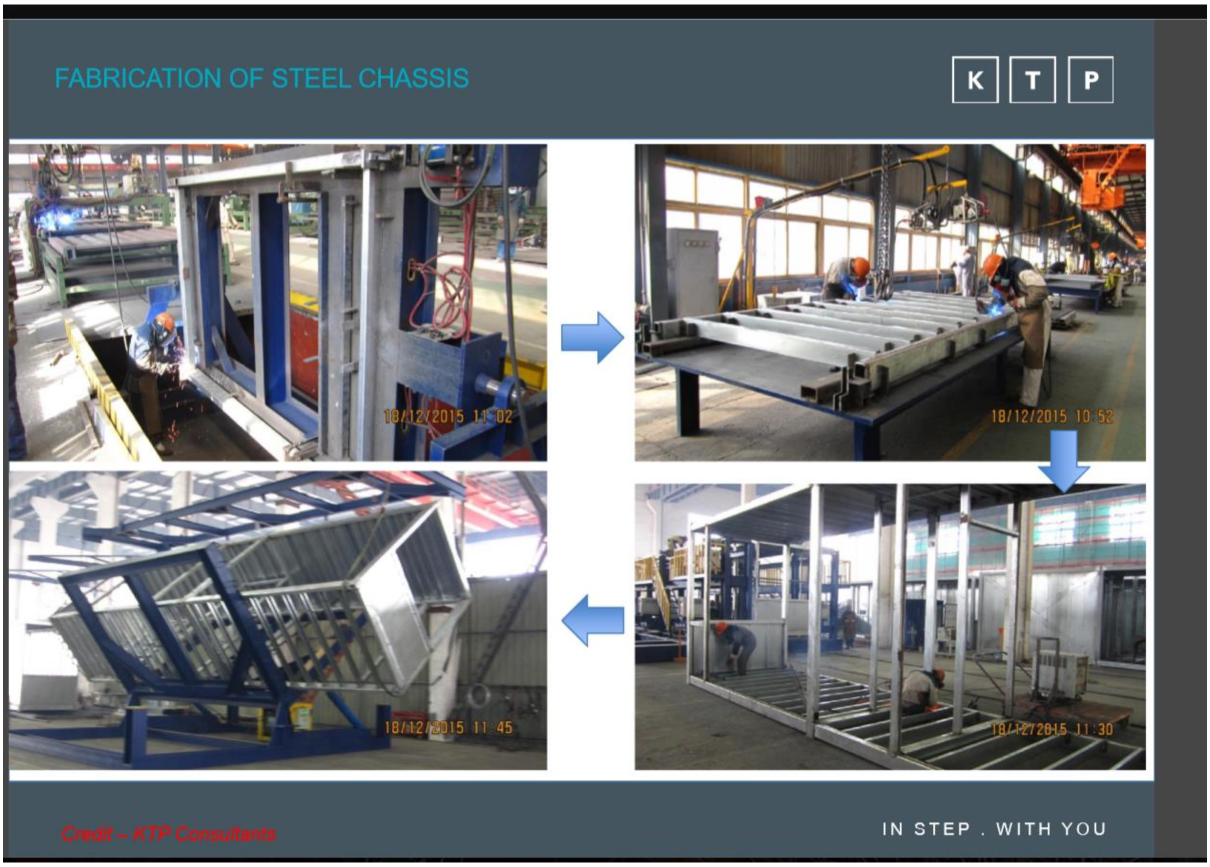


Figure 11: Manufacturing stage of a PPVC module

Once the frame structure has passed the inspection, it will then be transported to the second factory for architectural works like installation of rock wool, fire board, skim putty and windows. (Figure 12) Tiling and painting works are also done here before overseas shipment to Jurong Holding Yard in Singapore (Figure 13 and 14) in Singapore where the fins and ledges are attached to the modules and M&E works are fitted. (Figure 15)


Figure 12: Architectural works of a PPVC module

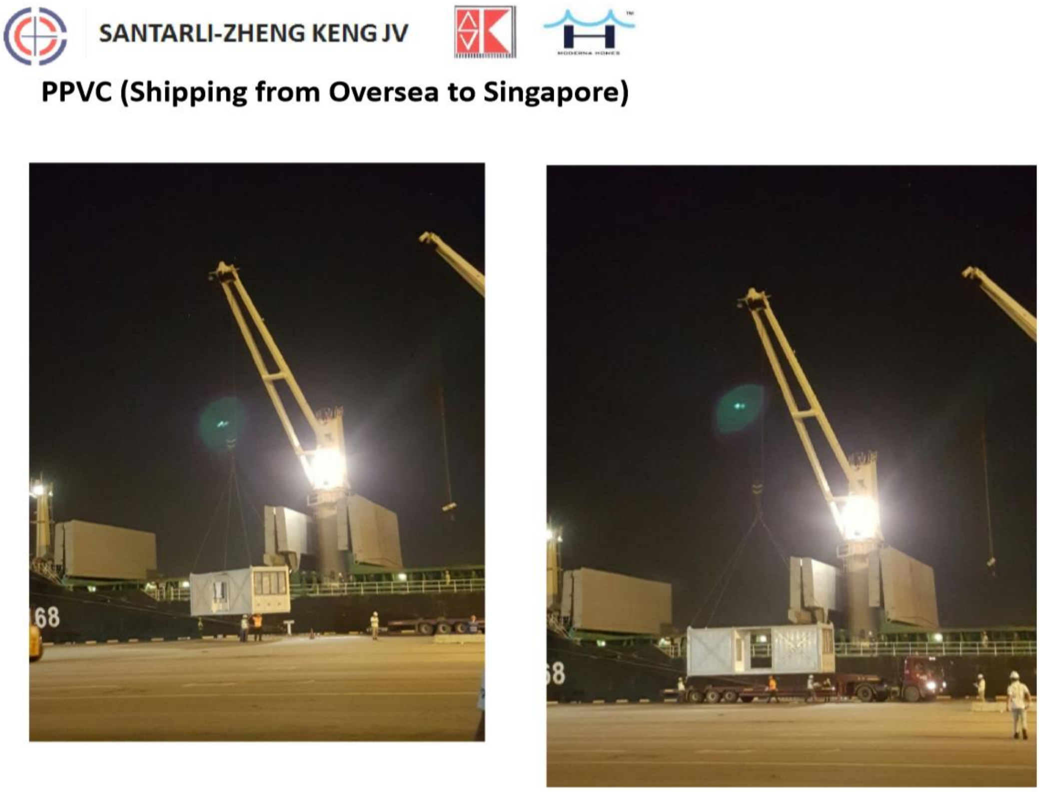


Figure 13: Overseas shipment of PPVC module to Singapore

SANTARLI-ZHENG KENG JV

## PPVC (Local Fitting Yard)

Setting up of Baseplate to receive Modules

Figure 14: Local fitting yard


Figure 15: Installation of fins and facades

2.3.3 Transportation Stage

As with the Land Transport Authority (LTA)’s regulations, any module that is overly large or bulky requires permit to travel on the roads or police to escort throughout the journey. Oversized vehicles are required to submit application to LTA before travel if: (Yang, 2015)

1. Overall width of the vehicle or the vehicle with load width exceeding 2.6 metres

2. Rear overhang of load is more than or equal to 40% of the vehicle length or 1.8 metres, whichever is lesser

3. Heavy vehicles exceeding laden weight limits

In addition, police escort could be necessary during the vehicle movement when:

1. Overall vehicle height exceeding 4.5 metres

2. Vehicle laden weight of 80,000 kg or more

3. Overall vehicle width of 3 metres or more

The modules used in this development were within the range accepted by the LTA and hence transportation of such modules did not require permit application or additional police escort. The PPVC modules were able to be transported as per normal working hours via a trailer to the construction site.

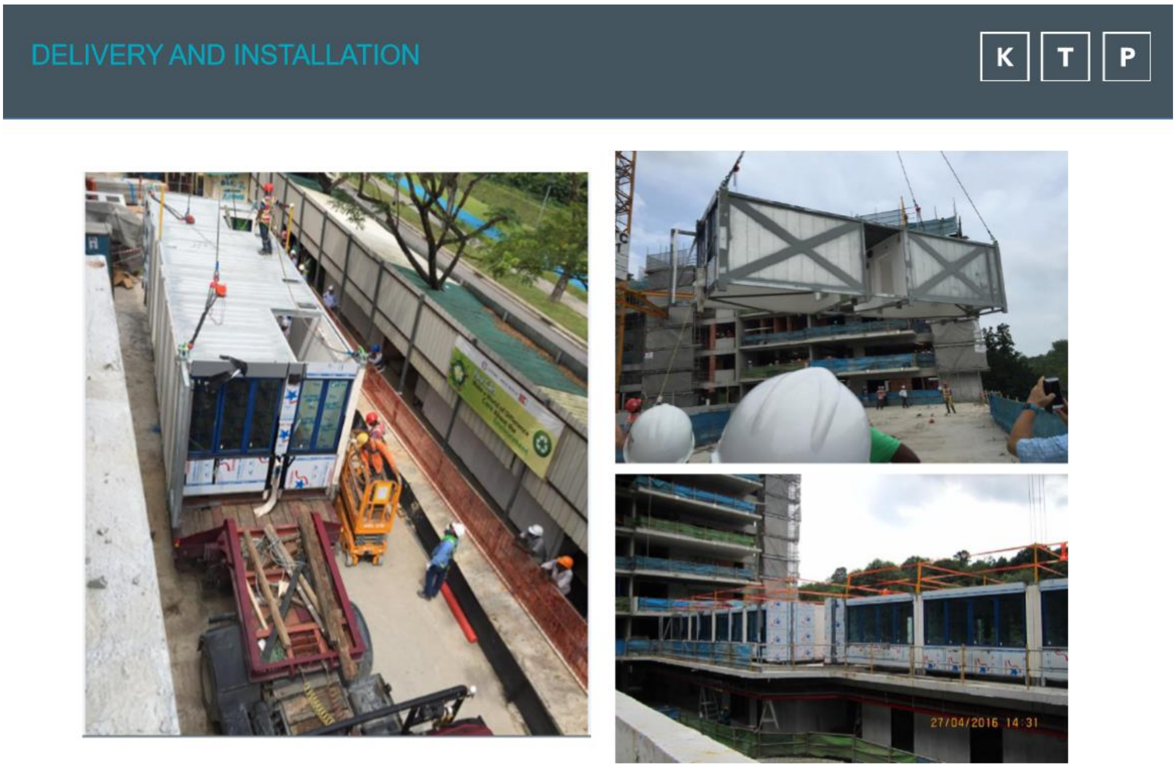


Figure 16: Transportation of a PPVC module

2.3.4 Installation Stage

The size of the site area has to be taken into consideration when installing the PPVC modules given the space constraints at the site.

Figure 17 shows the site layout for this development. The location of the tower cranes has to be stragically planned before commencing installation to fully utilised the limited amount of space onsite. For a more convenient installation of PPVC modules, the installation of PPVC modules took a circular pathway (i.e. PPVC modules were hoisted and installed for block 2 to block 3 to block 1B to block 1A then back to block 2 again).

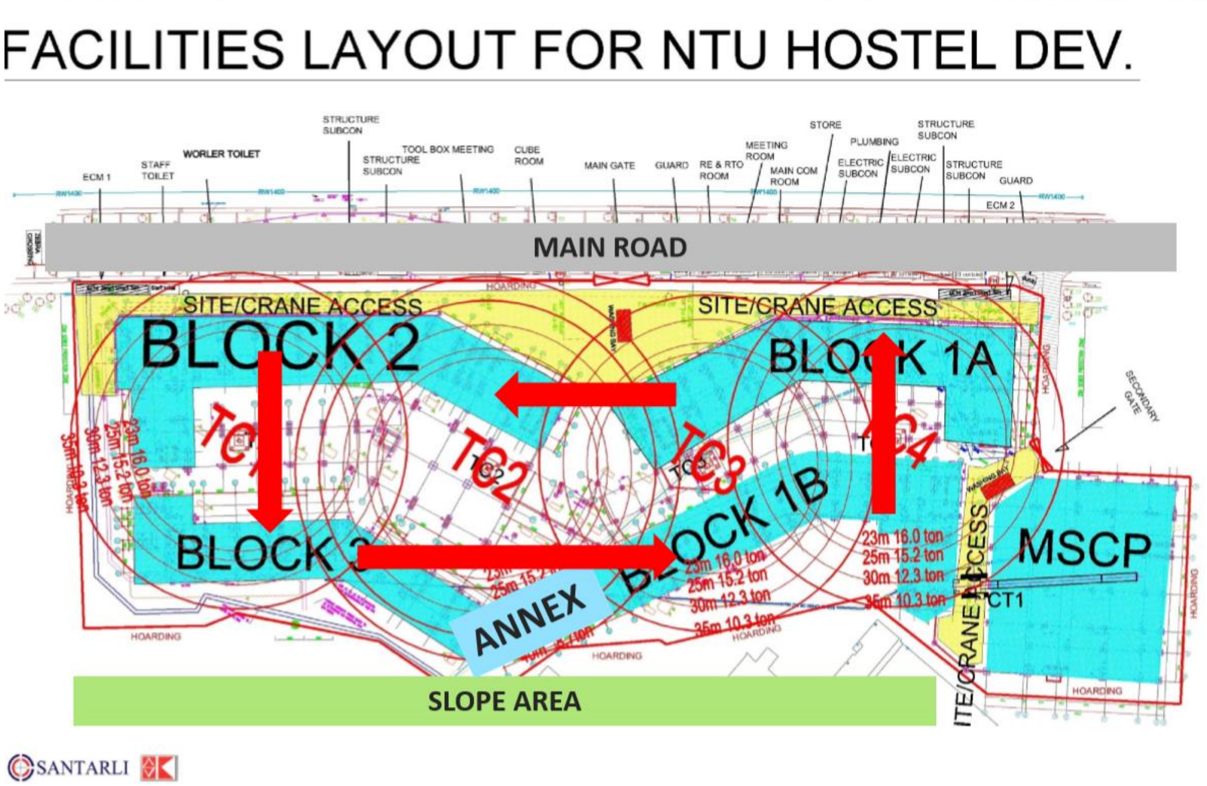


Figure 17: Site layout of NTU PPVC 2 Hostel

Three storeys of PPVC modules were installed in a block before moving on to another block where another three storeys of PPVC modules are installed again. Also, the modules were installed inside out so that the tower cranes do not need to lift the other modules higher. (Figure 18) Figure 19 and 20 show the hoisting and installation of the PPVC module onto the blocks. Following, a layer of waterproof sealant is applied on the PPVC module after installation. (Figure 21 and 22)

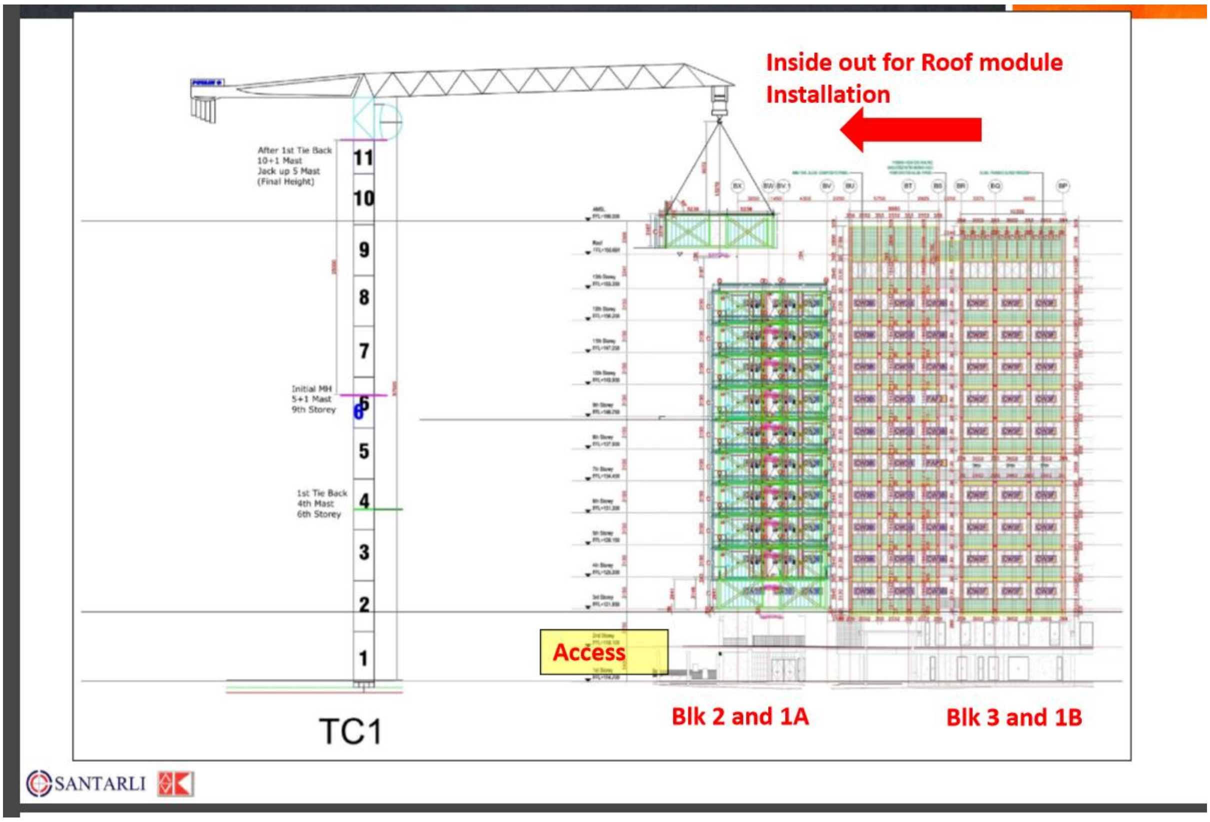


Figure 18: Installation stage of PPVC module

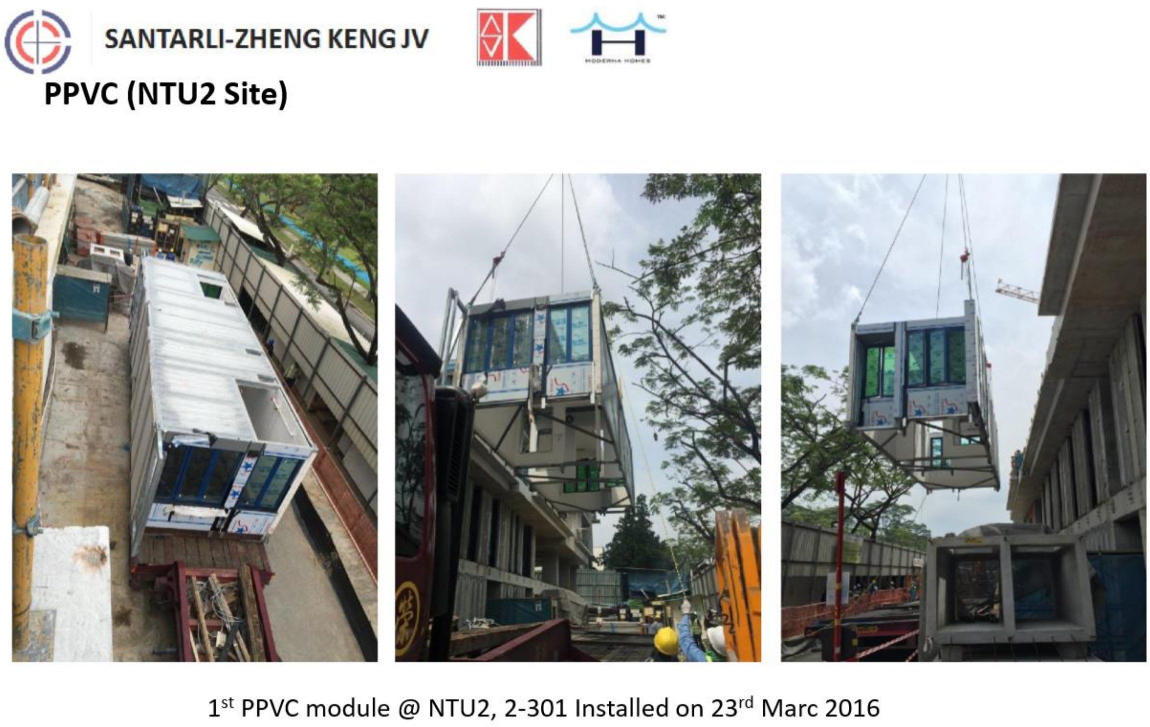


Figure 19: Hoisting of PPVC module


Figure 20: Installation of PPVC module


Figure 21: After installation of PPVC module


Figure 22: Waterproofing the roof of PPVC module


Figure 23: Elevation view of the NTU PPVC 2 site

At present, construction works for this development is still going on. Therefore, further information on construction works beyond the module installation process is unknown.

## Chapter 3: Methodology

### 3.1 Research Method

This project adopts a qualitative research approach to determine the impact BIM has on the productivity of PPVC projects. Qualitative research depends on human experience and this is more compelling than quantitative data. It also allows researchers to gain a clearer understanding about the targeted market since they types of questions asked during the process usually starts with "Why". With a clearer understanding, researchers are able to reach out to people even more. Furthermore, this removes research biasness arising from any preconceived perception that the researcher might have, thus ensuring that the research focuses on facts and is objective. The qualitative data in this project was gathered through structured interviews with the consultants and contractors of NTU PPVC projects.

### 3.2 Project Procedures

A PPVC module was first modelled in Autodesk Revit, a BIM software as a parametric component. Then a series of face- to- face interviews were conducted on different stakeholders of two different BIM- based PPVC projects- NTU PPVC 1 and NTU PPVC 2 to gather information on their project developments and to discuss the potentials and feasibility of using a PPVC parametric component. The interviews also covered other areas like the impact of BIM in construction productivity, prevalent issues in the present workflow of the companies and the difficulties they face in the different stages of BIM and PPVC usage. Their answers are then evaluated.

In order to achieve the maximum potentials of a BIM- based PPVC development, changes that has to be made to the current workflow would then be identified and a new workflow would be developed to fully utilise the potentials of BIM on a PPVC project.

### 3.2.1 Creation of a PPVC Module as a Parametric Component in BIM

Figure 24 shows an example of a PPVC module parametric architectural design done in Autodesk Revit. Other views of the BIM PPVC module parametric component can be found in the Appendix.

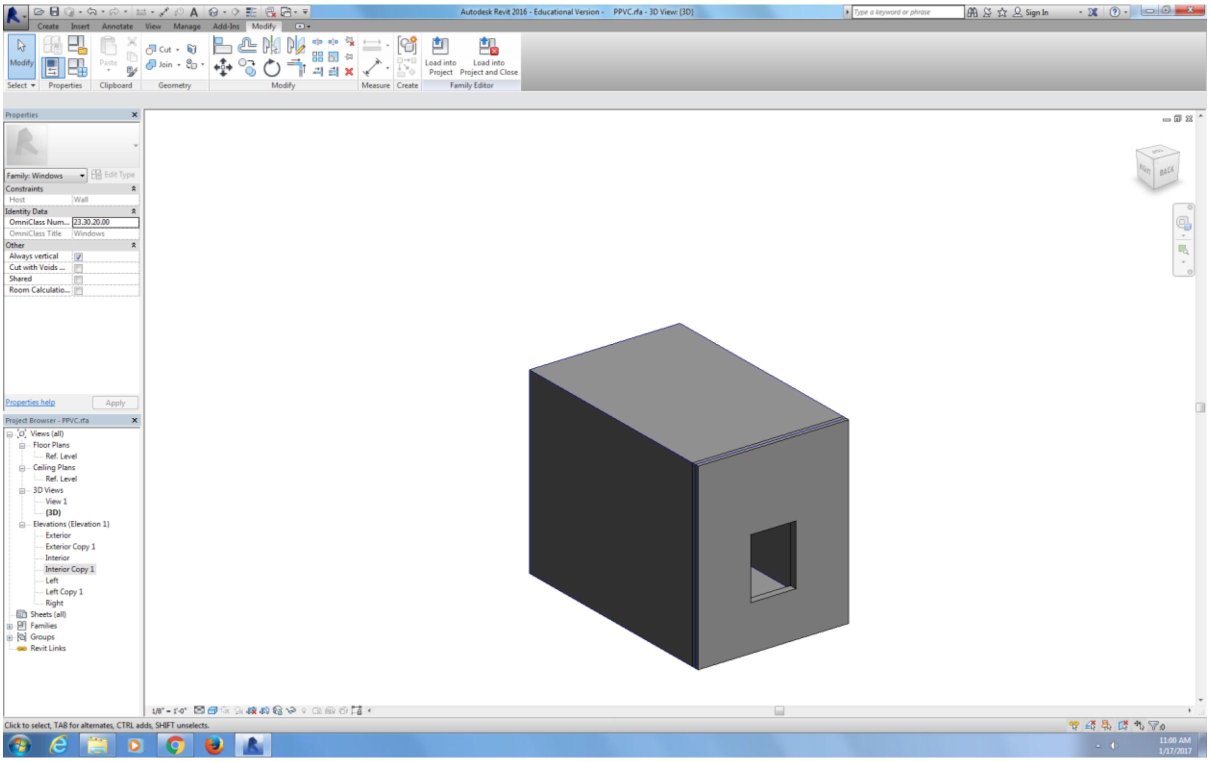

Figure 24: PPVC module as a parametric component

## Chapter 4: Findings and Discussions

### 4.1 Companies interviewed

Three different companies involved in local PPVC projects were interviewed-

P & T Consultants Private Limited (Project management consultant to NTU PPVC 2 development)

Santarli- Zheng Keng Joint Venture (Main contractor to NTU PPVC 2 development)

Sunhuan Construction Private Limited (Main contractor to NTU PPVC 1 development)

### 4.2 Potential Challenges from interviewees point of view

**Design**

Parametric component of PPVC module should not be designed over meticulously. In the case of NTU PPVC 2 development, 13 different types of PPVC modules were used for a total of 676 PPVC modules. As such, a fully- detailed PPVC parametric component will not be as productive as there are many variation of modules. It is also counter-productive to redesign an already fully-designed PPVC parametric component. The consultants commented that the PPVC parametric component could still be productive if it were to be designed in a more generic way (i.e. not to the details of bolts and nuts) that could be used to design multiple variations of PPVC modules without redesigning or amending.

**Industry Practice**

In current industry practice, the different stakeholders of the same project are to purchase the drawings or information within themselves. A formal request known as the Request For Information (RFIs) has to be made. It is noted that some contractors were not given BIM plans unless they pay a hefty price for the drawings. This defies the whole purpose of BIM which promotes productivity in a project through effective collaboration and communication between the different stakeholders of the project.

**Resistance to change from conventional work processes**

In the case of the NTU PPVC 2 development, structural engineers had used their own non-BIM supported software to analyse the structural components. Computational Fluid Dynamics (CFD) studies on the development were also done on a non- BIM supported software. These could be done using BIM technology. However, in this case the maximum capability of BIM was not fully utilized. This is especially so for subcontractors who are hired to do a minor part of the development. These companies usually do not have the capacity to have purchase BIM software or to retrain their employees. This also leads on to another issue on interoperability.

**Issues on interoperability**

Interoperability is the ability to exchange data between disparate file formats and operating platforms. (Ong, 2014) It is principally due to the problems of incompatibility with the reference models adopted by the software application they are working with. This problem arises not only during the project phase but also across the whole life cycle that includes operation and maintenance stages. (Grilo et al., 2010)

Coincidentally, in the NTU PPVC 2 development major stakeholders of the project used Revit so there were no issues on interoperability. However minor stakeholders like subcontractors and in other developments not all stakeholders use the same software or have the documents in the same file format. Since every software has its own file format, there will be interoperability issues. The only exception is when the different software are from the same software company.

## 4.3 Proposed Workflow

**Current Workflow**

Figures 25 and 26 show the current workflow of a BIM based PPVC project. Figure 25 shows a typical workflow of a PPVC development while Figure 26 shows the design stage specifically. At the design stage, the owner’s specifications of the development are noted by the project management consultant who will then pass on the information to the architects for architectural design and analyses. Currently, BIM software is only used purely for architectural design. Architectural analyses like CFD studies are done with the architects’ own software which is not supported by BIM. With the architectural plans, engineers then proceed to do their specific analyses and come out with their plans which will then be passed to the contractors for the construction to commence. At any one point in time, if any stakeholder experience difficulty in designing the workflow reverses. For example, should the engineers find a structural fault in the architectural design they have to first communicate with the architects to find for possible solution. If there is a change in architectural design, the consultant and owner have to be informed. This slows down the process once there is a fault or a clash.

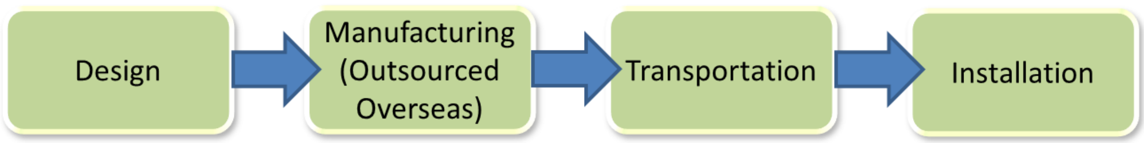


Figure 25: Current workflow

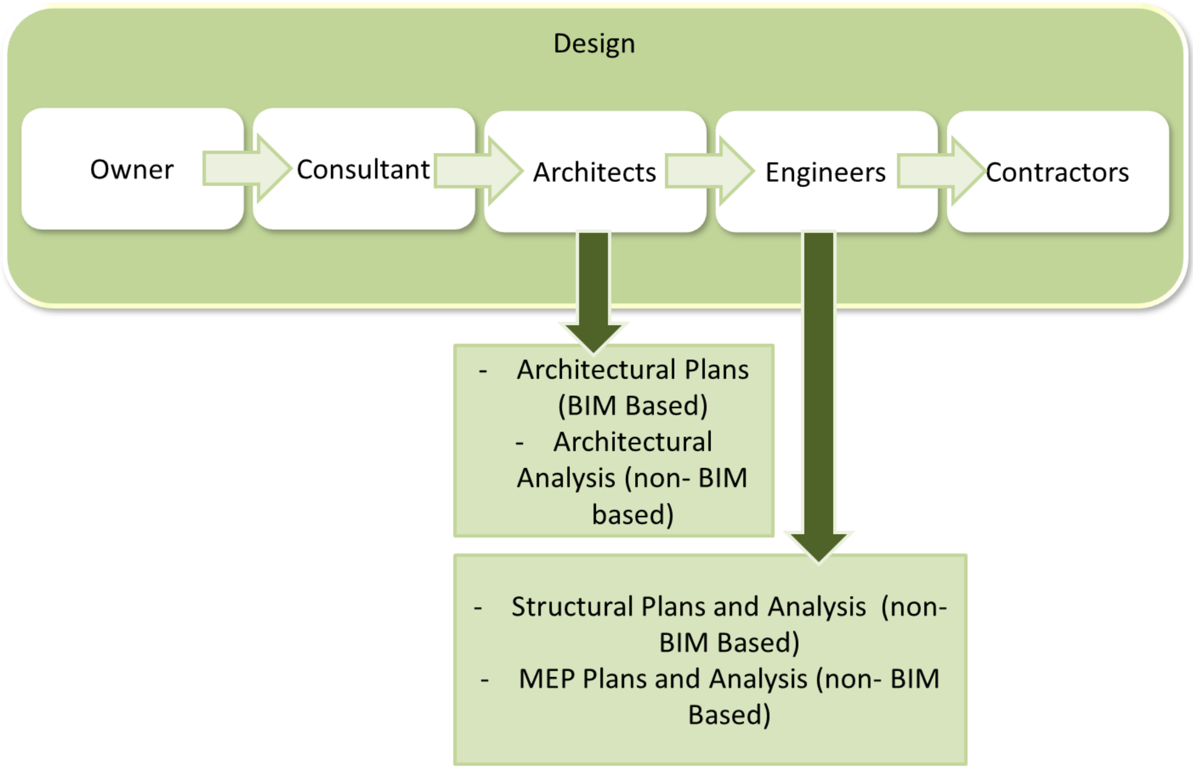


Figure 26: Design stage of current workflow

From the workflow, it is noted that BIM is not utilized to its maximum capacity since BIM is only used for architectural design in the design stage. In areas like architectural and structural analyses for example could be done with BIM technologies. Furthermore, BIM technologies could also aid in facility management during both the construction and post-construction. Henceforth, the proposed new workflow will further encourage the usage of BIM in every stage of the development to further enhance productivity.

**Proposed New Workflow**

Figure 27 shows the typical PPVC workflow redesigned into four stages while figure 28 shows the design stage of the proposed new workflow.

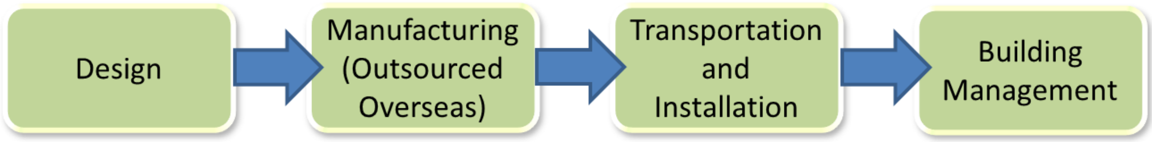


Figure 27: Proposed new workflow

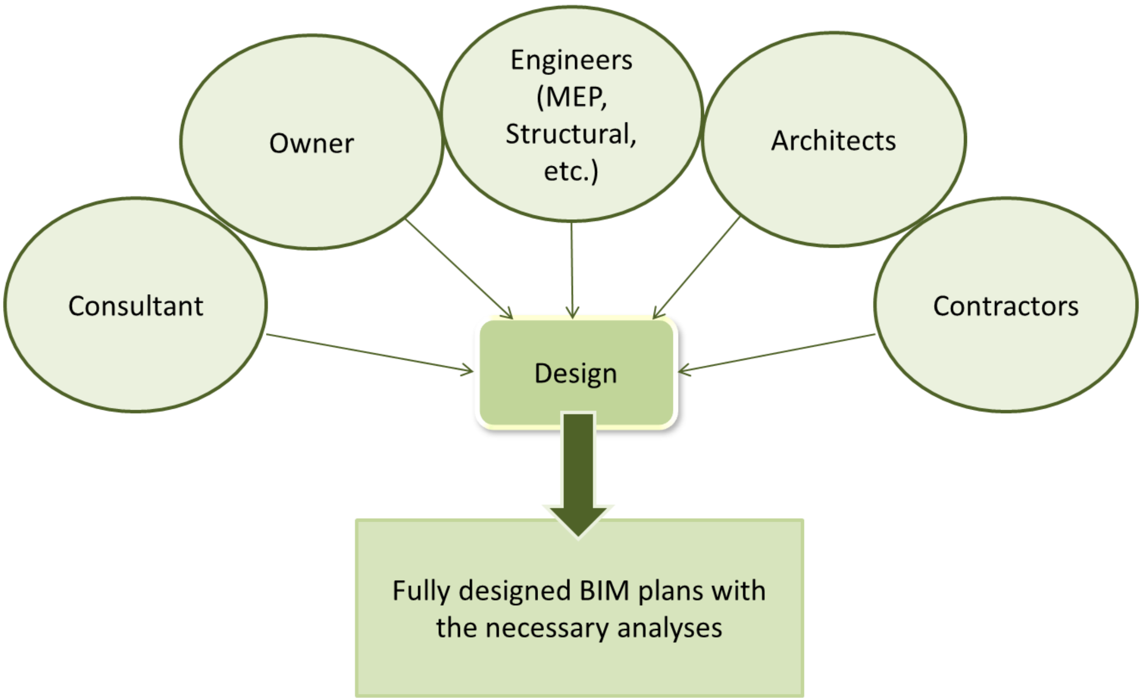


Figure 28: Design stage of proposed new workflow

Starting from the design stage, a more integrated approach is taken by including all major stakeholders of the development. This is to encourage a more collaborative effort and early involvement by major stakeholders so that potential downstream risks and mismanagement can be reduced or avoided. To maximize the potentials of BIM at the design stage, parametric components are encouraged where appropriate. These parametric components are not just limited to architectural designs, structural and MEP parametric components are also applicable. With BIM technologies, building analyses such as structural analysis and CFD studies can be done on the model. Simulation analyses like crowd control analysis or acoustics analysis and Quantity Surveyors' (QS) works like cost budgeting and cost control are also possible. Therefore by the end of the design stage a comprehensive and fully designed model of the building will be in place.

With the fully designed model, specifications of the building structure like PPVC modules are straightforward and the design for PPVC module can now be sent for overseas fabrication. In the meantime, other works at site like foundation works or cast in-situ works can begin. BIM technologies can also be used to monitor site works and progress with its facility management capabilities.

Once the PPVC modules arrive in Singapore, transportation and installation process of the PPVC modules can also be monitored by BIM technologies making site control more efficient. This is especially important as sites are usually constraint by limited space and PPVC modules that arrive must be installed almost immediately. On the other hand, late installation of PPVC modules will result in a built up of PPVC modules at the site which is not ideal at a site which has already limited space.

In the next stage, after the building has been fully constructed and passed to the owner, the owner can now manage the building with the help of the model. Facility managers can use the model to simulate a scenario and then configure the spaces. This allows for a more efficient planning and usage of space. In addition, BIM technologies can assist in the building facility's maintenance management. For an instance, if a leakage is suspected the owner can refer to the model to look for potential places and causes of leakage and then physically inspect the possible faults. This is faster and more convenient then to have to inspect the whole entire pipe system physically to look for the leakage and the cause.

With this proposed new workflow, major stakeholders will have a say in the design stage to ensure that the model is designed holistically. The created BIM model will then be part of the building cycle throughout, from the design stage to maintenance of the building and even to the demolition of the building. With a single holistic and comprehensive model, we would expect a reduction in miscommunications and time wastage in doing repetitive works.

## Chapter 5: Conclusion and Recommendation

### 5.1 Conclusion

Both BIM and PPVC are technologies identified by BCA to help enhance the productivity of the construction sector in Singapore. While both are evident in showing the potentials of productivity enhancement, these technologies are still but at their infant stages locally.

BIM is both a technology and also a process. BIM technology is largely used for 3D visualization in a simulated environment. This aids in identifying downstream risks such as looking out for potential design faults. BIM as part of a process serves as a platform for different levels of project details to be viewed. This can be done via BIM supported platforms like VDC where BIM models are used to manage beyond the design of the development like construction costs and facilities management. However the success of BIM relies heavily on collaboration and communication between stakeholders of the development. Without both, the potentials of BIM cannot be exploited. In addition, BIM also requires the early involvement of stakeholders so as to discuss the development in further details right from the pre-construction stage. This allows the maximization of quality, constructability and affordability of the project since it encourages a more holistic planning of the development right from the start.

PPVC is a form of modular construction that Singapore is new to. It enhances construction productivity through the ease of construction. In PPVC, modules are prefabricated in a factory before being shipped to the construction site where they are then stacked on top of each other. Such a construction method allows for quality control since the modules are built in a controlled environment and efficiency since modules only have to be stacked on-site and no additional construction work is needed. PPVC can be classified into four stages- design, manufacturing, transportation and installation of modules. At the design stage, the modules are deliberately designed to be the same, if not as similar as possible so that the modules can be repetitive. This reduces the need for redesign. At the manufacturing stage, the modules are produced in bulk to achieve economies of scale. Since the modules are similar, fabrication of the modules will also be faster. Following the modules will be transported to the site via a trailer for installation. All stages of the PPVC technology promote productivity through simplicity and bulk fabrication.

The potentials of BIM and PPVC are evident. However, both are still relatively new locally and more research needs to be done to mitigate the rising challenges and to further improve on the technologies. In this study, a local case-study (NTU PPVC 2 Hostel Development) is analyzed. It is found that BIM is only used in the design stage purely to aid in 3D visualization when it could have done more to contribute to the project progress. Construction works for this PPVC development were also not as efficient as there were too many varying types of PPVC modules.

Having too many types of PPVC modules would not only hinder productivity but also add on to the workload of the stakeholders. As such more can be done to enhance the productivity of a BIM based PPVC project.

The current PPVC workflow where BIM was used minimally was reviewed and the challenges hindering it were evaluated. A series of interviews were carried out with the stakeholders of BIM based PPVC projects to get to know more about the challenges involved and the feasibility of a proposed new workflow. Therefore, a new workflow is proposed based on interviewees' responses to encourage the further use of BIM in the different stages of a PPVC development. This is so that BIM's potential is utilized to the maximum and its potential challenges are mitigated in a PPVC development.

In this proposed new workflow, the four typical stages of the current workflow are redesigned- design, manufacturing, transportation and installation and building management. At the design stage, a more integrated approach is adopted to so that there can be early collaboration between all, if not most of the stakeholders of the development. Early collaboration allows for potential downstream risks and mismanagement to be reduced. In addition, in the design stage the use of parametric components are encouraged where appropriate. With BIM technologies, building analyses like structural analysis and CFD studies can be done on the model. With these, by the end of the design stage, a fully designed and comprehensive model of the project will be available. Following, this fully designed model will be essential and useful for construction. Where a PPVC module is involved, prefabrication can be started in the factory while foundation works are ongoing. With works progressing concurrently, we would expect time to be saved. Once prefabrication is done, the module will be transported to the site and installation progress can be monitored via BIM technologies as well. At the final stage, once all construction once has been completed and the building is handed over to the owner the owner or facility managers can then manage the building with the help of BIM technologies. With a comprehensive model at hand, they are better able to plan and use the spaces of the building. Henceforth, the BIM model will be useful throughout the building cycle from pre-construction to post-construction to even demolition.

All in all, the proposed new workflow will break away from conventional horizontal workflow which is less productive and will focus on a more integrated approach to form a single and comprehensive model that is usable for one and all. Most of all, it is designed to last right from the start to the end of the building cycle so that there will be a reduction in miscommunications and time wastage doing repetitive works even in the long run.

## 5.2 Limitations

There are however certain limitations to this paper.

**Lack of numerical data**

In this research, qualitative analysis is done and hence there is no numerical value to evaluate the extent of potential benefits and challenges. Without numerical data, it is difficult to gauge the progress and makes the opinions of the interviewees very subjective.

**Limited point of view**

Due to time constraints, only three representatives involved in BIM based PPVC projects were interviewed. Of the three, two were represented by contractors and the remaining one was a consultant. Therefore, the views of other stakeholders (e.g. owner and MEP engineers) were not represented. To add on, only NTU hostel developments were taken into consideration in this study. This is because at present there are only three PPVC developments locally and NTU hostel developments is the only one that is BIM based.

**Feasibility of proposed workflow in reality**

The proposed workflow suggests a more integrated approach right from the design stage. This approach breaks apart the conventional horizontal workflow that the industry has been following for a very long time. Furthermore, the conventional workflow allows for profit-making opportunities through the selling of plans amongst the different stakeholders. Depriving the stakeholders of such profit- making opportunities makes industry practitioners more reluctant to leave the conventional workflow.

## 5.3 Future Research

**Quantitative analysis**

A more quantitative analysis can be done for a more precise evaluation. A study can be done on a BIM based PPVC development right from the design stage and be compared to a conventional construction development to gauge the extend of productivity improvement. A more numerical data will also allow for a more comprehensive comparison.

**Other potentials of productivity enhancements through BIM and PPVC**

There are more rooms for further productivity improvements other than project management. Other areas like structural improvements of the PPVC module through the aid of BIM can be studied to further exploit the benefits of BIM. For example, the possibility of creating a foldable PPVC module to conserve space during transportation can be studied via BIM analyses.

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# Appendix

Various view plans of PPVC module as a parametric component