Off-site Construction Study for Potential Application in Bandung

Liang Guo
Faculty of Architecture & the Built Environment, Delft University of Technology
Julianalaan 134, 2628BL Delft
Layto_2010@Foxmail.com

ABSTRACT

The housing shortage in Bandung has been an acute problem for long, which requires to be solved urgently; however, the affordability of housing blocks people away from improving their living condition. This paper is trying to focus on the rapid and repeatable off-site construction system which could be the possible option to accommodate the housing shortage in a short period. The comparative analysis of different off-site construction methods and materials as well would be introduced in this paper to figure out the preferable solution for the context of Bandung. Also, the off-site construction industry and its workflow would be would be discussed in this paper. This research paper is part of my graduation project and would be beneficial to the future bio-based off-site construction design project.

KEYWORDS: Off-site Construction, Bandung, Prefabricate, Modular, Industry, Housing.

1. INTRODUCTION

The concept of off-site construction transforms the architecture from a customized design into a purchase-assembly product as many other merchandises. Per the Off-site Construction Council of the National Institute of Building Sciences, “Off-site construction is the planning, design, fabrication and assembly of building elements at a location other than their final installed location to support the rapid and efficient construction of a permanent structure.”

The history of off-site construction housing begins with the global colonial movement when western people manufactured and shipped their shelters from Europe to various locations. The first case could be traced back to 1624 that the houses were made in England and later shipped to a fishing village in Massachusetts. During the Second World War and postwar period in the 20th century, the off-site construction has been widely adopted to meet the need of rapid construction. Nowadays the buildings finished in off-site construction method account for more than 2% of the entire construction market, the share of which is increasing by 25 percent in recent years. Especially in some developed countries, taking the UK for instance, the percentage

of the off-site construction in the domestic construction market is even more than doubled to 5 percent.³

Although the off-site construction is not the latest invention, it regains the attention at present for its high efficiency and construction speed to conserve labor, physical and financial resources. Another explanation for its popularity is the shortage of skilled workers coupled with an aging trend occurs in many countries. Due to the poor working conditions and limited vocational perspective, young people no longer regard the construction worker as an attracting occupation, which to some extent promotes the off-site construction.

2. Material

Theoretically, every material can be applied to off-site construction for there is no fundamental distinction between it and on-site construction.⁴ Although nowadays many construction materials are newly invented or developed, the primary materials that have been widely used in the off-site construction can be classified as timber, metal, concrete, and the composite material. The preference of materials depends on many factors such as climate, cost, convention, and the type of buildings.

As a biodegradable natural material, wood is easy to process by hand or machine with good mechanical performance, and its easy availability and warm-feeling characteristic make it popular for residential construction in the worldwide. Unlike the artificial material which can be made in various shape, the raw wood is observably limited to its species and size in some circumstance.⁵ To standardize the material, wood can be transformed into the engineered material, includes but not limited to the laminated board, veneered beam, flake board, and plywood, to improve its performance. Nowadays some entire wood off-site construction has been developed, such as the Houtskeletbouw in the Netherlands and Muji Prefab House in Japan.⁶

Concrete is composed of coarse aggregate and cement mortar, reinforced by fiber or steel from inside. Being both affordable and flexible, it can be made in various shapes in a short time; however, it requires a significant amount of labor to blend the elements, to support the formwork and assemble the reinforcement before the final solidification. During the on-site construction, the quality control of concrete has always been a trouble that the reinforcement should be joint and placed properly which cannot be changed after casting the concrete mix; however, the quality control of concrete would be better in the off-site construction due to the standard component and the standardized operation procedure. The projected lifetime of concrete for civil architecture can be exceeding 50 to 75 years, which is extremely durable.⁷

As Figure 1 suggests, the buildings accompanied by off-site construction usually follow the prototype which contains five factors from outside to inside, namely foundation, skin, structure, service, and interior finishing.\textsuperscript{8} Due to the fact that houses in Bandung are merely decorated by plaster without any insulation layer, the structure and enclosure system would be the primary focus.

![Figure 1. Off-site Construction Layer and Traditional Housing (own illustration and photo)](image)

As the natural resources are abundant and readily available in the tropical region, the traditional Indonesian houses, as the case in Kampung Naga shown in Figure 1, widely use balsa wood, coconut wood, and bamboo as the structural material, and sago palm or coconut leaves as the roofing material. However, based on the excursion in Bandung, the majority of people nowadays live in the newly-built houses finished in the concrete structure enclosed by the brick wall, for their durability and affordability. People explain that traditional houses can last for 20 years or more with careful maintenance, still not as durable as the concrete ones with even little maintenance. Besides, the natural material requires skilled workers to proceed for plenty of time, both of which are not easy to reach. The steel structure can rarely be found for housing structure, but tends to be used for sunshade or parking shed.

More interestingly, known from the investigation, residents are more willing to purchase used materials from the second-hand building material shop. The price of used components can be reduced to around one-third of that of a new one, and appearance of which remains the same after painting. Table 1 records the price for some common construction material in Bandung.

<table>
<thead>
<tr>
<th>Material</th>
<th>New Material</th>
<th>Second-hand Material</th>
<th>Price in Euro (New)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood</td>
<td>750,000 IDR per m³</td>
<td>550,000 IDR per m³</td>
<td>50 EURO per m³</td>
</tr>
<tr>
<td>Brick</td>
<td>600 IDR per piece</td>
<td>200 IDR per piece</td>
<td>0.04 EURO per piece</td>
</tr>
<tr>
<td>Concrete</td>
<td>60,000 IDR per 50 kilo</td>
<td>No data</td>
<td>0.08 EURO per kilo</td>
</tr>
<tr>
<td>Bamboo</td>
<td>15,000 IDR per piece</td>
<td>9,000 IDR per piece</td>
<td>1.00 EURO per piece</td>
</tr>
<tr>
<td>Sand</td>
<td>1,300,000 IDR per truck</td>
<td>No data</td>
<td>5.66 EURO per m³</td>
</tr>
</tbody>
</table>

3. **CONSTRUCTION METHOD**

The classification of various off-site construction methods is based on the degree of completion during the manufacturing process. As the figure 2 shows, materials, components, panels, and modules are the general categories in which architectures are produced and assembled.\(^9\) Generally, the advantages of prefabrication would increase with a greater degree of prefabrication.

![Figure 2. Category of materials, components, panels, and modules for the off-site construction.](Retrieved from *Prefab architecture: a guide to modular design and construction.*)

3.1. **Material**

The category of the material refers to the prefabricated structural element, for example, columns and beams that made of wood and metal. Normally columns, beams, and slabs that made of the precast concrete are classified in the same category. Such prefabricated material forms the structure of a whole building, allowing the construction or assembly process to be continued on site. The prefabricated material usually collaborates with prefabricated components or panels to form a hybrid construction system, especially supporting the non-bear-loading wall system listed in the panel category. To manufacture such materials requires only a limited number of machines due to their linear characteristics and single element; therefore up to 60% of labor can be saved compared to the on-site constructed structure.\(^10\)

3.2. **Component**

The component can be seen in almost all buildings despite on-site and off-site construction, including small-scale composite components such as doors, windows, interior equipment. Normally such components are made in the factory without being processed on site, yet requires assembly to the certain place by skilled workers. Although componentization offers a great degree of freedom for customization during the design process, and the degree of prefabrication is limited to some certain components rather than the whole construction system.

3.3. **Panel**

Thanks to the flat nature of most buildings, panels system has been adopted to various components for long, including exterior and interior walls, floors, roofs, and claddings, etc. The


Panelized construction can be divided into the load-bearing and the non-load-bearing types, the latter of which can be easily replaced and upgraded. According to the magazine *Automated Builder* from the US, 56% of all residential buildings are finished with off-site construction method, where panelized systems take the largest percentage, up to 43% of all methods. However, the project varies from each other which leads to different basic units, making the panels manufacturing process more complicated than the linear materials.

### 3.4. Module

Originally developed from the portable housing in the 1950s, the modular construction has been applied on many types of architecture until now, especially the large building with many repeatable units such as schools, hospitals, and hotels. The completion degree of the modular system tends to be higher than all other off-site construction methods, going up to 95 percent. It can be regarded as an almost entirely off-site construction, and significantly reduces the onsite working and thus minimizes the environmental impact to the surrounding. Different from the panelized system, the modular system is manufactured in three-dimensional form, proposing higher requirements for skilled workers and machines.

### 3.5. Comparison

Generally, the off-site construction adopts a single system or the composite method, for instance non-load-bearing panel plus prefabricated structure, to make a building. Take the main influence factors into consideration, Table 2 is drew to make comparison among different methods to present the estimated assessment for a hypothetic project.

<table>
<thead>
<tr>
<th></th>
<th>On-site construction</th>
<th>Non-load-bearing Panel + Structure</th>
<th>Load-bearing Panel</th>
<th>Modules</th>
</tr>
</thead>
<tbody>
<tr>
<td>Labor Efficiency</td>
<td>●</td>
<td>●●●●</td>
<td>●●●●</td>
<td>●●●</td>
</tr>
<tr>
<td>Equipment Quantity</td>
<td>●</td>
<td>●●●●</td>
<td>●●●●</td>
<td>●●</td>
</tr>
<tr>
<td>Skill Requirement</td>
<td>●●</td>
<td>●●●●</td>
<td>●●●●</td>
<td>●●●</td>
</tr>
<tr>
<td>Time Consumption</td>
<td>●</td>
<td>●●●●</td>
<td>●●●●</td>
<td>●●●●</td>
</tr>
<tr>
<td>Delay Risk</td>
<td>●●</td>
<td>●●●●</td>
<td>●●●●</td>
<td>●●●●</td>
</tr>
<tr>
<td>Transport Easiness</td>
<td>●●●●●●</td>
<td>●●●●</td>
<td>●●●●</td>
<td>●</td>
</tr>
<tr>
<td>Upgrade Possibility</td>
<td>●●●●●●</td>
<td>●●●●</td>
<td>●●●●</td>
<td>●●</td>
</tr>
<tr>
<td>Environmental Impact</td>
<td>●</td>
<td>●●●●</td>
<td>●●●●</td>
<td>●●●●●</td>
</tr>
<tr>
<td>Flexibility</td>
<td>●●●●●●</td>
<td>●●●●</td>
<td>●●●●</td>
<td>●●</td>
</tr>
<tr>
<td>Durability</td>
<td>●●●●●●</td>
<td>●●●●</td>
<td>●●●●</td>
<td>●●●●</td>
</tr>
<tr>
<td>Overall Cost</td>
<td>●●●●●●</td>
<td>●●●●</td>
<td>●●●●</td>
<td>●●</td>
</tr>
</tbody>
</table>

---

4. Manufacture

The manufacturing process in the prefabricated factory, which is regarded as the core of off-site construction, is a combination of machines, workers, and spaces to make products. Although the manufacturing methods might be different for various materials according to their characteristic, the majority of the shaping work would be finished by the CNC machine.

Computerized Numerical Control (CNC) machining is used to remove part of the material to achieve the expected shape through the use of saws, blades, drills, routers, and mills. These tools can be used for both structural and enclosed material. The one-axis drills make vertical holes while saws and blades cut straight lines. The six-axis milling and routing tool is the most flexible machining method which uses a carbide cutter head and runs in a circular pattern, offering an enormous degree of freedom to operate on a variety materials. Compared with some advanced machines such as water-jet, plasma or laser cutting equipment, it is more affordable and easier to maintain, making it a perfect choice for CAD/CAM manufacture process.

Figure 3. Factory layout example producing 40 houses (left) and 80 houses per year (right).

Figure 3 shows the two typical layouts for the prefabricated wood house factory provided by the company Lissmac that the factory on the left is capable of producing 40 houses per year while the larger one more than 80 houses per year. For the smaller factory, due to the limited space and equipment, all the prefabricated panels have to be produced on the assembly table and further transported via the top crane in the middle. More than ten skilled workers are required to ensure the standard manufacturing rate. As for the larger factory, the production line appearance implies a more automatic work flow with more than 80 houses producing capacity per year. The existence of joinery machine ensures the detailed woodwork while the fully automated panel processing machine works in a CNC machining way. All the panels are assembled on the assembly tables as in the smaller factory, then transferred to the plastering station through the cross conveyor to make the finishing layer, and finally transported to the truck via the top crane. Such an automatic production line requires around 20 skilled workers to maintain the normal operation.

Figure 4 implies the panelized components to form a typical housing, produced from the prefabricated factory. The interior modules, used as a kitchen, toilet and roof shown in the figure, can also be panelized and transported to the site before assembling. The typical housing,

---

consists of more than 50 panelized subassemblies, transported in the truck and assembled by hand on site. The flexibility and low requirement for transportation and construction equipment increases the possibility of applying such construction method in Bandung.

Figure 4. A house product made of the non-loading enclosure panels and the structural components. (Retrieved from Design in modular construction.)

5. WORKFLOW

As figure 5 shows, the off-site construction system involves many sectors. The market survey made by the contractor or the third party suggests the general housing information such as the financial research and the typical housing study in certain areas. Then the contractor drafts the development planning and then invite architects to propose the detailed residential building design. The majority of prefabricated products would be manufactured in the factory and later transported to and assembled on the construction site while the rest of the components might be produced according to the customization of the self-builder or sold to the society directly. The feedback report of the prefabricated product would be sent back to the contractor as well as the architect to make modification as well as improvement.

Figure 5. Flowchart of the off-site construction industry (own illustration)
The mature off-site construction system functions successfully in many countries, suggesting competitive off-site construction method compared to the normal construction method. Take the Netherlands for instance, the construction price for the individual detached house of a medium standard in Amsterdam is 1,214 euros per square meter.\textsuperscript{14} According to the Dutch company ScanaBouw website, the price for \textit{Houskeletbouw}, or timber frame construction in English, estimates to be 200 to 230 euros per cubic meters for a 400 to 600 cubic meters housing.\textsuperscript{15}

Figure 6. Flow chart of the future off-site construction industry (own illustration)

As the design process of residential building is largely simplified that components and structures are repeatable on various sites, the necessity of architect tends to be decreasing. The role of contractor turns to be designing and testing the housing prototype, and pushing it to the market as ordinary industrialized products as figure 6 implies. The role of architect would not disappear but becomes a counselor that provides contractors with professional advice and legal consulting while the manufacturer takes the responsibility of producing the standardized product and collaborating with the contractor to improve the quality and efficiency together.\textsuperscript{16}

The assumed workflow is coherent with the phenomenon in Bandung that people who plan to build their own houses need no architect to do the design but base on the experience of construction workers. For contractors who would like to maximize their profits, they are more willing to collaborate with the construction workers directly. The application of off-site construction would even intensify the phenomenon for its standardized product and purchase-assembly construction method.

6. CONCLUSION

In brief, the off-site construction has been proved as a feasible method to make both rapid and efficient construction in many countries, which will play a more critical role in the construction market in the future.

Through the comparison of different off-site construction material and methods, the non-load-bearing enclosure system supported by the prefabricated reinforced concrete structure is


\textsuperscript{16} Thomsen, A. (2010). \textit{The role and influence of the architect in industrialized building}. Göteborg: Chalmers University of Technology.
supposed to be the optimal choice for the Bandung context for both durability and flexibility. The bio-based material like wood and bamboo would be the primary choice for the low-income family to form the enclosure system for its efficiency. Besides the cheap material, people are also capable of selecting a more comfortable material to build their houses. The panelized system provides people with great possibility to easily upgrade the houses by replacing the enclosure material as their income would probably increase in years. The used and removed panels can be sold to other self-builders who use the same prefabricated system to increase the lifetime value of the house.

As for the manufacturing process, the typical factory layout example with a production rate of 40 houses per year only requires limited machines, which lowers the investment threshold and suggests the financial feasibility. Due to the fact that the equipment in the factory is capable of producing both affordable and comfortable products, the target group can be extended to both low-income people and the middle class in Bandung. Once the off-site construction standard is set up by the architect, the contractor is able to enrich the categories of panels independently based on the market demand. Further detailed study about the off-site construction would continue in the following research and design process.

**Reference**


