A COMPARATIVE USER-FRIENDLY STUDY OF VERTICAL AQUAPONIC DESIGNS FOR BUILDING BALCONIES

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A COMPARATIVE USER-FRIENDLY STUDY OF VERTICAL AQUAPONIC DESIGNS FOR BUILDING BALCONIES

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A project report submitted in partial fulfillment of the requirement for the award of the degree of Bachelor of Science (Hons) Construction Management

Faculty of Engineering and Green Technology
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DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

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APPROVAL OF SUBMISSION

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ABSTRACT

Urban farming is a localized food system wherein growing, processing, distribution of foods and other products through plant cultivation around or in the cities. The popularity of urban farm has increased over the past few years because concerns about the population growth, climate change, pollution, urban heat and decreasing food supplies in urban area. Aquaponic is one of the farming techniques that can be used in urban farm. Aquaponic is defined as cultivation of fish and plants together in a constructed, re-circulating ecosystem utilizing natural bacterial cycles to convert fish wastes to plant nutrients. In simple words, aquaponic is a system that uses fish wastes to harvest the biggest amount of vegetables. By using re-circulating aquaponic system, plants can be grow with 90 percent less water than traditional farming method and the citizens can produce their own fresh foods at home. Vertical aquaponic system is a technique where the plants grow in a vertical structure rather than across a horizontal surface. It is a fantastically efficient use of space, whether in an efficiently managed greenhouse or the building balconies.

This research is to compare the user-friendliness of vertical aquoponic designs and determine which types of aquaponic designs meet the user friendly criteria. The objective of the study is to design three vertical aquaponic systems with varying materials and to collect the user-feedback on user-friendliness of aquaponic systems mainly through video recording. The information and data are gathered through the involvement of students from Westlake International School in Kampar. This research can be used as a medium to encourage more people to be involved in this project as there has been no standard design that has proven it to be easy to assemble. There is a need for user-friendly modular aquaponic system to be designed to allow scalability. This is beneficial as it brings positive impact towards the environment such as reducing the effect of global warming as well as lower down the green house effect. There are three aquaponic designs in this research. The results show that time improvement of Design A (Bamboo) is up and down, which means that it is difficult to assemble. Design C (PVC) takes the longest time to finish assembling as it has a larger number of parts. Nevertheless, Design B (Aluminium) takes the shortest time in assembling and the data shows that it is easy on assembly and easy to learn. The time assembled is just 15 minutes in group of 4 and the design's learning curve improved by 5 minutes and above from first attempt to second attempt indicating of shallow learning curve. At the end of this research, it was found that the Design B (Aluminium) is the best design as it meets all the user-friendly criteria.

Keywords: *Urban farming, Aquaponic Designs, User-friendliness.*

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CHAPTER 1

INTRODUCTION

1.1 Research Background

Urban farming is defined as a localized food system wherein growing, processing, distribution of foods and other products through plant cultivation around or in the cities (Hendrickson & Porth, 2012). The farming activities can improve the value and quality of life in terms of economic, socio-cultural aspects by growing vegetations using different spaces in urban areas (Moon, 2012). These urban spaces are schoolyard, rooftops, roadsides, apartment, balconies, abandoned buildings, hospitals and railways.

There are three main types of urban farm such as backyard gardens, community gardens, and commercial farms (Hui, 2011). Backyard gardeners are using the land around their home for plant growing such as rooftops and balconies. Community gardener is a larger piece of land gardened collectively by several households. The produces from both types of garden are used mainly for home consumption. Urban commercial farms are established for profit businesses, thus the producers are selling to the farmers markets and restaurants. Urban farming affects food security, health, and rate of poverty in a city (Stewart, et al., 2013). In order to provide food for the citizens, urban farming makes use of the local resources such as land, water and organic waste in the city.

The popularity of urban farm has increased over the past few years because concerns about the population growth, climate change, pollution, urban heat and decreasing food supplies in urban area (Despommier, 2011). In 2030, the urban population will be doubled and expecting an increase in greenhouse gas emissions will be from the rapidly growing cities in developing countries (The World Bank, 2015). The climate change will reduce the crop yields and affect optimal environmental growing conditions through increasing temperatures and changes in rainfall pattern. In addition, coastal flooding will reduce the amount of land available for agriculture. Urban farming is an important strategy for climate change adaptation and mitigation (Lebedeva, 2008). Presence of vegetation in urban areas can lower temperatures and greenhouse gas emissions (Zeeuw, 2011). Plants within urban areas can regulate the urban heating effect, and carbon dioxide and dust can also be captured. Less energy is used for transport, cooling, storage and packaging because the fresh food can be provided in the city (Zeeuw & Drechsel, 2015). Furthermore, the urban wastes can be reuse as fertilisers thus there is no chance of bringing the waste to heap in landfills (Cofie, et al., 2010).

As the urban deserts are increasing around the world, the farming methods in city should be improved in order to supplement urban food needs (Game & Primus, 2015). The advance farming methods in cities may include using aquaponic and hydroponic farming techniques in rooftop farm, community garden, vacant lots, greenhouses, balconies and indoor farm. Aquaponic is one of the farming techniques that can be used in urban farm other than hydroponic and soil based gardening. Aquaponic is defined as cultivation of fish and plants together in a constructed, re-circulating ecosystem utilizing natural bacterial cycles to convert fish wastes to plant nutrients (Bernstein, 2011). In simple words, aquaponic is a system that uses fish wastes to harvest the biggest amount of vegetables. This is an environmental friendly and natural food growing method as the fishes and plants can be growth without the need to filter or adding chemical fertilizer. By using re-circulating aquaponic system, plants can be growing with 90 percent less water than traditional farming method (Chow, 2015). Furthermore, the citizens can produce their own fresh foods at home.

1.2 Problem statement

Aquaponic system is not widely being developed because it is very complex, difficult to assemble and there has been no standard design that has proven it to be easy to operate (Davis, 2013). Another problem is that aquaponic is difficult in maintenance because it requires constant feeding, water adding, checking the pH level and cleaning out pumps and plumbing (Mwaafrika, 2012).

Selecting the right aquaponic system design and turn the idea into reality is not an easy task, especially for beginners without any sort of guidance as evidenced by common barriers faced by user (Brook, 2016). There is a need for user-friendly modular aquaponic system should be designed to allow scalability as most design is inflexible (Brook, 2013). Many people face difficulties in assembling these components together because all of these components need to be drilled and cut with actual dimension and length to ensure the aquaponic system can function well. The fish and plants will die due to design flaws in the actual aquaponic system. As most researchers focus on other areas such as practices and technologies (Skar, et al., 2015), there is a lack of research into user feedback on ease of assembly of aquaponic system.

1.3 Aim and Objective

The aim of this study is to identify which vertical aquaponic designs that meet the user-friendly criteria.

1. To design three alternative vertical aquaponic systems with varying materials.
2. To collect user feedback on the user-friendliness of aquaponic systems mainly through video recording.

1.4 Scope and Limitation

The scope of this study is generally focused on the literature review and video recording. Through the literature review, three alternative aquaponic vertical systems are designed. The feedback on the user-friendliness of vertical aquaponic designs can be obtained mainly through video recording by using recording tools such as camera.

In order to collect the feedback on the user-friendliness of aquaponic designs, this study is focused on the observation process of students who are located at Westlake International School, in Kampar through video recording. This is mainly due to the student facing the same mental challenges when building aquaponic system as adults do when putting different parts together. This factor plays a part in assessing how easy or difficult students find it to build an aquaponic system. One of the limitations of this study is that the project is only focused on the time used for assembling the prototypes due to limited budget rather than the time used for fabrication. Due to time constrains, the research does not specifically mentioned the aquaponic designs should be used in which type of building balconies.

1.5 Significant of Study

The significance of study is that this research can be used as medium to encourage more people to be involved in this project as it is an environmental friendly product. This is also beneficial as it brings positive impact towards the environment such as reducing the effect of global warming as well as lower down the green house effect. Other than that, citizens are able to obtain fresh produce for their own use despite having limited spaces in city. This study also allows room for improvement to assemble and modify better designs for future use.

1.6 Chapter Outline

Chapter 1 contains introduction of vertical aquaponic system in urban farming, followed by the problem statement, aim and objectives, scope and limitation as well as significant of this study. Lastly, the chapter outline of this research.

Chapter 2 includes the literature review that is relevant and detailed with the research topic which is the types of aquaponic system, benefits of urban farming, barriers of urban farming, and flexible system design as well as the uses of bamboo in agriculture.

In Chapter 3, it shows how the research methodologies will be carrying out. Several tactics have been used to carry out this research in data collection. This chapter also shows how the observation and interview are conducted.

Chapter 4 will deliver the result of data collected in this study and analysis of data based on respondents' feedback. Summaries on the respondents' feedback will be carried out and comments will be make.

In the last chapter, the overall conclusion of the analysis will be carrying out and the aim and objectives of the study will be evaluated whether they meet with the report. The recommendations and suggestions will be provided for future study.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter mainly discusses the types of aquaponic system, benefits and barriers in urban farming. It also further discussed the system design of aquaponic system by using bamboo and PVC. It helps to generate the design ideas for vertical aquaponic system. Through understanding the basic concepts of aquaponic system, the design of the modular aquaponics system can be expected.

2.2 Types of Aquaponic System

There are three primary aquaponic systems, differentiated by the type of plant growing components used. All these systems are based on a hydroponic system design, with accommodations for fish and filtration.

2.2.1 Basic Flood and Drain

Flood and drain system is the simplest of all configurations to understand and assemble. For any beginning system, the design works well by using 1:1 grow bed volume to fish tank volume (Bernstein, 2011). In this system, the plants are grown in media filled grow bed and the media serves as the mechanical and biological filter for the fish in the tank as shown in Figure 2.1. The second function of the media is to provide support for the plants. In a basic flood and drain design, the grow beds are usually located above the fish tank.

During the flood, the nutrient water is pumped up into the plant root zone. During the draining process, air is drawn into the plant root zone and the water returns to the fish tank via gravity when the power to the pump is switched off by a timer or through constructing an automatic draining device for the grow bed, called an auto-siphon (Viladomat, 2012). The advantages of this system are that high amount of yields can be obtained and will grow faster when compared to other aquaponic techniques but it is very expensive to be built (HapaFarms, 2013).

Source: Homeaquaponicssystem.com

Figure 2.1: Basic Flood and Drain System

2.2.2 Nutrient Film Technique

In nutrient film technique, the plant roots are exposed to a small amount of nutrient water that passes through the growing tubes. The technique is that the thin layer of water flow only reaches the bottom of the thick layer of roots while the top of the root mass is exposed to the air, thereby receiving a sufficient oxygen supply (Connolly & Trebic, 2010).

To ensure the plants can receive enough water to grow, the length, channel slope and flow rate must be calculated. Figure 2.2 show that NFT system can obtain very high plants quantities if constructed properly. The bio-filter is very important in NFT system because there is no extensive surface area for the beneficial bacteria to develop (Nelson, 2008). The main advantages of this system are that it can be built with low costs and can use of vertical space. However, there is a limitation for the types of plant to be grown in this system and filter is required.

Source: Aquaponics.ie

Figure 2.2: Nutrient Film Technique System

2.2.3 Floating Raft

The floating Styrofoam raft that floats on the water surface is usually used for plant growth. The plant roots hang freely in water to extract the nutrients as shown in Figure 2.3. The Styrofoam rafts have to be cut into small holes for the placement of plants.

The difference between the floating raft systems and the other systems is the amount of water used. The water below the raft is at least 10 to 20 inches deep and the other systems are approximately four times lower than floating raft systems. This is one of the advantages of the raft system as the extra water volume in the raft tank gives a buffer for the fish; it reduces the stress and potential water quality problems (Nelson & Pade, 2010).

Most often, the water must be filtered before it reaches the channels because the solid wastes in the water will clog up the plant roots and will inhibit their ability to receive oxygen and nutrients. Floating raft system is the most commonly used method in commercial aquaponic systems as it provides the flexibility to grow a various kind of leafy plants and herbs and can be built relatively inexpensively (Goldstein, 2013).

Source: Aquaponics.com

Figure 2.3: Floating Raft System

2.2 Benefits of Urban Farming

There are some benefits that can be obtained by farming in the city. Generally, the benefits may include improving food security and health. Urban farming can also be used as a school project to educate the children. Furthermore, it reduces the environment issue in city and brings a sense of belonging among citizens.

2.2.1 Food Security

Food security means that safe and nutritious food can be obtained by a reasonable price at anytime. There are some foods that the rural farm cannot provide because some foods may perish when they are being delivered to the cities and there are certain crops require rapid delivery when ready (Smit, et al., 2001). Furthermore, there are a lot of food loses part of its nutritional value during the transport from rural areas. The transported foods may incur higher food price as these foods passes through few middle men, storages and the cost spent on transportation. Thus, urban farming can enhance the efficiency of supplying food in the city rather than waiting the rural farm to supply food to the city.

Food and Agriculture Organization of the United Nations (2011) stated that the poor populations spent over half of its remuneration on food in the huge cities. The food prices are getting higher and higher, lower income populations in cities cannot afford the food prices. As the rate of urban poverty increases, food security becomes a critical issue in the city. The nutrition and security of foods in urban poor are worse than the rural poor. In other words, they lack of food security. With insufficient income, urban farming is a critical solution for food security. Lower income populations are able to gain the greatest benefits from urban farming. Through urban farming, lower income populations can produce their foods in cities for self consumption (Hoornwe & Munro-Faure, 2008). It is a good solution to increase the food security among the urban poor. When bad economy strikes, they are still able to obtain the foods that they cannot afford because the daily foods are not dependent on their low incomes. In addition, lower income populations can also earn additional incomes by selling their home production foods.

Through increased availability and access to food, farming enhances the food security of the poor. It provides an opportunity to poor families to gain control over the nutrition balance of their diet. Populations that perform urban farming are able to produce variety of nutritious foods such as vegetables, fruits and meats. By improving the nutritional balance of the diet, urban farming can also enhance the nutritional balance of the poor family (Smit, et al., 2001). Urban farming encourages the citizens to grow their own food rather than purchasing food from the buyers.

2.2.2 Health and Wellness

Problems in relation to obesity that occur in cities are due to the lack of knowledge regarding consumption of healthy food and these foods are difficult to obtain in cities. Urban farming is a good strategy to solve this issue. Urban farming can produce the healthy foods for community in the cities and reduce the risks of obesity, coronary heart diseases and diabetes (Bellows, et al., 2010). In addition, urban farming gives hands on experiences with fresh produce, teaching about healthy eating and providing mental health relief in order to have a city filled with healthy citizens.

Farming is a good exercise for the citizens. As the urban farming requires hands on maintenance, it is a good opportunity for the citizens to exercise their bodies. In cities, it is very difficult to find a place to do this kind of exercise because there is a lack of green spaces for traditional gardening. Working on urban farm aids the citizens in reducing stress, boosts happiness, and personal wellness of individuals (Ruff, 2015).

2.2.3 Education

Urban farming can use as teaching materials in school for the students. For example, teachers can use soil-based gardens, hydroponics and aquaponics as science projects in the schools to explain various scientific principles and create experiential hands-on learning experiences for the students. Through urban farming activities, the students have an opportunity to grow their own food and understand where their foods come from (National Gardening Association , 2014). This teaches the students to appreciate foods and not to waste the foods as well as teaching students about healthy eating. Urban farming in school gives students to reconnect with nature. A connection to growing food allows students to have a perception how an ideal healthy lifestyle should be.

2.3.4 Create a Sense of Belonging

In the world today, urban populations are highly mobile. It is becoming harder to find a stable sense of belonging. The urban populations may not have a chance to reconnect with the nature by farming. However, urban farming is one of the methods to let the citizen to have a chance to be a farmer to reconnect with the nature and come together to establish a sense of community. Urban farming provides a chance to the citizens to express a shared interest in farming. The farm in the cities can also be a citizen’s gathering place in their neighbourhood that provide chances to make connection. Urban farming not only attracts citizen’s family, friends, relatives farm together in the city, strangers can also work together to achieve higher food security (Hagey, et al., 2012). From this, the entire community will be benefit and a sense of belonging will be developed among the citizens.

Neighbourhoods that include urban farming normally can foster social interaction because farming is not usually an indoor activity and it always requires large number of population to work together on the street (Golden, 2013). Sometimes, neighbours will present their fruits and vegetables that grow on urban farm to their neighbours. The neighbour will try to discuss among each other to find out the best farming methods to be used on their farm. From this, it builds a long lasting relationship among neighbours.

2.3.5 Environmental Enhancement

Rapid growth in urban population and unmanaged expansion not only damages the environment of the cities, but also their surrounding regions (Smit, et al., 2001). The pollutions may include air, water and soil pollution. Urban farming not only minimizes the negative environment issues of urban growth in populations, even the surrounding environment can also be improved.

Urban farming is the effective method to clean the exhaust gas produced by the vehicles. The plants not only reduce the amount of carbon dioxide in the air, but also provide oxygen and eliminate toxins as well (Chinappi, 2010). Indoor farming helps to oxygenate the air and filter out noxious gases, which are particularly harmful to sensitive people (Kobayashi, et al., 2007). Farming in city can keep the surrounding cool. Thus, urban farming can greatly reduce the surrounding heat which creates urban ‘heat islands’ in cities (Block, et al., 2012).

Normally, environment quality is not good in low income residential areas of cities due to poor sanitation and hygiene awareness. The surrounding of residential area is full of pests such as cockroaches, houseflies and rodents. In low income residential areas, urban farming can improve the environmental health (Hagey, et al., 2012). If the farm is managed properly, it improves the sanitation of low income communities by reusing the solid waste in farming. The urban waste such as black water can be composted, recycled and used for farming in the city.

2.3.6 Economic Benefits

Urban farming provides a lot of economic opportunities. Growing local foods in city leads to increased job opportunities, as well as utilizes on underused resources. Urban farming has the capacity to increase property values of surrounding buildings and produce multiplied effects through the attraction of new food-related businesses, including processing facilities, restaurants, farmer markets, transportation, and distribution equipment (Hodgson, 2011).

In the developing world, food is the largest single element of the urban economy in cities. Urban farming is a competitive economic activity and the industry of choice for millions of urban entrepreneurs (Smit, et al., 2001). The risk of urban farm business confronted by entrepreneurs is low because the food is a basic consumption item with a stable and dependable demand, even during an economic downturn (Smit, et al., 2001). Urban farmers who stay near to the markets give competitive advantages by saving transportation and storage costs. The urban farmers can deliver foods and services faster, with shorter distribution links and smaller inventories (James, 2012).

Urban farming gives low income residents an opportunity to participate in their farm business. Urban farming often utilizes unused resources in the city such as wastewater, solid waste, rooftops, abandoned buildings and vacant lots (Knizhnik, 2012). It puts vacant and underutilized area into productive use, as well as conserves natural resources while enhancing the environment for urban living.

2.4 Barriers of Urban Farming

Although the entire society can gain a lot of benefits through urban farming, but there are some challenges that prevents it from happening. The challenges may include the start up cost and land tenure policy for urban farming. Other than that, soil contamination and vandalism issues in urban areas can also be the barriers for urban farming. The last barrier is where there is a lack of familiarity regarding urban farming among citizens.

2.4.1 Lack of Familiarity

One of the biggest barriers for urban farming is the urban growers may lack of familiarity with urban farming. Some residents do not understand what urban farming is and how it benefits the community. In their mindset, when they hear farm, they will picture cows or fields of wheat and they do not see how urban farms can fit into their cities to change the urban environment (Winch, 2014).

Some residents rejected urban farming project simply because they are resistant to change. This explains why residents felt discomfort with the things that they do not familiar with. They refuse to invest money on farming in cities by giving excuses such as soil safety, pests and so on. Other than soil safety and pest issues, processing and marketing in foods are the major barrier for them to involve in farming because these requires knowledge and skills in production (Oberholtzer, et al., 2014).

2.4.2 Start up and Operating Costs

The start up cost and operating cost for urban farming can be a barrier to people with limited income. To build an urban farm in cities, the expenses may include seeds, soil, tools and equipments as well as processing, packaging and marketing materials (Brown & Carter, 2003). The starting and maintaining costs depends on the venue, size and objective of the farms.

The start up cost of water tapping lines is very expensive and the delivered areas, compost areas as well as trucks and tractors are normally needed for large farms. Other than the facilities, the farmers need to pay for soil testing before farming because most of the land in cities is contaminated by the industrial, commercial and residential wastes (Smit, et al., 2001). Most urban farmers find it difficult to obtain permits for their farm and delaying in issuing a permit will lead to increased time and costs. To add on, banks usually will not loan the money to farmers who plan to operate a large scale urban farm and even those who plan to operate small farms too.

2.4.3 Land Tenure

Land tenure issues are potentially major barriers for urban farming. Urban farms are normally constructed on empty or abandoned land that provides little security in terms of long-term land access (Hagey, et al., 2012). Most of the farmers and gardeners do not own the land. So, without title, or three to five years leases, they run the risk of losing their farms and their investment when the developer takes over the land for other purposes. There is no protection from being expelled. This lack of security in land tenure induces urban farmers not willing to invest in infrastructure inputs such as machinery, storage facilities and water line access.

Urban farming is often carried out under tenure arrangements based on informal tenures. Normally, these are short term agreements that benefit both parties, but just as often access are simply gained by squatting, without any form of agreement, on temporarily available vacant land (Diouf, 2006). The informal tenure arrangements are not recognised by statuses, so it can be disregarded when the tenure land area develops. Low formal recognition of land authorities in urban cultivations causes insecure tenure, thus reducing food security, social stability and livelihood possibilities.

2.4.4 Soil Contamination

In urban cities, most of the farmers concern about the soil whether it is clean and safe to use for food production or not. The urban farm can be affected by the pollutions that come from commercial, industrial and residential in cities. There are a lot of factors which causes pollution in urban areas such as inadequate waste disposal, automobile exhaust, industrial solid waste and so on (Smit, et al., 2001).

The pollutants may deposit heavy metal in soil, air, water or on plants. When the citizen consumes the vegetables that grow from urban farm may affect their health because the vegetables are picking up from the contaminated soil. Sometimes, the citizen not only influenced by consuming the contaminated vegetables, but the pollutants are transferred to citizen through direct contact with the contaminated soil during farming. For example, the health issues may include dizziness, blurred vision, or coma. Lead is the most harmful heavy metal. Children may suffer from anaemia, lowered IQ, and neurological impairment with high levels of lead in their blood (World Health Organization , 2010).

2.4.5 Vandalism and Crime

Most farmers are concerned with vandalism and crime in urban farms. The perception or reality of vandalism is an unfortunate characteristic that hinders urban farming efforts (Kaufman & Bailkey, 2000). In cities, most of the farms are located near the streets have a significant amount of vehicles and foot traffic both day and night. Thus the probability for different forms of vandalism to appear always exists, especially at night.

When farms are left unguarded, vandals invade the farm at night to steal the vegetables and equipment, damaging the properties and dispose the rubbish into the farm sites (Rissman, 2016). In most cases, unemployed teenagers are accused of being guilty of these crimes. Consequently this problem becomes a major barrier for the residents that wish to participate in farming activities. Rural farms also deal with incidents of vandalism but much less frequently (Rissman, 2016). They are located in less populated areas and on larger plots of land. This means vandals take more effort to damage the rural farms.

2.5 Aquaponic System Design

When designing an aquaponics system, it should be as simple as possible because less complexity means less maintenance and less potential problems. Normally, most constructed aquaponic systems consist three groups of components, which is fish tank, grow bed and plumbing fittings.

2.5.1 Fish Tank

Fish tank is an important component in aquaponic system design because it will affect the survival rate of the fish. The shape, material and colour of tanks are the important aspects to consider when selecting the fish tanks.

2.5.1.1 Shape

The shape of aquaponic tanks affects water circulation and brings impact on the water quality. Round flat bottom tanks are usually used in aquaponic and they can sit right on the ground and are self-cleaning (Jess, 2012). The round shape provides a circular flow of water and causes the solid wastes to be settled in the middle by centripetal force. If square tank with flat bottoms are used instead, more active solid-waste removal is required but it is acceptable to be use for aquaponic system.

The shape of fish tanks with many curves and bends are not recommended as dead zone is created (Somerville, et al., 2014). The solid wastes can store in these areas and create an anoxic environment to the fish. It is essential to select fish tanks to fit the characteristics of fish species because the fish will grow better with sufficient space.

2.5.1.2 Materials

The fibreglass and plastic tanks are recommended due to its durability. Plastic and fibreglass are light and can be install easily for plumbing. The plastic container must able to resist the UV light because sunlight can damage the plastic. Low-density polyethylene (LDPE) tanks are more preferable to use due to its high resistance and food-grade characteristics (Somerville, et al., 2014). LDPE tanks are usually used to store the water for civil uses.

Source: Terapeak.com

Figure 2.4: LDPE Tanks

A second option is to use flexible pond liner as shown in Figure 2.5. It is a water proof material and usually used to create man-made pond. Most liners are either EPDM (ethylene propylene diene monomer) rubber or PVC (polyvinyl chloride). EPDM is the better choice due to its durability and lack of plasticizers. As EDPM liners are rubber based, they are extremely flexible. Pond liner gives flexibility in the design of aquaponic tanks (Bernstein, 2011).

Source: Centerpointpond.com

Figure 2.5: EPDM Pond Liner

Another option includes intermediate bulk containers (IBCs), bathtub and barrel (Stout, 2013). The container which used to store toxic material previously should not be used. For example, solvent-borne chemicals are impossible to be removed with washing once it penetrates into plastic itself.

Source: Idiotsguides.com

Figure 2.6: Intermediate Bulk Containers (IBCs) and Barrel

2.5.1.3 Colour

The tanks should use light colour such as white in order to view or check the wastes that settled at the bottom. White tanks can keep the water cool by reflecting the sunlight (Somerville, et al., 2014). Fish tanks should be shaded to prevent algal from growing and debris entering it. In addition, it prevents pests from attacking the fishes. The shading nets can be used as cover for the fish tanks.

2.5.2 Plumbing and Fittings

Aquaponic system requires selecting the PVC fittings, connections, hoses and tubes, as well as the PVC pipe to channel the water flow into each component. Half inch inner diameter PVC is recommended to be used for the aquaponic system as it is large enough for sufficient water to flow without becoming clogged with solids and this standard size and the fittings can be find easily (Bernstein, 2011).

Larger sizes PVC can also be used but it is costly. Whenever there is a need to drill a hole in the grow beds in order to attach a water in, out or to overflow the pipe, there is a chance for a leak to occur. Thus, proper seal must be created such as using Uniseals and Bulkhead Fitting (Bernstein, 2011). Uniseals is a rubber material and are used to hold a pipe using pressure. There is variety of sizes for PVC pipes. A bulkhead comes in two threaded pieces, including a gasket and is hollow in the middle where the water can pass through.

Source: Ruaf.org

Figure 2.7: Plumbing and Fittings

2.5.3 Submersible Water Pump

Water movement in aquaponic system is very important as it keeps all organisms alive in the system. If the water movement stops, the fish may die within few hours. Furthermore, the water in NFT, DWC and media bed system will stagnate, becomes anoxic and will dry out.

The impeller-type submersible water pump is commonly used in aquaponic system and this type of pump is recommended to use in small scale aquaponic units (Somerville, et al., 2014). The pumping power is reduced at each pipe connection and up to 5 percent of total water flow rate can be lost. Therefore, the number of connections between the pump and fish tank should be reduced. The larger pipe should be used in aquaponic system because it enhances the water flow rate and less maintenance is required to remove the build up of solids accumulating inside. In practical terms, the electricity and operating costs for aquaponic system can be saved. The submersible pump should be located in an accessible location because periodic cleaning is necessary. Furthermore, pump should not be run without water, if not it will break.

Source: Homeaquaponicssystem.com

Figure 2.8: Submersible Water Pump

2.5.4 Grow Media

There are certain criteria which are essential when selecting grow media to the aquaponic system. For example, the media requires sufficient surface area to allow the water flow in the grow pipe and the plants roots to breathe. The media have to be free from dust, non toxic and neutral pH so that the quality of water will not be affected.

2.5.4.1 Volcanic Gravel

Volcanic gravel is widely used for media bed units because it can be obtained easily, as it has high surface area and cheap. It is chemically inert once it is washed of dust and dirt. The high surface area of the volcanic gravel can give the bacteria colonize. (Hallam, 2010) The size of volcanic gravel should be ranged between 8mm to 20 mm in diameter. The gravel that is too small may clog with wastes and larger gravel will create larger air pocket where the plants cannot be supported.

Source: Latortugaverde.com

Figure 2.9: Volcanic Gravel

2.5.4.2 Expanded Clay Pebbles

Expanded clay pebbles are known as Hydroton as shown in Figure 2.10. The shape of pebbles is round and the weight of pebbles is light compared to other mediums. It has been widely used in aquaponic because it is highly porous and easy to handle. The size of pebbles with diameters 8mm to 20mm is suitable to be use for aquaponic. The porosity of expanded clay pebbles is ideal for supporting beneficial bacteria in aquaponic system and it can be easily cleaned with bleach and hydrogen peroxide.

Source: Hydroponicsinfocentral.com

Figure 2.10: Expanded Clay Pebbles

2.5.4.3 Others Substrates

Organic substrates such as coconut fibre and rice hull can also be used as a growing medium for grow pipes because they are cost effective (Somerville, et al., 2014). However, there is a risk of becoming anoxic; clogging the system and it deteriorates over time. Thus, the grow media should be removed when it starts to deteriorate.

Source: Farmtech-mart.com & Communityfirst-global.org

Figure 2.11: Coconut Fibre and Rice Hull

2.5.5 Nutrient Film Technique Grow Pipes

PVC pipes are normally being used as grow pipes in nutrient film technique (NFT). The PVC pipes are placed horizontally to enable the plants to grow by receiving the nutrients in rich water from the fish tank. One of the advantages of the nutrient film technique (NFT) is that the pipes can be placed in different patterns thus it is very flexible and space efficiency (Somerville, et al., 2014). For example, the vertical fence and wall, and overhanging balconies can also be used for nutrient film technique (NFT).

The water is pumped from the tank into grow pipes and providing a little amount of nutrient water flowing along the grow pipe's bottom. There are number of holes along the grow pipes for placement of the plants. When the stems and leaves grow out and starts developing root system inside the grow pipes, the shallow stream along the grow pipes ensure the roots to obtain big amounts of oxygen at the root zone (Somerville, et al., 2014). The plant roots have a bigger air exchange surface by keeping a shallow stream.

2.5.5.1 Grow Pipe Shape and Size

The round pipes are usually used for plant growth. 11cm diameter grow pipes are required for large fruiting vegetables and for the fast growing leafy greens require pipes with a diameter of 7.5cm (Somerville, et al., 2014). However, 11cm diameter pipes are recommended for large and small vegetables because this prevents limitations in selecting plants.

The grow pipe length can be ranged between 1m to 12m. The length of pipes that are more than 12m will result nutrient deficiencies in plants at the end of the pipes because all the nutrients are absorbed by the first plants (Somerville, et al., 2014). To ensure the water flows through the grow pipes easily; a slope of about 1cm for 1m of pipe length is required. PVC pipes are recommended as they are usually available and cost effective. White pipes are used because the colour reflects the sunlight and keeps the inside of the pipes cool.

2.5.5.2 Planting within the Grow Pipes

Drilled 7cm-9cm in diameter holes on the grow pipes that match the size of net cups. The difference between the middle of each plant hole should be 21cm to allow sufficient plant space for plants growth (Somerville, et al., 2014). The plant seeds placed in the net cup that are filled with grow media, then placed within the grow pipe holes. If further support is needed for plants, 5cm length PVC pipe can be place inside the net cups. Other than net cups, regular plastic drinking cups can be used too and it is cheaper than net cups. Drilling the holes on the plastic drink cups enables the nutrient water can be received by the plant roots. Furthermore, it is very important to ensure the roots can touch the stream of water at the grow pipe's bottom, if not the plant seeds may be dehydrated.

2.5.6 Vertical Growing

Vertical growing is a technique where the plants grow in a vertical hanging structure rather than across a horizontal surface. It is an efficient use of space, whether in an efficiently managed greenhouse or window of the building. It benefits to the users who have limited space (University of Maryland Women in Agriculture, 2015).

2.5.6.1 Window Aquaponics System

The windows are filled up with the recycled bottles to grow plants. The bottoms of the bottles are being cut off and hanged upside down, then fill it with grow media and hang it in succession from the top to the bottom of a window frame and attached to an aquarium. The window aquaponics system can fit in any apartment, no matter how small (Ridden, 2011).

2.5.6.2 Grow Tower

For grow tower, 4 inch PVC pipes with gravel works well for vertical growing in an aquaponic system (Bernstein, 2011). Add a screen to the bottom of PVC pipes and hang the tower directly over the fish tank; the water will flow through the PVC tower from above to the fish tank. To create growing spaces, slit the pipe half way through the diameter, then use hot gun to soften the plastic above the silt. Once it is soft remove the heat and push it in with a screw driver, leaving the screwdriver in place until the PVC cools (Bernstein, 2011).

2.6 Dieter Rams Ten Principles of "Good Design"

Good design is not just aesthetic, but it also needs to perform and fulfil its purpose. A good design must be measured based on multiple perspectives.

Table 2.1: Dieter Rams Ten Principles of Good Design (Rosenfield, 2012)

Principles	**Explanation**
Good Design is Innovative	The possibilities for innovation are not, by any means, exhausted. Technological development is always offering new opportunities for innovative design. But innovative design always develops in tandem with innovative technology, and can never be an end in itself.
Good Design makes a Product Useful	A product has to meet certain requirements, not only functional but also aesthetic and psychological. Good design emphasizes the usefulness of a product while disregarding anything that could possibly detracts from it.
Good Design is Aesthetic	The aesthetic quality of a product is integral to its usefulness because products are used every day and have an effect on people and their well-being. Only well-executed objects can be beautiful.
Good Design makes a Product Understandable	It clarifies the product's structure and it makes the product clearly expresses its function by making use of the user's intuition. At best, it is self-explanatory. If a design is good, the users immediately know how to use it. There are three simple rules for self explanatory design: • Present a minimal amount of information. • Arrange the information so there is an obvious starting point. • Build each "next step" on the logic of the step before.

Good Design is Unobtrusive	Products fulfilling a purpose are like tools. They are neither decorative objects nor works of art. Their designs should therefore be both neutral and restrained, to leave room for the user's self-expression.
Good Design is Honest	It does not make a product more innovative, powerful or valuable than it really is. It does not attempt to manipulate the consumer with promises that cannot be kept.
Good Design is Long-lasting	It avoids being fashionable and therefore never appears antiquated. Unlike fashionable design, it lasts many years – even in today's throwaway society.
Good Design is Thorough down to the Last detail	Nothing must be arbitrary or left to chance. Care and accuracy in the design process show respect towards the consumer.
Good Design is Environmental Friendly	Design makes an important contribution to the preservation of the environment. It conserves resources and minimises physical and visual pollution throughout the lifecycle of the product.
Good Design is as Little Design as Possible	Less, but better – because it concentrates on the essential aspects, and the products are not burdened with non-essentials. Back to purity, and to simplicity.

2.7 Criteria for User Friendliness

User-friendly is defined as product that is easy to be used and not is complicated for the user (Robertson & Robertson, 2013). It is "friendly" to the user, meaning it is not difficult to learn or understand. While "user-friendly" is a subjective term, the following are several criteria for user friendly product.

Table 2.2: Criteria of User-friendliness (Christensson, 2014)

Criteria	Explanation
Simple	• A user-friendly product is not overly complex, but instead is straightforward. It is well-organized and easy to locate. • The number of parts should be reduced because for each part, there is an opportunity for an assembly error. Less part implies less assembly difficulty (Arif, 2011). • The probability of a perfect product goes down exponentially as the number of parts increases. As the number of parts goes up, the total cost of assembling the product goes up (Boothroy, et al., 2011) • As the product structure and required operations are simplified, fewer assembly steps are required, assembled time is further reduced.
Intuitive	• In order to be user-friendly, a product must make sense to the average user and should require minimal explanation for how to use it. • The design is easy to understand and self-explanatory regardless of the user’s experience, knowledge, or current concentration level. It must be user-friendly to reduce manuals to a minimum (Bergh, 2000). • The term intuitive means having the ability to understand or know something without any instruction (Stangeland, 2014).

Reliable	• An unreliable product is not user-friendly, since it will bring undue frustration for the user. A user-friendly product is reliable and repeatable. • A product that is easy to assemble for a user in assembling process should be easy to learn, with a very steep learning curve (learn-ability), thus enabling the user to improve learning by increasing the number of repetition. After the initial learning process has ended, the user must be able to achieve high level of learn-ability (Holzinger & Simonic, 2011)

2.8 Uses of Bamboo in Agriculture

In agriculture, the farmers have utilised bamboo for a multitude of purposes such as green house, plant support, water pipe, furniture, fence, bridge and so on.

2.8.1 Greenhouses

In developing countries, most farmers wants to be involved in greenhouse farming business but most of them give up on this business plan due to the high cost of construction materials. The greenhouses which are built by using metal and wooden frames are very expensive. This problem can be solved by using bamboo because bamboo is not only cheap, but also good in terms of strength and reliability. In Malaysia, Philippines and other Asian countries, many greenhouses are constructed by using bamboo (Ndawula, 2015). As the bamboo is hollow, it is very light and the strength of bamboo is comparable to mild steel. Bamboo also helps to maintain the temperatures in the greenhouse as low as possible because bamboo is a poor conductor of heat.

Source: Downtoearthph.com

Figure 2.12: Bamboo Greenhouse

2.8.2 Plant Support

Bamboo is a good material for plant support sticks, stakes or props as shown in Figure 2.13. For example, it can be used as props for banana plants, as stakes to support climbing beans, growing of vegetables and as a support frame for passion fruits. It can also be used to make plant nursery sheds. However, the poles need to be treated first with wood preservative to prolong their service life. In Central America, Bambusa vulgaris poles were used to support bananas for United Fruit (Schroder, 2012). The poles require special treatments to extend their service life.

Source: Guaduabamboo.com

Figure 2.13: Plant Support Sticks

2.8.3 Water Pipes

The bamboos are currently being used to distribute the water in various locations throughout the world. For example, in Orissa, India over one hundred women came together to construct a bamboo piping system to transport water from a nearby stream to multiple villages (Asenso, et al., 2011).

In Tanzania, the village uses wood and bamboo to supply the water to the entire community. There are 200 km of bamboo pipeline that have been laid in 28 villages and around 100,000 people are being supplied with water (Lipangile, 2012). The bamboo pipes are cut from the jungles and made from bamboo stems. The bamboo pipe is made by removing out the internodes that are across the bamboo stem. The bamboo pipes are reinforced by galvanized wire, knotted at intervals of about 50mm. The polythene is used for bamboo pipe joint, which forms watertight joint. The joint is formed by wrapping the leather round the two bamboo ends like a bandage. The critical problem of bamboo pipes technology is their durability of it when it is buried into the ground.

Source: Permacultureglobal.org

Figure 2.14: Bamboo water piping system

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Introduction

This chapter describes the methodology used in carrying out this study to achieve the aim and objectives of the study. Research methodology is the process used to collect information and data for the purpose of making decisions.

In this chapter, the methodology is detailed out and explanation is provided. The objective of this study is to collect the user feedback on the user-friendliness of aquaponic system mainly through video recording. The study uses observation as the principal research method to collect the normative data. The main means of observation was achieved through video recordings. This was complemented by interviewing the students after the observation session.

3.2 Research Design

Research design is a plan for connecting the conceptual research problems to the solution. It articulates the data required, methods to collect and analyses data to generate more ideas in relation to the topic. Research design gives direction and systematizes the research.

3.3 Data Collection

Normally, the sources of data employed during the course of this study were:

- Secondary Data
- Primary Data

3.3.1 Secondary Data

Secondary data is obtaining information from existing source; it can be collected through many ways, which is:

- Books
- Internet Resources
- Newspaper
- Journals
- Magazines

3.3.2 Primary Data

Primary data is the source of data that have yet to be interpreted by others. Primary data can be collected through several ways:

- Interview
- Observation
- Questionnaire
- Experiment

Technique used to collect the primary data through observation is selected.

3.4 Observation

Observation methods are useful to researchers for generating in depth descriptions of organisations or events, for obtaining information that is otherwise inaccessible, and for conducting research when other methods are inadequate. They provide researchers with methods to check for nonverbal expression of feelings, determine who interacts with whom, grasp how participants communicate with each other, and check for how much time is spent on various activities (Kawulich, 2005).

3.5 Video Recording

Video recording is a data collection tool for researchers who are interested in the multimodal character of social interaction. It provides a fine-grained multimodal record of an event detailing gaze, expression, body posture, and gesture. It is a sharable digital record in which all modes are recorded sequentially (Jewitt, 2012).

3.6 Collecting the Data

Video recording is used in this study because it is more flexible than observations done by hand (Jewitt, 2012). After viewing the video tapes, various data categories can be developed. This allows the data itself to affect the category system design derived from analysing it rather than being imposed on it.

Sometimes the audio tape is not good enough to answer a research questions by recording what students' talk but the video has an opportunity to search for meaning in the actions and dialogue, it can reduce the potential ambiguities introduced by analysis based on words alone. Other advantage of video recording is enabling the researcher to replay the user's actions as often as it is necessary.

3.7 Using Video Camera

Two cameras are used to record the interaction between the students and modular aquaponic system. One camera records the students' hands and faces in front view while another camera is used for side view. The purpose of using two cameras is to allow the students to be viewed in two different angles. It enhances the accuracy of the data because sometimes there is a blind spot, the hand's action of students may not be recorded.

Through the video and time recording, the data is obtained when the student is assembling the modular aquaponic systems. According to their assembling hand's action in video tapes, the shortages of the modular aquaponic design system can be discovered. Brief handwriting should be used in recording because sometimes the video recording is unable to capture the data during the observation session. Other than video recording, the photographs obtained during observing session can be used to recall the memory.

After the students finished assembling the aquaponic system, a short structured interview should be conducted. The purpose is to verify the observation data because sometimes through observation, the obtained data is not reliable.

3.8 Observation Session

There are 54 students randomly picked from the Westlake International School to conduct this research. 27 students are randomly picked to assemble the aquaponic system without assembly instruction manual, given only a picture of the completely assembled modular designs and the remaining students will be given an instruction manual to assemble the aquaponic system. The students are divided into three groups as there are three alternative aquaponic vertical designs. Therefore, each design was built by 9 students in three different groups of students and three sets of data are collected. The recording team consists of the researcher, time recorder, as well as first and second camera operator who hide themselves from the students' field of vision during the recording sessions.

Before the observation session begins, the researcher splits 9 students into 2 students, 3 students and 4 students for each small group to adopt each modular design. Each small group is repeated three times in assembling the modular aquaponic system. Once the session begins, the recorder has to start recording the time that are used by students to build the system while the first and second camera operator have to begin recording the whole aquaponic assembly process through videotaping. After the students finish assembling the modular aquaponic system, the researcher approaches the students and asks them questions about their use of modular aquaponic system.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

Three vertical aquaponic systems are designed with varying materials that is bamboo, aluminium and PVC as shown in Figure 4.1, 4.2 and 4.3. These prototypes will be assembled by the Westlake International School students. There were 54 students being participated under observation sessions. The completed time in assembling the prototypes will be recorded through video recording. The data are then tabulated according to the number of students, number of repetitions and availability of instruction manual. These parameters are used to determine which prototypes is the best in fitting the user-friendly criteria.

4.2 Vertical Aquaponic Designs

Vertical aquaponic system is a technique where the plants grow in a vertical structure rather than across a horizontal surface. It is a fantastically efficient use of space, whether in an efficiently managed greenhouse or the building balconies.

4.2.1 Design A (Bamboo)

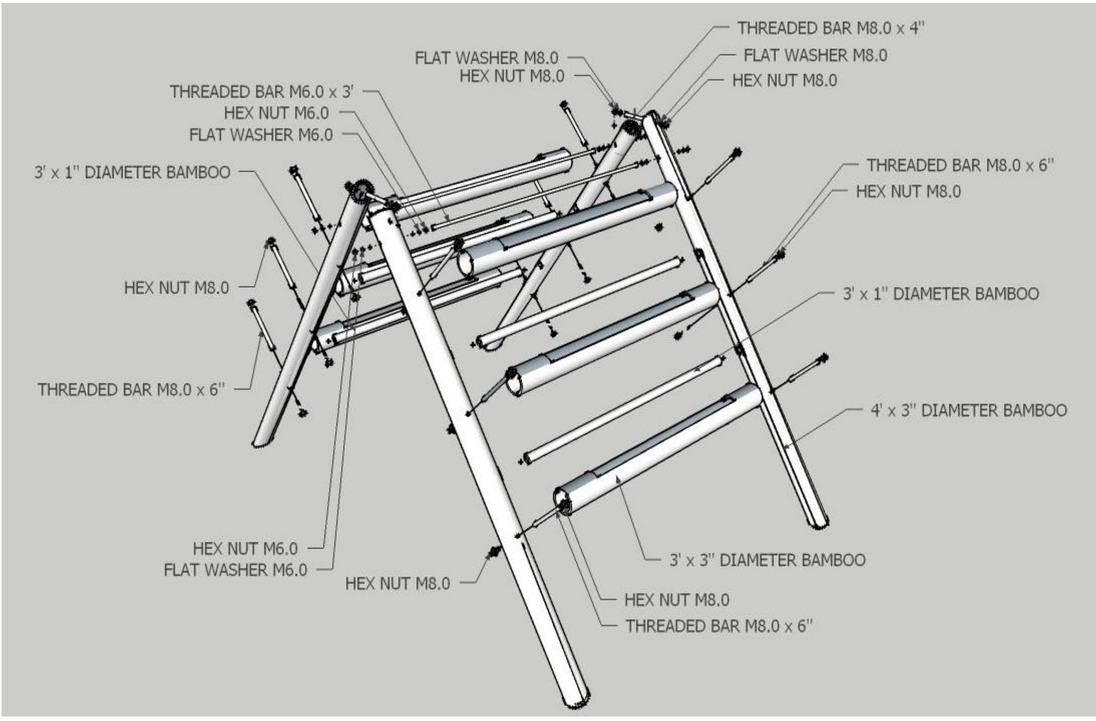

Figure 4.1: Design A (Bamboo) Components

4.2.1.1 Bamboo Support Frame

The support frame is constructed by using (4) 3'' bamboo poles and (4) 1'' bamboo sticks. Bamboo is used to construct the frame because it is cheap and good in term of strength. The 3'' bamboo poles that used for support frame are joined by using hex nuts, M6.0 and M8.0 threaded bars. The bamboo support frame uses (4) 4ft x 3'' bamboo poles, (4) 3ft x 1'' bamboo sticks and (2) 3ft M6.0 threaded bars to provide stability for the whole structure.

4.2.2 Design B (Aluminium)

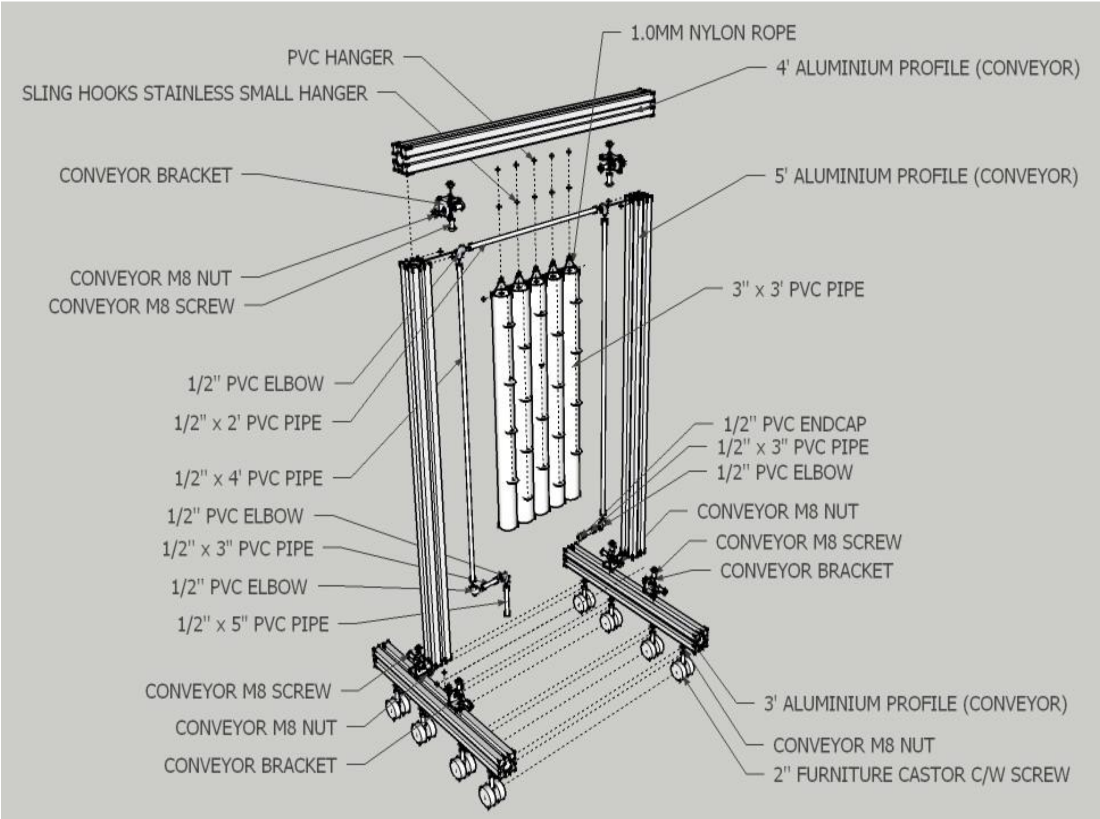

Figure 4.2: Design B (Aluminium) Components

4.2.2.1 Design Opportunities of T-slotted Aluminium Frame

The modular and flexible nature of the T-slotted Aluminium frame provides various design opportunities. The components can be connected in different combinations to create a variety of joints. The connection system makes it very easy to build simple aluminium frame structure. By adding extra T-slotted aluminium extrusion, the framing can be covered with different roofing materials of temporary or permanent nature. Aluminium extrusions will be easy to use in assembling as it is lightweight and is also a durable material. The brackets and fasteners that is used to joint aluminium extrusions are easy to assemble. The concave surface of aluminium extrusions makes it a versatile joint that is suitable for all screw items. It is easy and quick to construct by using only a spanner or a hex key. No special tools or process is required to construct the structure frame.

4.2.3 Design C (PVC)

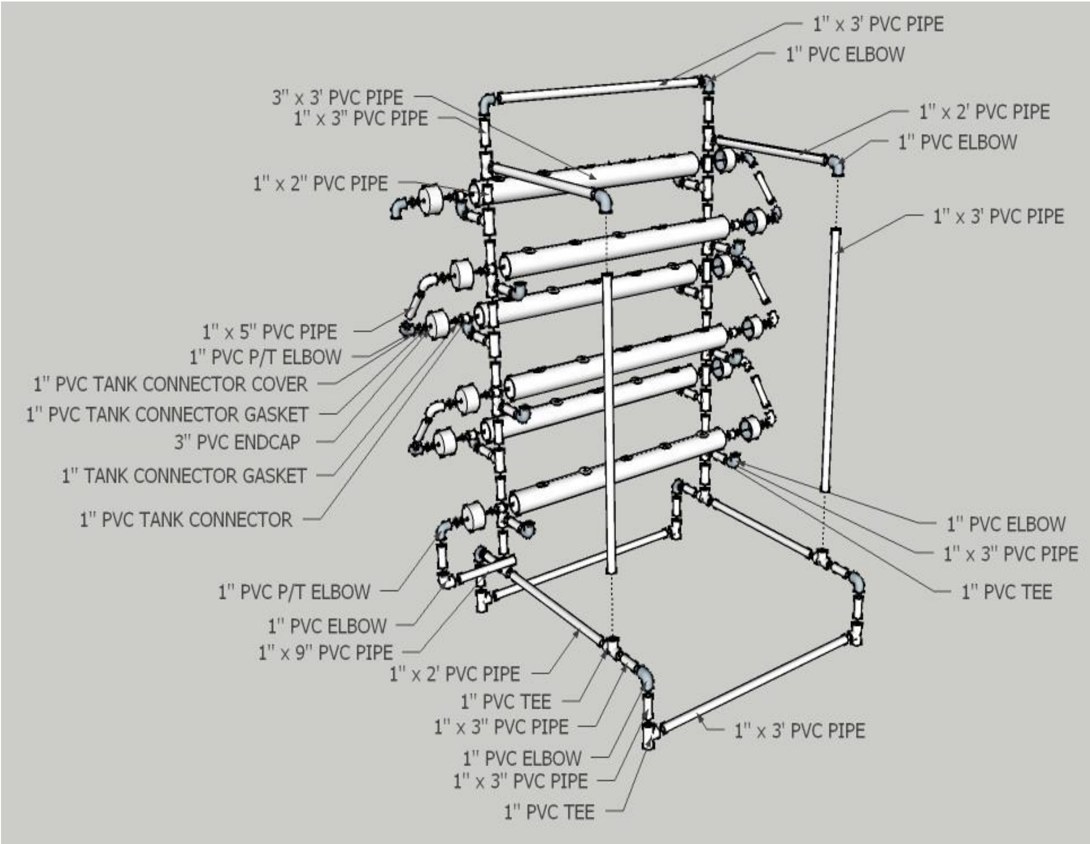

Figure 4.3: Design C (PVC) Components

4.2.3.1 Modular Properties of PVC Support Frame

The support frame is constructed by using 1'' PVC pipe, 1'' PVC elbow and 1'' PVC tee. PVC is used to construct the frame because of their modular properties. PVC components are easy to fit together and eases sizing. All 1'' PVC pipes that used for support frame are joined by using 1'' PVC elbow and PVC tee. The PVC support frame uses (5) 3ft x 1'' PVC pipe and (4) 2ft x 1'' PVC pipe to provide stability for the whole structure. The PVC support frame is not glued for ease of disassembly purpose.

4.3 Discussion on Findings

Table 4.1 shows that there are 18 sets of data collected (with instruction manual and without instruction manual) to determine which prototypes is the most user-friendly for the users. This table generates the learning curve graph which can be used to prove that which prototypes are able to meet the user-friendly criteria. Based on the students' performance in assembling prototypes and experience measures, the user friendly criteria is analysed by using time difference in percentage to determine their percentage of improvement in assembling prototypes without instruction manual and with instruction manual.

Table 4.1: Assembly Performance Evaluation

		Time (min)						Time Difference (%)		
		Without Instruction Manual			With Instruction Manual					
Prototypes	Attempts / No. of students per group	1st	2nd	3rd	1st	2nd	3rd	1st	2nd	3rd
Design A (Bamboo)	2 person	40	37	39	36	34	35	+11.1	+8.8	+11.4
	3 person	38	36	35	35	32	31	+8.6	+12.5	+12.9
	4 person	30	31	29	25	27	26	+20.0	+14.8	+11.5
Design B (Aluminium)	2 person	35	26	21	28	23	19	+25.0	+13.0	+10.5
	3 person	32	23	19	25	20	17	+28.0	+15.0	+11.8
	4 person	28	20	17	22	17	15	+27.3	+17.6	+13.3
Design C (PVC)	2 person	57	39	34	42	35	32	+35.7	+11.4	+6.3
	3 person	55	37	31	40	31	29	+37.5	+19.4	+6.9
	4 person	52	34	28	36	27	25	+44.4	+25.9	+12.0

The result shows time difference of Bamboo prototype is improved by 11.1% in first attempt with instruction manual for 2 person per group, while this prototype shows the smallest improvement at 8.6% in the first attempt for 3 person per group, which means that the students are able to assemble these prototypes although the instruction manual is not provided. The reason is due to fewer parts that can be used in this design. The students are able to figure out which parts to be assembled first in assembling process. Furthermore, the Bamboo prototype is a little design and it is straight forward. The presence of instruction manual does not affect much the assembling process. Conversely, PVC prototype is improved by 35.7% in first attempt for 2 person per group. There is a large difference between these two designs in terms of time. The students require much longer time to assemble the PVC prototype if the instruction manual is not provided, which means that instruction manual plays a significant role in completing the assembling process. The reason is that the number of parts of PVC prototype is more than Bamboo prototype. Aluminium prototype stands in between Bamboo and PVC prototypes. This is because the number of parts used is more than Bamboo prototypes and less than PVC prototypes. When there are more parts used in designing, more time is required to complete it.

Table 4.2: Time Difference by Increasing the Number of Students

			Time (min)			Percentage (%)	
	Prototypes	**No. of students per group / Attempts**	**2 person**	**3 person**	**4 person**	**Difference between 2 person and 3 person**	**Difference between 3 person and 4 person**
Without Instruction Manual	**Design A (Bamboo)**	**1st**	40	38	30	+5.3	+26.7
		2nd	37	36	31	+2.8	+16.1
		3rd	39	35	29	+11.4	+20.7
	Design B (Aluminium)	**1st**	35	32	28	+9.4	+14.3
		2nd	26	23	20	+13.0	+15.0
		3rd	21	19	17	+10.5	+11.8
	Design C (PVC)	**1st**	57	55	52	+3.6	+5.8
		2nd	39	37	34	+5.4	+8.8
		3rd	34	31	28	+9.7	+10.7
With Instruction Manual	**Design A (Bamboo)**	**1st**	36	35	25	+2.9	+40.0
		2nd	34	32	27	+6.3	+18.5
		3rd	35	31	26	+12.9	+19.2
	Design B (Aluminium)	**1st**	28	25	22	+12.0	+13.6
		2nd	23	20	17	+15.0	+17.6
		3rd	19	17	15	+11.8	+13.3
	Design C (PVC)	**1st**	42	40	36	+5.0	+11.1
		2nd	35	31	27	+12.9	+14.8
		3rd	32	29	25	+10.3	+16.0

Table 4.2 shows the time difference by increasing the number of students in assembling the prototypes. The result shows an improvement of time used in assembling the prototypes by increasing the number of students. This shows that the improvement of time to complete for Bamboo prototype is not so effective by increasing the number of students from 2 people to 3 people. However, the completion time can be sharply reduced by increasing the number of students to 4 people per group, which means that the Bamboo prototype requires even number of

people which is either 2 or 4 to assemble this prototype. This is because the design of the bamboo frame requires one to hold on a part of it while the other assembles it. The time improvement in assembling Aluminium and PVC prototypes is improved consistently by increasing the number of students. Therefore, the completion time in assembling Aluminium and Bamboo prototypes may improved by increasing the number of students to 5 people and above. However, there is a limit of how many students should be used to assemble the prototypes.

Figure 4.4 shows comparison learning curve of aluminium and bamboo.

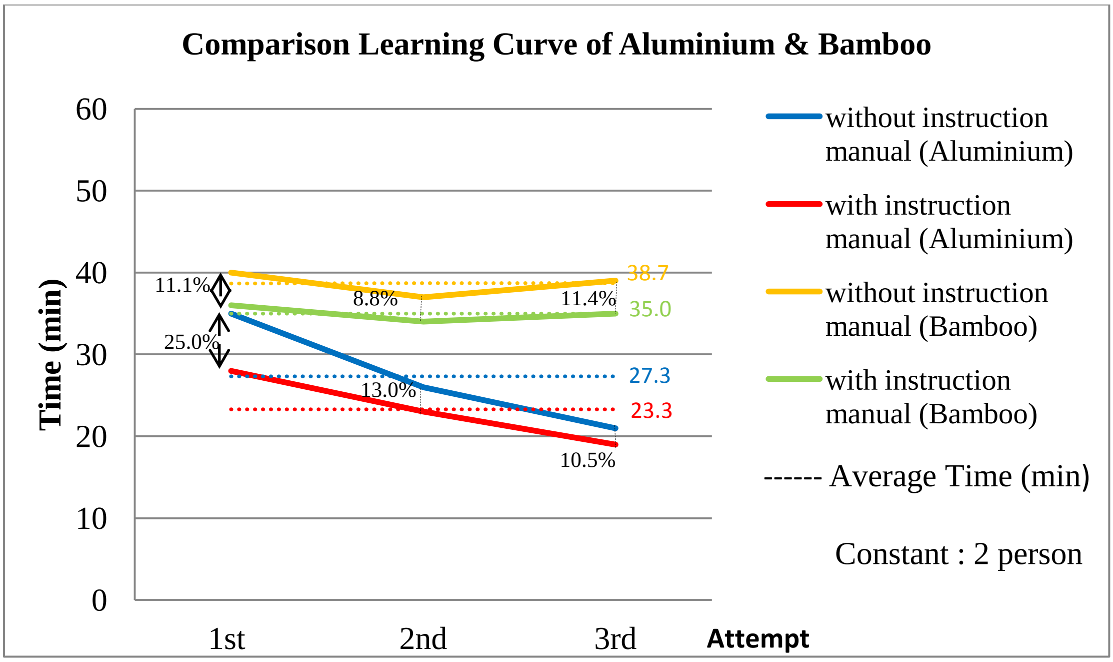

Figure 4.4: Comparison Learning Curve of Aluminium and Bamboo (2 person)

Figure 4.4 shows the comparison learning curve of Aluminium prototype and Bamboo prototype. Bamboo prototype is ranked as second prototype that requires longer time to assemble. This may due to the natural properties of bamboos and some technical problems faced. One reason why natural properties had contributed to the longer time spent in assembling is because a drilled hole on the face of a bamboo will shrink over time due to the lost of moisture in the bamboo. This will then lead to technical problems because drilling across the bamboo results the holes from both sides are not equal in position to each other, thus the threaded bar will unable to pass through equally from both sides and thus making assembling process difficult.

Figure 4.5 shows comparison learning curve of aluminium and PVC.

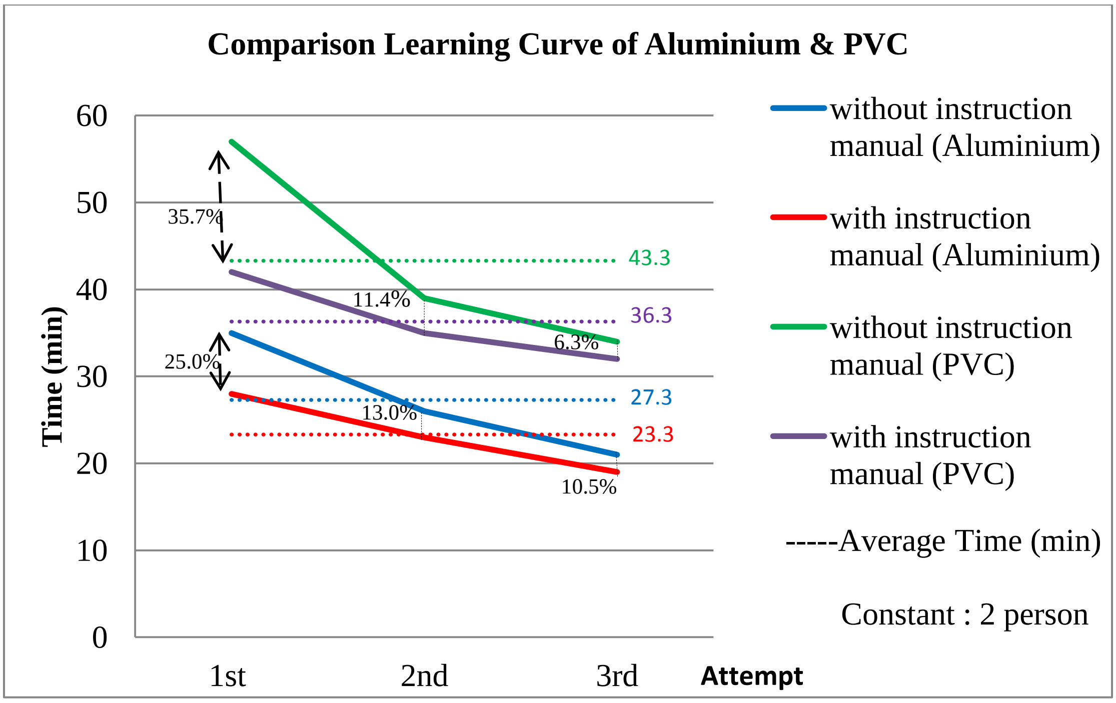

Figure 4.5: Comparison Learning Curve of Aluminium and PVC (2 person)

Figure 4.5 shows that PVC prototype has to use longer time to assemble by comparing to other prototypes. This is because PVC prototype has a larger number of parts. Therefore, the students faced difficulties to figure out which parts should be assembled first as this prototype has many designs and it is too complex to assemble. The students took the shortest time to complete in assembling Aluminium prototype as the design is not overly complex and the number of components is lesser than the other prototypes. A few joints are required for this design as the grow tower is hanged by using a roller hanger. There is a huge difference when compared to PVC prototype as the horizontal grow pipe requires high number of joint, such as the joints of the end caps and tank connectors. High number of joints in prototypes may confuse the students in assembling process. Furthermore, by reducing the number of joints and simplifying the design, the students may locate the components easily.

Table 4.3: Improvement of Students’ Performance by Increasing the Number of Repetitions

			Time (min)			Improvement of students’ performance in Percentage (%)	
	Prototypes	Attempts / No. of students per group	1st	2nd	3rd	Difference between 1st attempt and 2nd attempt	Difference between 2nd attempt and 3rd attempt
Without Instruction Manual	Design A (Bamboo)	2 person	40	37	39	+8.1	-5.1
		3 person	38	36	35	+5.6	+2.9
		4 person	30	31	29	-3.2	+6.9
	Design B (Aluminium)	2 person	35	26	21	+34.6	+23.8
		3 person	32	23	19	+39.1	+21.1
		4 person	28	20	17	+40.0	+17.6
	Design C (PVC)	2 person	57	39	34	+46.2	+14.7
		3 person	55	37	31	+48.6	+19.4
		4 person	52	34	28	+52.9	+21.4
With Instruction Manual	Design A (Bamboo)	2 person	36	34	35	+5.9	-2.9
		3 person	35	32	31	+9.4	+3.2
		4 person	25	27	26	-7.4	+3.8
	Design B (Aluminium)	2 person	28	23	19	+21.7	+21.1
		3 person	25	20	17	+25.0	+17.6
		4 person	22	17	15	+29.4	+13.3
	Design C (PVC)	2 person	42	35	32	+20.0	+9.4
		3 person	40	31	29	+29.0	+6.9
		4 person	36	27	25	+33.3	+8.0

Table 4.3 shows the percentage of improvement of students’ performance over time by repeating the operation in assembling the prototypes. The result shows improvements over number of repetition in assembling the Aluminium and PVC prototypes; however the time improvement of Bamboo prototype shows up and down lines, which means that the students faced difficulty in assembling this prototype. The connections of bamboo poles with threaded bar is the main difficulty in assembling process as shown in Figure 4.6.

Figure 4.6: Difficulties Faced when Assembling the Bamboo Frame

Figure 4.7 shows comparison learning curve of Aluminium and PVC.

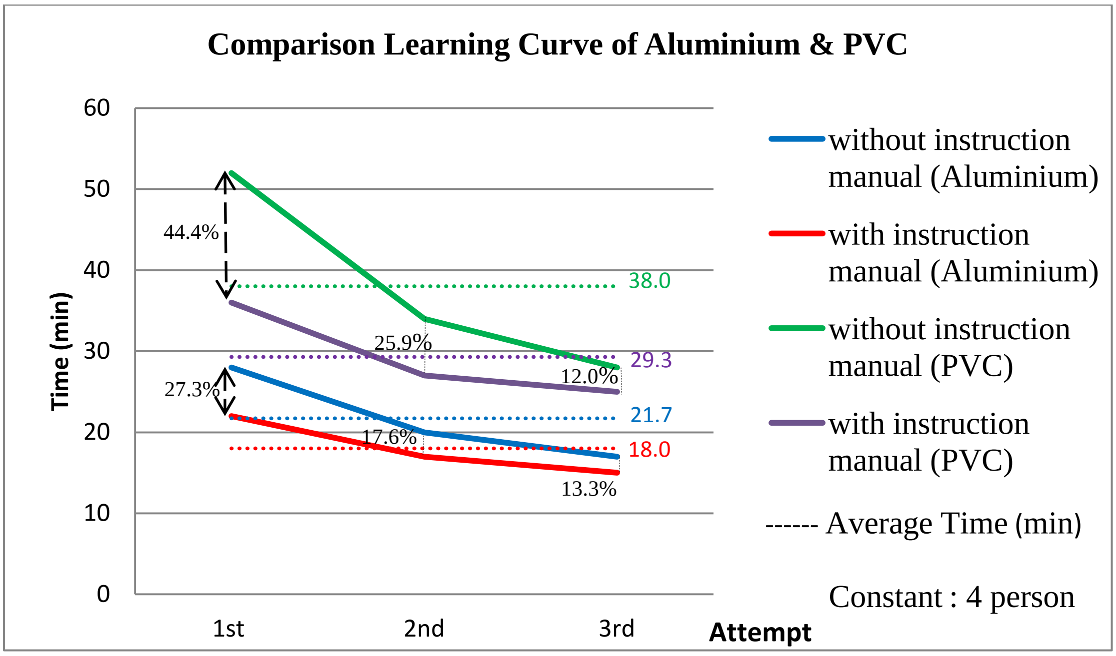

Figure 4.7: Comparison Learning Curve of Aluminium and PVC (4 person)

In Figure 4.7, it can be seen that the assembling process whether the used of instruction manual is present or not for PVC prototype shows a steep learning curve, which means that it takes lots of time and efforts to assemble but it is easy to learn because there is an increase in the number of repetition. However, Aluminium prototype shows shallow learning curve, which means that the students learned a lot while putting relatively little effort in assembling it. Although Aluminium prototype and PVC prototype are different in terms of efforts needed to assemble, both prototypes show that there is a learning improvement from students when there is an increase in the number of repetitions. Therefore, both prototypes are reliable products and these will not cause undue frustration for the users.

Figure 4.8 shows comparison learning curve of Aluminium and Bamboo.

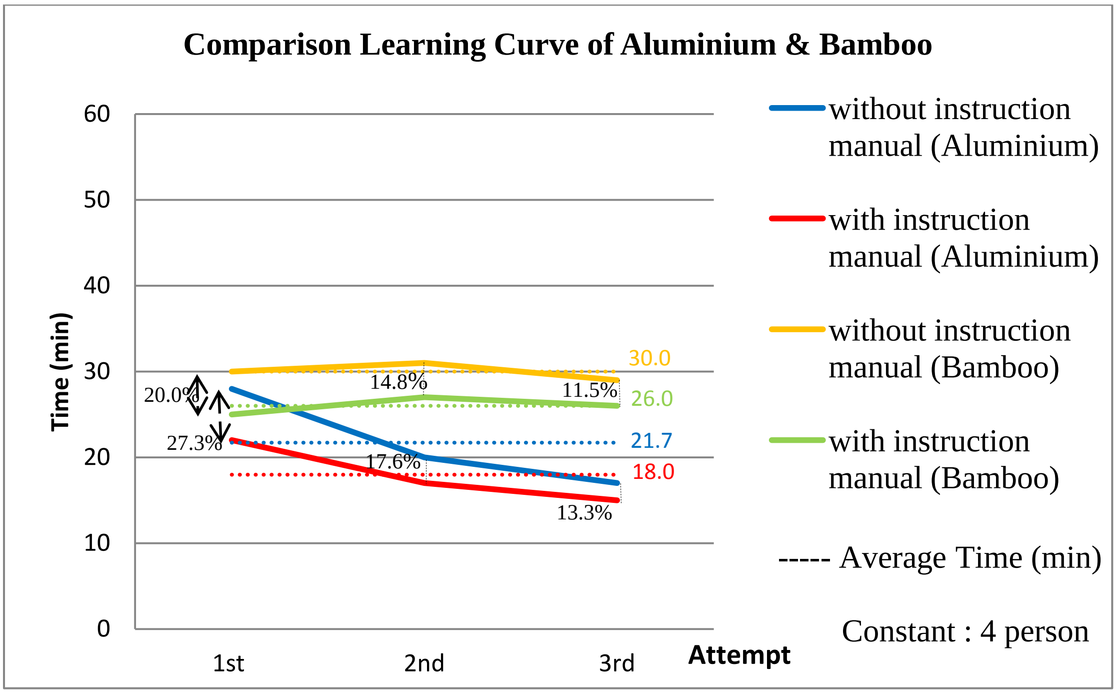

Figure 4.8: Comparison Learning Curve of Aluminium and Bamboo (4 person)

Conversely, in Figure 4.8, it can be seen that the assembling process whether the used of instruction manual is present or not for Bamboo prototype shows shallow up and down learning curve, which means that it takes little effort to assemble but it is difficult to learn because the bamboo holes from both sides are not equal in position to each other, thus threaded bar will be difficult to pass through equally from both sides. Hence, it will cause undue frustration for the users and it is an unreliable product.

Figure 4.9 shows comparison learning curve of aluminium and bamboo

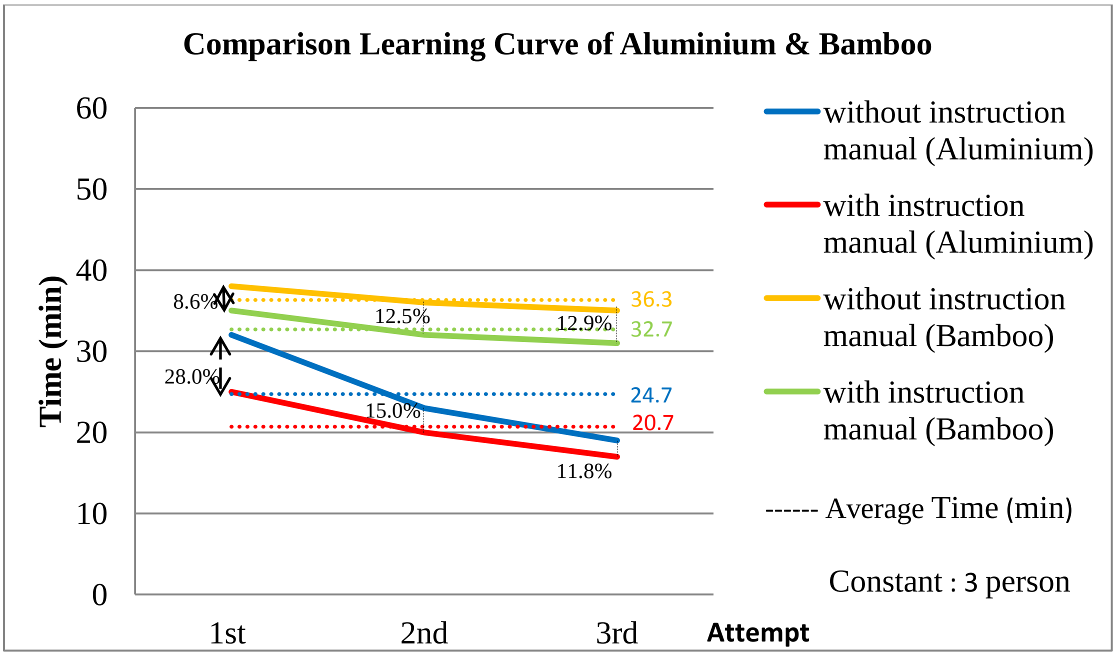

Figure 4.9: Comparison Learning Curve of Aluminium and Bamboo (3 person)

Figure 4.10 shows comparison learning curve of aluminium and PVC.

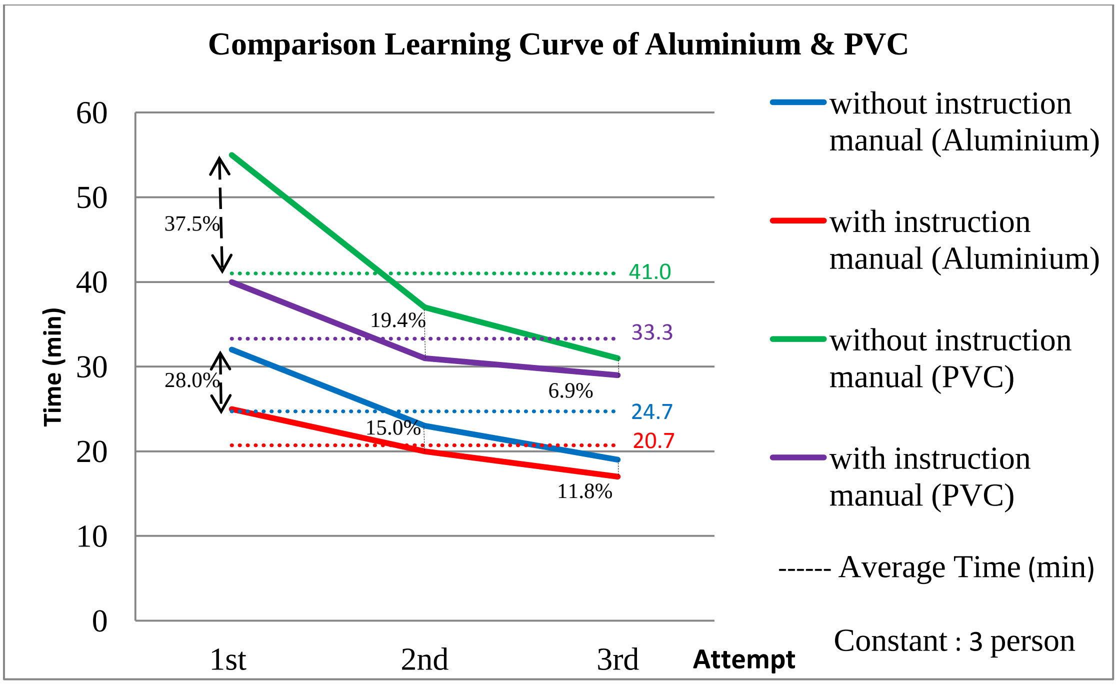

Figure 4.10: Comparison Learning Curve of Aluminium and PVC (3 person)

Figure 4.9 and Figure 4.10 shows the learning curve of students' performance in assembling three different prototypes without instruction manual and with instruction manual. It can be observe that the assembling process whether the used of instruction manual is present or not for PVC prototype shows a significant difference in terms of percentage of time (37.5%) compare to the Bamboo prototype (8.6%). This shows that the use of instruction manual in assembling PVC prototype is important because it reduces the efforts needed to think of how to conduct the assembling process, while the use of instruction manual is not necessarily required when assembling the Bamboo prototype. However, for the Aluminium prototype, although there is a different of 28.0% whether the use of instruction manual is present or not, based on both figures it does not show much diverging as similar to Bamboo prototype which compare to the PVC prototype that has a significant large diverging lines, hence it can also be assumed that the use of instruction manual is not necessarily needed as similar to the Bamboo prototype.

Table 4.4: Intuitive Product Design Evaluation

			Time (min)								
			Without Instruction Manual			With Instruction Manual			Without Instruction Manual	With Instruction Manual	The difference of average completion time to assemble
Prototypes	Frequency to inquire	Attempt / No. of Students per group	1st	2nd	3rd	1st	2nd	3rd	Average Time of Completion to assemble	Average Time of Completion to assemble	
Aluminium	0	2 person	35	26	21	28	23	19	27.3	23.3	4
Bamboo	1	2 person	40	37	39	36	34	35	38.7	35.0	4
PVC	2	2 person	57	39	34	42	35	32	43.3	36.3	7
Aluminium	0	3 person	32	23	19	25	20	17	24.7	20.7	4
Bamboo	1	3 person	38	36	35	35	32	31	36.3	32.7	4
PVC	1	3 person	55	37	31	40	31	29	41.0	33.3	8
Aluminium	0	4 person	28	20	17	22	17	15	21.7	18.0	4
Bamboo	1	4 person	30	31	29	25	27	26	30.0	26.0	4
PVC	1	4 person	52	34	28	36	27	25	38.0	29.3	9
			*The difference of average completion time for Aluminium act as an indicator to prove intuitive design as the frequency to inquire in assembling process is 0.								

The average time of completion to assemble the three different prototypes with instruction manual and without instruction manual are shown in Table 4.4. By referring the frequency of students to inquire in assembling process and the difference of average time completion to assemble the prototypes with instruction manual and without instruction manual, this proves that which prototypes is an intuitive design. Aluminium prototype is the only prototype that does not require inquiry from students in the assembling process. Therefore, the difference of average time completion to assemble the Aluminium prototype without instruction manual and with instruction manual act as an indicator for these three prototypes to prove which prototypes are intuitive design. The result shows that difference of average time completion to assemble Bamboo prototype without instruction manual and with instruction manual is similar to Aluminium prototype which is 4 minutes, which means that these two prototypes are intuitive design. Conversely, the students have to spend more time to assemble the PVC prototype if the instruction manual is not provided as shown in Table 4.4. The difference of average time completion to assemble PVC prototype without instruction manual and with instruction manual is 7 minutes, 8 minutes and 9 minutes respectively by increasing the number of students.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Introduction

Upon completing the research, two objectives and aims have been achieved. The objectives include designing three vertical aquaponic systems with varying materials and collect the user feedback from Westlake International School student on the user-friendliness of aquaponic systems.

For the first objective, the aquaponic systems were designed by three different materials, which is PVC, aluminium and bamboo. Secondly, the user feedback on user-friendliness of aquaponic system was presented by using the completion time recorded in video recording to analyse which aquaponic designs is the best in fitting the user friendly criteria.

5.2 Recommendations for Future Research

In this research, three vertical aquaponic systems were designed and the user-friendliness of these designs was discussed. However, further studies can still be carried out. The following is the suggested studies:

(a) To collect the user feedback on user-friendliness of aquaponic designs by increasing the number of person per group to 5 and above.

(b) To collect the user feedback on user-friendliness of aquaponic designs by changing types of respondents from students to adults.

(c) To identify what types of plants and fish is suitable for these vertical aquaponic systems.

(d) To compare growth times and production of plants for each vertical aquaponic designs.

5.3 Research Limitations

Although the research has reached its objectives, there are some unavoidable limitations. Due to time and cost constraints, the time of pre-fabrication cannot be recorded. Therefore, to include more details regarding the topic selected, the study should be given a longer time frame.

5.4 Conclusion

Design B (Aluminium) is the best design because it achieves all user-friendly criteria of products as shown in Table 5.1. The design is not complex and only little number components are required. The achieve parameter of aluminium design was shown in Table 5.2.

Table 5.1: User-friendliness Criteria of Products

Criteria / Design	Simple	Intuitive	Reliable
Design A (Bamboo)	✓	✓	
Design B (Aluminium)	✓	✓	✓
Design C (PVC)			✓

In terms of simple, the achieved parameters of Design B (Aluminium) are time assembled is just 15 minutes in group of 4 and the design must be not more than 79 components. In terms of intuitive, Design B (Aluminium) received zero inquiries from students in assembling process. The time difference (percentage) to assemble prototypes with and without instruction manual should not be more than 28% in the first attempt. In terms of reliable, the achieved parameters are the design’s learning curve has improved by 5 minutes and above from first attempt to second attempt indicate of shallow learning curve.

In short, principles learnt in this research is that light materials do not automatically translate to ease of assembly. It also depends on connection design where standardize dimension are critical. Minimize the number of components in design is better as it makes the users easy to figure out which parts to be assembled first in assembling process. Although there is an improvement of time used in assembling process by increasing the manpower but more manpower does not mean the assembling process will be easier as there is a limit of how many manpower should be used to assemble the prototypes.

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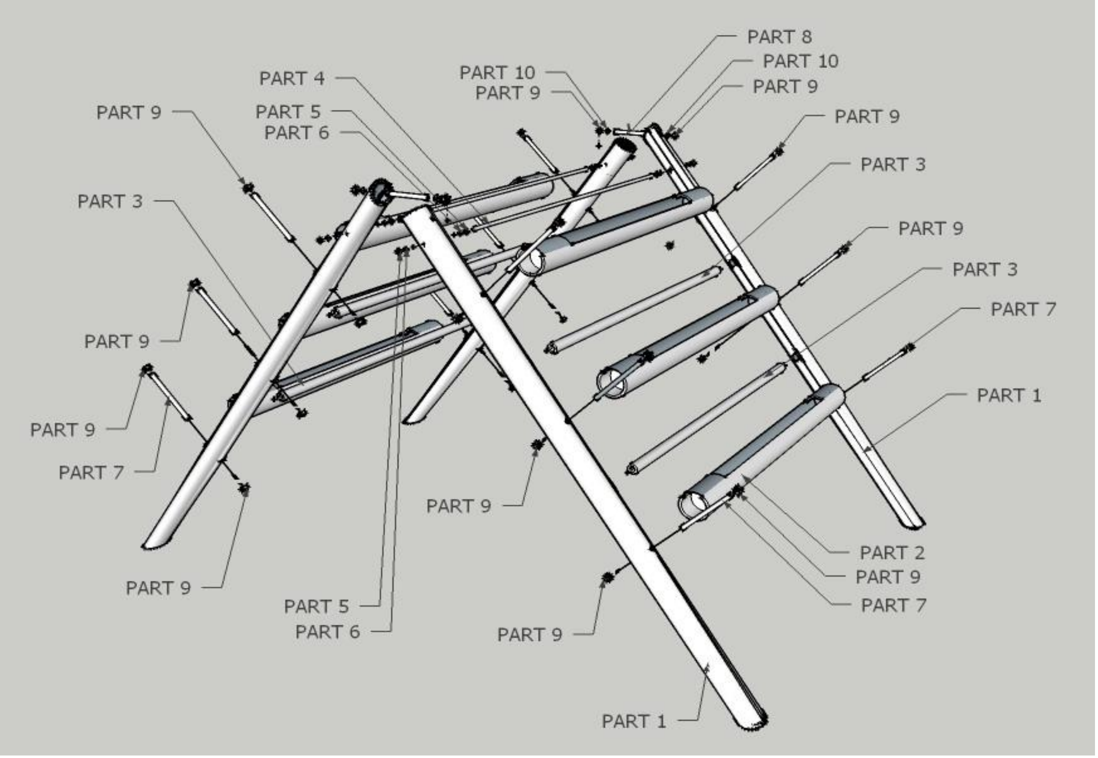
APPENDICES

APPENDIX A: Sample of Assembly Instruction Manuals

Assembly instruction manuals consisted of Section A (Instruction Manual Drawing) and Section B (Instruction Manual with words).

Section B

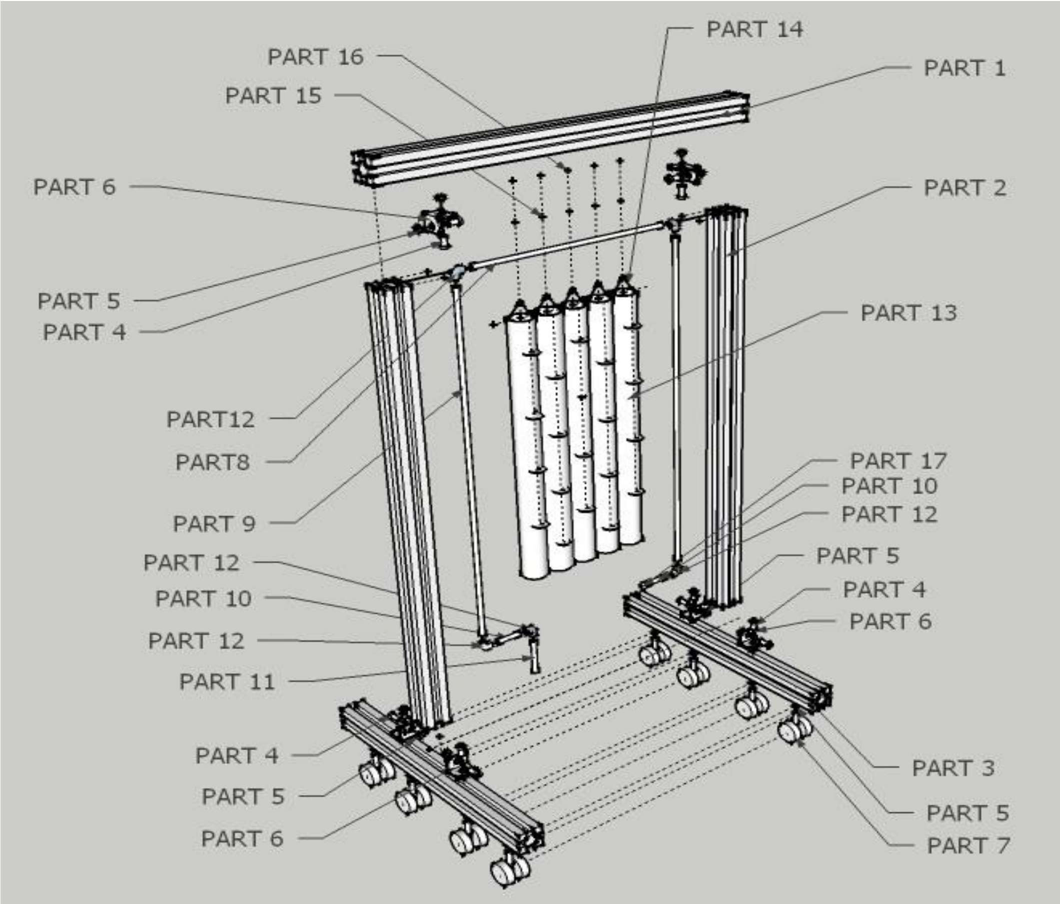


Design A (Bamboo) Parts List

System assembly instruction

- Insert the 4inch length threaded bar M8.0 (Part 8) into the hole of (2) 4ft length bamboo poles (Part 1) and screw tightly with M8.0 hex nuts (Part 9).
- Repeat the following steps to another side of bamboo support frame.
- Pre-assemble by insert the (2) hex nuts M6.0 (Part 5) into both end of (2) 3ft threaded bars M6.0 (Part 4).
- Insert (2) 3ft threaded bars M6.0 (Part 4) into the both side of bamboo holes to make the connection between 4ft length bamboo poles (Part 1) for temporary support.
- Insert (4) 1'' diameter bamboo sticks into the bamboo holes for further support.
- Adjust the size and length of bamboo frame correctly, then screw tightly with (2) M6.0 hex nuts (Part 5).

- Insert (12) 6inch M8.0 threaded bars (Part 7) into the holes of (4) 4ft length bamboo poles (Part 1) to prop up (6) 3'' diameter bamboo poles (Part 2).
- Placed (6) 3''diameter bamboo poles act as plant grow bed (Part 2) on M8.0 threaded bar (Part 7).



Design B (Aluminium) Parts List

System assembly instruction

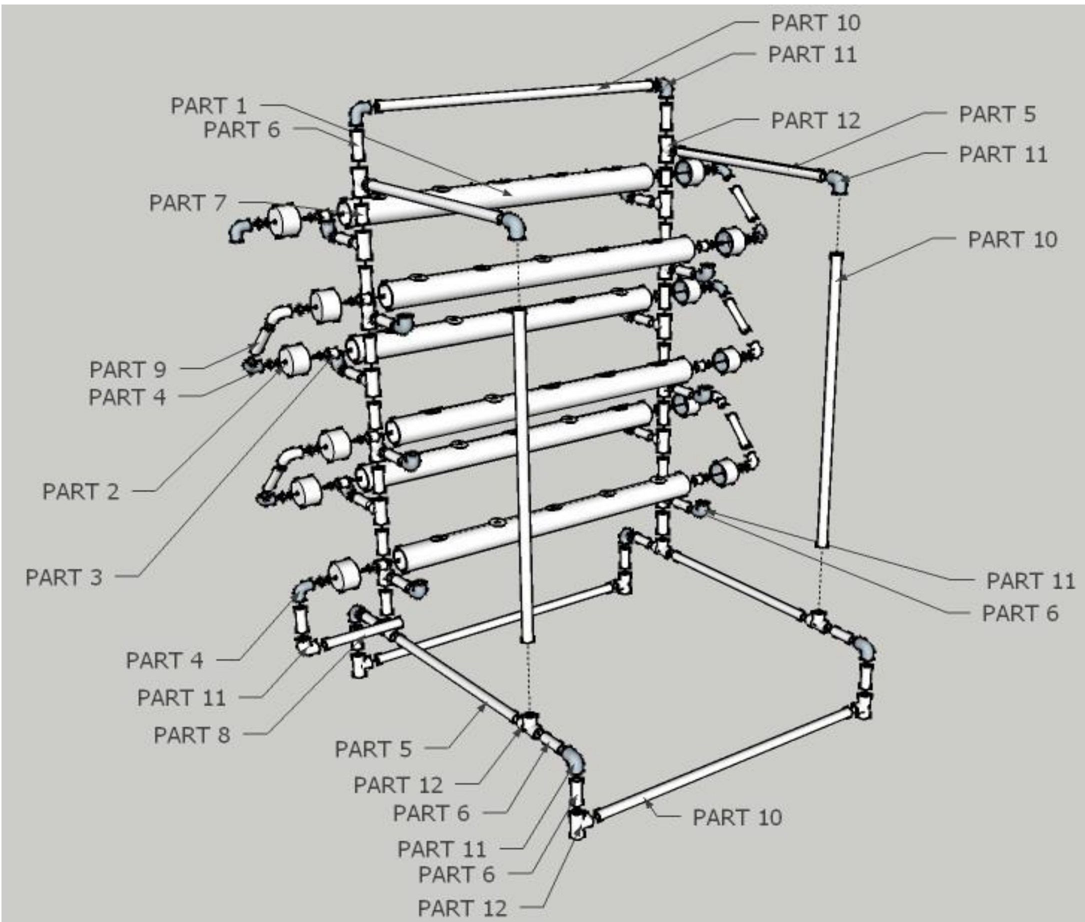
Base of Castor Screw

- Pre-assemble by screwing the (8) castors (Part 7) into the (8) hex nuts (Part 5). (Do not tighten it fully)
- Slide (4) castors (Part 7) into the 3ft T-slots aluminium profile (Part 3).

- Repeat the following steps to another side of support frame.
- Using a spanner, tighten all the castor screws until the connection is secure.

Joining Brackets

- Joining brackets require three main components that are joining bracket (Part 6), screws (Part 4) and hex nuts (Part 5).
- Pre-assemble by placing the screws through the bracket holes and screw into the hex nuts.
- Slide two joining brackets into the front and behind of 3ft T-slots aluminium profile (Part 3). (Do not tighten it fully)
- Slide 5ft T-slots aluminium profile (Part 2) onto the joining bracket; square and align both profiles.
- Using a hex key, tighten all the screws until the connection is secure.
- Repeat the following steps to another side of support frame.
- Slide the PVC roller curtain hook (Part 16) into the concave surface of 4ft aluminium profile (Part 1).
- Slide two joining brackets into 4ft aluminium profile in opposite directions. (Do not fully tighten)
- Slide 2 set of 5ft T-slots aluminium frame profile (Part 2) into the joining brackets of 4ft aluminium profile (Part 1); square and align both profiles.
- Using a hex key to tight all the screws until the connection is secured.
- The T-slotted Aluminium support frame is formed.



Design C (PVC) Parts List

System assembly instruction

Support Frame – Bottom

Part 11 and Part 12 are 1’’ PVC elbow and tee. Require (8) PVC tee and (4) PVC elbow joint the 1’’ PVC pipe to complete the support base.

- Fit (2) 1’’ pipe (Part 10) into the (4) 1’’ PVC tee (Part 12) with opening on the top.
- Fit (4) small 1’’ pipe (Part 6) into the top of (4) PVC tee (Part 12).
- Fit (4) small 1’’ pipe (Part 6) into (4) PVC elbow (Part 11).
- Fit (4) small 1’’ pipe (Part 6) into (4) PVC elbow (Part 11).
- Fit (4) small 1’’ pipe (Part 6) into (4) PVC tee (Part 12) with side opening.
- Fit (2) 1’’ pipe (Part 5) into the (4) PVC tee (Part 12).

Support Frame – Top

Require (14) PVC tee and (18) PVC elbow joint 1’’ pipe to complete the vertical support frame.

- Fit (3) small 1’’ pipe (Part 6) into PVC tee (Part 12).
- Fit small 1’’ pipe (Part 6) into PVC elbow (Part 11).
- Repeat the steps 7 times; the vertical support frame is then formed.
- On the top of vertical frame, used the PVC elbow (Part 11) to fit the 1’’ pipe (Part 10) for the stability purpose.
- Fit 1’’ pipe (Part 5) into PVC tee (Part 12) - top of vertical frame.
- Fit 1’’ pipe (Part 10) into PVC tee (Part 12) - bottom of frame.
- Use PVC elbow (Part 11) as joint to connect 1’’ pipe (Part 5) and 1’’ pipe (Part 10) to increase the stability of vertical frame to prevent it from collapsing.

Horizontal Grow Pipe

- Fit 1’’ tank connectors (Part 3) into the centre hole of end caps (Part 2) and screw it tightly with PVC tack connector covers.
- Fit 1’’ PVC P/T elbow (Part 4) into 1’’ PVC tank connector (Part 3).
- Fit (12) 3’’ end caps (Part 2) into both end of (6) 3’’ PVC pipe (Part 1).

APPENDIX B: Parts List and Designs Cost for Aquaponic Systems

Parts List and Designs Cost consisted of Section A (Design A), Section B (Design B) and Section C (Design C).

Section A

Vertical Aquaponic System Design A (Bamboo)					
Part	**Item**	**Unit**	**Quantity**	**Rate (RM)**	**Amount (RM)**
1	4’ x 3’’ diameter bamboo poles	Nr	4	8.00	32.00
2	3’ x 3’’ diameter bamboo poles	Nr	6	6.00	36.00
3	3’ x 1’’ diameter bamboo sticks	Nr	4	1.00	4.00
4	Threaded bar M6.0 x 3’	Nr	2	7.00	14.00
5	Hex nut M6.0	Nr	8	0.10	0.80
6	Flat washer M6.0	Nr	8	0.05	0.40
7	Threaded bar M8.0 x 6’’	Nr	12	1.50	18.00
8	Threaded bar M8.0 x 4’’	Nr	2	1.00	2.00
9	Hex nut M8.0	Nr	28	0.15	4.20
10	Flat washer M8.0	Nr	4	0.05	0.20
Total number of components			**78**	***Parts that used in assembling process**	
-	8’ x 5/8’’ diameter crystal hose	Nr	1	6.10	6.10
-	½’’ PVC socket	Nr	2	0.40	0.80
-	1’ x ½’’ diameter PVC pipe	Nr	1	0.60	0.60
-	PH-PG3500 submersible water pump	Nr	1	98.00	98.00
-	36’’ x 24’’ x 12’’ fibreglass fish tank	Nr	1	110.00	110.00
-	4’’ x ¼’’ crystal tube	Nr	12	0.40	4.80
-	¼’’ water tube compression fittings	Nr	12	5.25	63.00
-	Plastic spray jet	Nr	7	0.80	5.60
-	1’’ LD PVC ball valve	Nr	1	6.10	6.10
-	1’’ PVC tank connector	Nr	2	2.50	5.00
-	3’’ x 1’’ diameter PVC pipe	Nr	2	0.25	0.50
Total material cost					**412.10**
-	Hammer	Nr	1	20.00	20.00
-	M8 Spanner	Nr	1	6.00	6.00
-	Hacksaw	Nr	1	35.00	35.00
-	Power drill	Nr	1	70.00	70.00
Total equipment cost					**131.00**
Total material & equipment cost					**543.10**

Section B

Vertical Aquaponic System Design B (Aluminium)					
Part	**Item**	**Unit**	**Quantity**	**Rate (RM)**	**Amount (RM)**
1	4’ Aluminium profile (conveyor)	Nr	1	41.00	41.00
2	5’ Aluminium profile (conveyor)	Nr	2	51.25	102.50
3	3’ Aluminium profile (conveyor)	Nr	2	30.75	61.50
4	Conveyor M8 screw	Nr	12	1.15	13.80
5	Conveyor M8 nut	Nr	20	0.20	4.00
6	Conveyor bracket	Nr	6	9.00	54.00
7	2’’ furniture castor C/W screw	Nr	8	2.65	21.20
8	2’ x ½’’ diameter PVC pipe	Nr	1	1.20	1.20
9	4’ x ½’’ diameter PVC pipe	Nr	2	2.40	4.80
10	3’’ x ½’’ diameter PVC pipe	Nr	2	0.15	0.30
11	5’’ x ½’’ diameter PVC pipe	Nr	1	0.25	0.25
12	½’’ PVC elbow	Nr	5	0.45	2.25
13	3’ x 3’’ diameter PVC pipe	Nr	5	5.00	25.00
14	1.0mm Nylon rope	Roll	1	7.40	7.40
15	Sling hooks stainless small hanger	Nr	5	1.00	5.00
16	PVC hanger	Nr	5	0.40	2.00
17	½’’ PVC end cap	Nr	1	0.35	0.35
Total number of components			**79**	***Parts that used in assembling process**	
-	2’’ diameter net pot	Nr	65	0.20	13.00
-	36’’ x 24’’ x 12’’ fibreglass fish tank	Nr	1	110.00	110.00
-	PH-PG3500 submersible water pump	Nr	1	98.00	98.00
-	1’’ PVC tank connector	Nr	2	2.50	5.00
-	1’’ LD PVC ball valve	Nr	1	6.10	6.10
-	3’’ x 1’’ diameter PVC pipe	Nr	2	0.25	0.50
-	8’’ x ½’’ diameter PVC pipe	Nr	1	0.40	0.40
-	½’’ PVC socket	Nr	1	0.40	0.40
Total material cost					**579.95**
-	Fire bird torch	Nr	1	40.00	40.00
-	Gas cartridges	Nr	2	6.50	13.00
-	M8 Hex key	Nr	1	4.50	4.50
-	M8 Spanner	Nr	1	6.00	6.00
-	Hacksaw	Nr	1	35.00	35.00
-	PVC hole punch	Nr	1	35.00	35.00
Total equipment cost					**133.50**
Total material & equipment cost					**713.45**

Section C

Vertical Aquaponic System Design C (PVC)					
Part	**Item**	**Unit**	**Quantity**	**Rate (RM)**	**Amount (RM)**
1	3’ x 3’’ diameter PVC pipe	Nr	6	5.00	30.00
2	3’’ diameter PVC end cap	Nr	12	5.00	60.00
3	1’’ diameter PVC tank connector	Nr	14	2.50	35.00
4	1’’ diameter PVC P/T elbow	Nr	12	2.00	24.00
5	2’ x 1’’ diameter PVC pipe	Nr	4	2.00	8.00
6	3’’ x 1’’ diameter PVC pipe	Nr	34	0.25	8.50
7	2’’ x 1’’ diameter PVC pipe	Nr	2	0.15	0.30
8	9’’ x 1’’ diameter PVC pipe	Nr	1	0.75	0.75
9	5’’ x 1’’ diameter PVC pipe	Nr	5	0.40	2.00
10	3’ x 1’’ diameter PVC pipe	Nr	5	3.00	15.00
11	1’’ diameter PVC elbow	Nr	20	0.90	18.00
12	1’’ diameter PVC tee	Nr	22	1.30	28.60
Total number of components			**137**	***Parts that used in assembling process**	
-	2’’ diameter net pot	Nr	42	0.20	8.40
-	PH-PG3500 submersible water pump	Nr	1	98.00	98.00
-	36’’ x 24’’ x 12’’ fibreglass fish tank	Nr	1	110.00	110.00
-	5’ x 5/8’’ diameter crystal hose	Nr	1	3.80	3.80
-	1’’ x ½’’ PVC socket	Nr	2	0.70	1.40
-	½’’ PVC socket	Nr	1	0.40	0.40
-	Fibreglass filter box	Nr	1	60.00	60.00
-	1’ x ½’’ diameter PVC pipe	Nr	1	0.60	0.60
-	1’’ LD PVC ball valve	Nr	1	6.10	6.10
-	3’’ x 1’’ diameter PVC pipe	Nr	2	0.25	0.50
-	Aquarium air pump	Nr	1	30.00	30.00
Total material cost					**549.35**
-	30-120mm Adjustable circle hole cutter	Nr	1	25.40	25.40
-	Hacksaw	Nr	1	35.00	35.00
-	PVC pipe cutter	Nr	1	28.00	28.00
-	Power drill	Nr	1	70.00	70.00
Total equipment cost					**158.40**
Total material & equipment cost					**707.75**

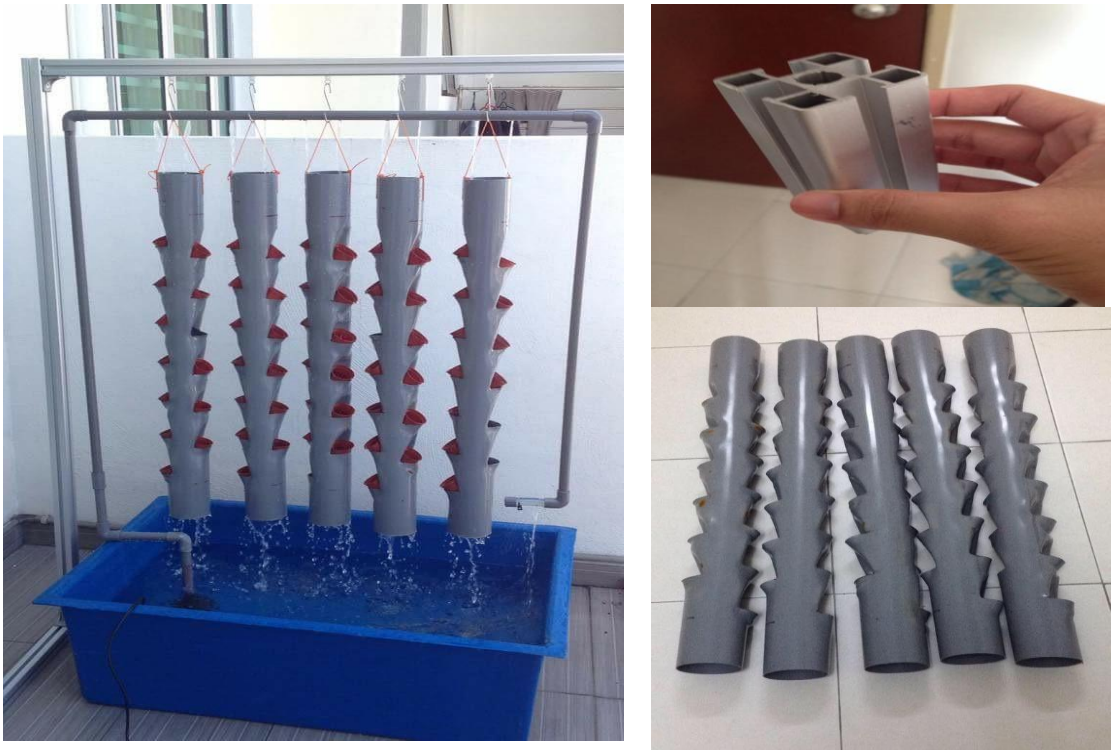
APPENDIX C: Pictures of Aquaponic Designs and Assembly Process

Pictures consist of Section A (Aquaponic Designs) and Section B (Assembly Process)

Section A

Three Vertical Modular Aquaponic Designs

Design A (Bamboo)



Design B (Aluminium)

Design C (PVC)

Section B

Assembly Process for Design A (Bamboo)

Assembly Process for Design B (Aluminium)

Assembly Process for Design C (PVC)

APPENDIX D: Step by step guide to constructing Vertical Grow Tower and Horizontal Grow Pipe from PVC pipe

Appendix D consisted of Section A (Vertical Grow Tower) and Section B (Horizontal Grow Pipe).

Section A

Preparation of the Vertical Grow Tower from PVC pipe (Design B)

1. **Marking the PVC pipe**

- Using hacksaw cut 3’’ diameter PVC pipe to 3ft length.
- Using a measuring tape to make a line vertically on PVC pipe and mark a mainline in every 5’’ starting at 4’’.
- Start at one end of the pipe, draw a square line the full length of the pipe and make a mark perpendicular to the line at 4’’.
- Make a mark every 5’’ perpendicular to the line going the full length of the pipe.

2. **Cutting the holes**

- Clamp the PVC pipe to a solid surface with the mainline facing up.
- Use the hacksaw cut into the pipe at each of your marks that are perpendicular to the mainline.
- Continue up the mainline until the last mark is cut.
- Reposition the pipe so that the offset line is facing up and re-clamp the pipe to a solid surface.
- Repeat steps for the offset line.

3. **Moulding the holes**

- Clamp the tower with one of the sets of cuts facing upwards.
- Starting at the bottom of the tower heat the PVC with the fire torch towards the top and bottom of the PVC pipe and use a quick side to side motion to avoid browning or burning the pipe.
- When the pipe is soft enough to mould, place the fire torch down and insert the wooden dowel to create the proper hole in the PVC pipe.

(The best method to get the dowel into the softened hacksaw cut is to press down on the top side of the cut, then move the dowel under the bottom side of the cut and rotate while pressing in towards the desired whole dimension mark of the dowel. To create the 45 degree angle and press down on the dowel slightly which will pull up on the bottom side of the cut.)

- Place a wet washcloth over the newly formed hole in the tower. Remove the dowel and insert 2'' net pot to ensure a good fit. If it does not fit, dry the area and repeat the steps until find the right size hole for your net pots.

4. Clean up

- Using a burr handle to clean the PVC burrs that were created in the cutting process.
- Sand all sharp corners of the holes.
- Wash grow tower with soft detergent and rinse thoroughly.

Water Supply and Return Cut List

The water supply and return system is constructed by using (6) ½'' PVC pipe, (5) ½'' PVC elbow and (1) ½'' PVC end cap. It is not overly complex and eases of assembly for the user. Water is pumped up through the ½'' pipe (Part 9, 10, 11) and water is supplied to the grow tower through the ½'' PVC pipe (Part 8) that consist drilled holes. The ½'' PVC end cap (Part 17) is connected at the end of water supply system functioned as water pressure adjustor. When the ½'' PVC pipe is closed by the end cap, the water will jet into the grow tower from ½'' PVC pipe holes (Part 8).

- Cut (1) ½ '' PVC pipe at 2ft and drill 10 holes on the pipe in every 2inch - (these are Part 8)
- Cut (2) ½'' PVC pipe at 4ft - (these are Part 9)
- Cut (2) ½'' PVC pipe at 3'' - (these are Part 10)
- Cut (1) ½'' PVC pipe at 5'' - (these are Part 11)

Section B

Preparation of the Horizontal Grow Pipe from PVC pipe (Design C)

1. **Drilling the plant holes on PVC pipe**

- Using measuring tape and marker pen to mark the dot on the 3’’ PVC pipe.
- Begin from the first dot, measure every 8 inches along the pipe and placing dots for each plant hole. Each long pipe should end up with 7 dots. Drilling a hole into each dot with power drill and use adjustable circle cutter cutting out the plant hole that marked on PVC pipe.
- Once all of the holes are cut, take a burr handle to clean the PVC burrs from each hole.

2. **Drilling the holes in centre of PVC end caps**

The drilled hole in centre of the end caps is used to transfer water into grow pipe through combination with tank connector and 1’’ PVC P/T elbow.

- Position the tank connector on the centre of end cap and use marker pen mark the cutting area.
- Clamp the end cap tightly and use power drill and adjustable circle cutter to cut the marked area.
- Take a burr handle to clean the PVC burrs once the hole is cut.

Support Frame Cut List

- Cut (4) 1’’ PVC pipe at 2ft - (these are Part 5)
- Cut (5) 1’’ PVC pipe at 3ft - (these are Part 10)
- Cut (34) 1’’ PVC pipe at 3inch - (these are Part 6)
- Cut (2) 1’’ PVC pipe at 2inch - (these are Part 7)

Water Supply & Return Cut List

- Cut (5) 1’’ PVC pipe at 5 inch - (these are Part 9)
- Cut (1) 1’’ PVC pipe at 9 inch - (these are Part 8)
- Cut (1) 5/8’’ diameter crystal hose at 5ft
- Cut (1) ½’’ PVC pipe at 1ft