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A SUSTAINABLE, ECO-FRIENDLY, AND DISASTER-PROOF DESIGN OF MOBILE BUNKHOUSE FOR CONSTRUCTION INDUSTRY APPLICATION

John Rogel S. Ursua¹, Consorcio S. Namoco Jr.², Ajimar Borlan¹, Rex Galopo¹ and Tobias Antolino Jr.¹

¹University of Antique, Sibalom, Antique, Philippines

²College of Technology, University of Science and Technology of Southern Philippines, Cagayan de Oro City, Philippines

E-Mail: johnrogel.ursua@antiquespride.edu.ph

ABSTRACT

Traditional and temporary bunkhouses are typically constructed of wood and lumber. As a result, the use of trees is maximized. With this, deforestation contributes to climate change. This research aims to create a mobile bunkhouse where the wood will be replaced with eco-friendly, sustainable, lightweight, and durable materials such as Galvanized iron, Steels, Polyvinyl Chloride (PVC), and Acrylic (PolyMethyl MethAcrylate or PMMA), making this study viable. The mobile bunkhouse is equipped with a site office, a restroom, a kitchen, a storage room, and a dormitory-typed bedroom. Moreover, the mobile bunkhouse is 75% more expensive than the temporary bunkhouse. However, the return on investment will be realized within one to two years. With this, the mobile bunkhouse is designed to withstand a maximum wind velocity of 155 kph and a maximum of 1.25m flood level, making it a calamity-proof structure per the National Structural Code of the Philippines (NSCP) 2015 and the National Building Code of the Philippines. Thus, the wheeled structure can be viewed as a long-term solution that can be the best substitute for a conventional and temporary bunkhouse.

Keywords: construction, design, disaster-proof structure, mobile bunkhouse, wind load.

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INTRODUCTION

Bunkhouses are temporary structures that must be demolished once the construction phase is completed. Primarily, it serves as non-transferable temporary shelters on construction sites, particularly as sleeping quarters for workers. These bunkhouses include a shared toilet, bath, and cooking facilities, usually located in an adjacent structure, to prevent fires and improve sanitation standards. On the other hand, some physical wastes generated after demolishing temporary structures are coco lumber, bamboo culms, bamboo strips, plywood, and galvanized iron sheets. As a result, utilizing trees as lumber is maximized, resulting in massive deforestation, which contributes to climate change. It is estimated that deforestation alone accounts for 25% of global greenhouse gas emissions [3]. Furthermore, forests around the world store more than twice as much carbon dioxide as the atmosphere. With this, when forests are cut down, the carbon dioxide stored in them is released into the atmosphere. The Philippines lost more than thirty (30) percent of its forest from 1990 to 2005, where nearly 5000 hectares were deforested, according to data provided by individual countries to the U.N. Foreign Agricultural Organization for the Global Forest Resources Assessment Report 2005.

The construction industry faces a significant challenge in reducing waste generated during construction, whether for residential or high-rise buildings. According to an interview conducted by the researchers among the ten (10) selected experts and licensed contractors in the Western Visayas Region, construction wastes occurred due to poor planning; poor workmanship; handling, storage, and procurement errors; and design errors.

Furthermore, temporary structures account for 1 to 3% of the total project cost. Construction waste problems are worsening globally due to the rapid expansion of construction activity [8]. The environment, cost, time, productivity, and social fabric of the nation are all negatively impacted by construction waste. The construction industry generates a large amount of waste four times that of households, with more than half ending up in landfills [6].

The Department of Public Works and Highways (DPWH) Standard Specifications for Highways, Bridges, and Airports state that the contractor must provide and maintain all necessary offices, stores, workshops, restrooms, housing, and messing facilities. Furthermore, Department Order No.13, Series of 1998, or the Guidelines Governing Occupational Safety and Health in the Construction Industry, states that employers must provide the following to workers to ensure humane working conditions: (a) an adequate supply of safe drinking water; (b) adequate sanitary and washing facilities; and (c) suitable living accommodation for workers and, as applicable, their families. Thus, this study aims to design a mobile bunkhouse that is sustainable, eco-friendly, and disaster-proof. The most common modern type of portable building is designed to be transported to and from a job site on a truck using a crane [5]. Various folding units make up the portable structure [4]. The time it takes to build a movable structure is less than it takes to build a traditional structure. All of the amenities of a permanent structure are available in a portable structure [10].

In this light, this study was conceptualized due to the demands and challenges met by the construction



industry. This study is aligned with United Nations Sustainable and Development Goals (UNSDG) Nos. 9, 11, and 15, which are Industry, Innovation and Infrastructure, Sustainable Cities and Communities, and Life on Land. The study proposed a sustainable, eco-friendly, and calamity-proof wheeled structure. Specifically, the study is aimed to plan and design a wheeled structure per the National Structural Code of the Philippines (NSCP) 2015 and the National Building Code of the Philippines (Presidential Decree 1096), determine the possible cost of materials and labor; and compare the cost of a typical temporary structure with the proposed design.

MATERIALS AND METHODS

Polyvinyl Chloride (PVC) Panels

PVC ceiling wall panels are widely used as a ceiling cladding material. PVC is a strong, lightweight, water-resistant polymer material factory-manufactured into ceiling panels in various designs, colors, sizes, and lengths. The properties of PVC are well-known and documented, and this uniqueness may make it a fascinating polymer to study in terms of its potential for sustainability [7]. This study uses 134 x 9 x 2850 mm PVC panels fastened to steel tubing for the walls and ceiling.

Galvanized Steel Pipe

GI (Galvanized Iron) pipes are essential in various industries. A zinc layer is applied to the iron to prevent corrosion. The zinc metal coating is more durable and helps to extend iron or steel's life. As wall studs, 2 x 2 inches and 2 x 3 inches GI tubing are welded together in this study. Also, this study uses a four-inch GI pipe as a floor support. On the other hand, the common ways to reduce corrosion during transport and storage or to achieve certain aesthetic appearances are to apply different kinds of surface treatments such as chromate-based surface treatments, thin organic coatings, primers, topcoats, or duplex coatings on the surfaces of zinc and galvanized steel. Zinc and zinc-based alloys are extensively used in society today. The main areas of application are external construction and corrosion protection of steel.

Steels

It is essential to select environmentally friendly building materials to implement principles and methodologies of "sustainable construction" [1]. In addition, he emphasized that steel is a unique structural component that has almost a closed-loop material cycling and can be reprocessed without quality losses. The checkered plate has many advantages, including a striking appearance, anti-skid properties, improved performance, and steel savings. It is widely used in transportation, construction, machinery, shipbuilding, and other industries. This study uses checkered plates for flooring, walls, and roofing with material dimensions of 2- 10 mm x 2200 mm x desired length. Also, this study utilizes 1 x 1 inch and 2 x 2 x ¼ inch angle bars to support the floor, wall, and roof.

Poly Methyl Meth Acrylate

Acrylic (Poly Methyl Meth Acrylate or PMMA) is a transparent plastic commonly known as "Plexiglass." It is similar to polycarbonate in that it is suitable for use as an impact-resistant alternative to glass. Acrylics are thermoplastic resins and can be dissolved in suitable solvents. Many of these are transparent with a refractive index lower than 1.49, suitable adhesives, and are said to be stable against oxygen and ultraviolet (UV) radiation. It is widely regarded as one of the most transparent plastics available. It has excellent optical clarity and transparency, is highly resistant to temperature variations, has up to 17 times the impact resistance of ordinary glass, is half the weight of glass, is ideal for precision machining, and is highly resistant to many different chemicals, according to www.carvilleplastics.com. The acrylic glass was used for window panes in this study.

Methods

This section presents the methodology for designing the mobile bunkhouse. It also covers the planning and design process involving drawings and computation of wind loads, cost estimation of the wheeled structure, and comparison of results. The figure below shows the process of designing the mobile bunkhouse:

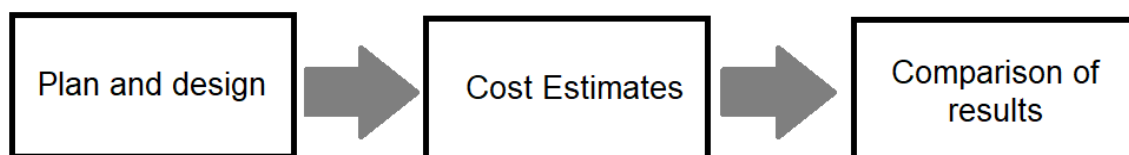


Figure-1. Process of designing mobile bunkhouse.

RESULTS AND DISCUSSIONS

Design of Wheeled Structure

The programmed data sheet for wind load calculation per NSCP 2015 [2] showed that the mobile bunkhouse could withstand a maximum wind velocity of 155.1275 kph with the calculated wind pressure at this

given velocity of 0.5936 kPa. With all this information, findings revealed that the mobile bunkhouse project could resist a typhoon with a wind speed of not more than 150 kph.

Correspondingly, the following unit weight factors of steel, Polyvinyl chloride (PCV), and PolyMethyl MethAcrylate (Acrylic) were used to obtain the wheeled



structure's total mass such as 7,850 kg/m³, 1,300 kg/m³ and 1,190 kg/m³ respectively. Based on the computed mass of the different materials, the wheeled structure weighs 2308.7 kilograms, excluding the tractor-trailer or the combination of truck and semi-trailer.

Furthermore, the Philippines is highly vulnerable to flooding due to severe typhoons and heavy rainfall. Flooding risks have been exacerbated by land-use changes such as urbanization and logging. Thus, the wheeled structure is elevated at 1.25 m to withstand the event of a flood.

Effective wind velocity pressure, qz, by the National Structural Code of the Philippines (NSCP) 2015, [2] is calculated as follows:

$$q_z = (47.3 \times 10^{-6}) (K_z)(K_{zt})(K_d)(V^2)(I_w) \tag{1}$$

Where:

- qz = velocity pressure at height “z” in kPa
- V = 200 kph, wind speed in kilometers per hour
- Kz = 0.98, wind velocity pressure exposure coefficient
- Kzt = 1.791, a topographic factor of unity
- Kd = 0.95, a wind directionality factor of unity
- Iw = 1.15, the importance factor

qz=	(47.3*10 ⁻⁶)*Kz*Kzt*KdV ² *Iw=	3.628 kPa
V=	200 kPh	
Kz=	0.98 (Velocity Pressure Exposure Coefficients)	
Kzt=	1.791 (Topographic Factor)	
Kd=	0.95 (Directionality Factor)	
Iw=	1.15 (Importance Factor)	
CNw=	1.3 (Net pressure coefficient Wind ward)	
Normal Pressure=	4.716 kPa	
W=	2.3 (Weight of the structure in Tons)	22.563 kN
Xc=	5.522353 m	
Yc=	4.33895 m	
ex=	2.022353 m	
ey=	1.33895 m	
Yh=	1.25 m	
Gross Area 1=	15.72 m ²	
Gross Area 2=	16.571 m ²	
Gross Area 3=	15.72 m ²	
Gross Area 4=	16.571 m ²	
Icy=	36 m ²	
Icx=	49 m ²	

Wind Direction Angle in degrees	Net Area (m ²)				Total Net Area	Unit Forced Component		CORNER REACTION				GROSS EDGE REACTION				Wind Resultant (kN)	Wind Pressure (kPa)	Wind Velocity (kPh)
	Area 1	Area 2	Area 3	Area 4		X	Y	1	2	3	4	1	2	3	4			
40	12.04222	10.65163	0	0	22.69385	0.76604444	0.6427876	3.99613	0	0	0	3.676442	0	0	0	13.558049	0.5974327	155.6272
41	11.86403	10.87155	0	0	22.73559	0.75470958	0.656059	3.99613	0	0	0	3.676442	0	0	0	13.558049	0.59633596	155.4843
42	11.68224	11.08816	0	0	22.7704	0.74314483	0.6691306	3.99613	0	0	0	3.676442	0	0	0	13.558049	0.59542429	155.3654
43	11.49688	11.30139	0	0	22.79828	0.7313537	0.6819984	3.99613	0	0	0	3.676442	0	0	0	13.558049	0.59469627	155.2704
44	11.30802	11.51118	0	0	22.81921	0.7193398	0.6946584	3.99613	0	0	0	3.676442	0	0	0	13.558049	0.5941508	155.1991
45	11.11572	11.71747	0	0	22.83319	0.70710678	0.7071068	3.99613	0	0	0	3.676442	0	0	0	13.558049	0.59378703	155.1516
46	10.92003	11.92018	0	0	22.84021	0.69465837	0.7193398	3.99613	0	0	0	3.676442	0	0	0	13.558049	0.59360442	155.1278
47	10.72104	12.119262	0	0	22.840276	0.68199836	0.7313537	3.9961304	0	0	0	3.6764423	0	0	0	13.5580492	0.593602677	155.12754
48	10.51873	12.31465	0	0	22.83339	0.66913061	0.7431448	3.99613	0	0	0	3.676442	0	0	0	13.558049	0.59378181	155.1509
49	10.31325	12.50629	0	0	22.81954	0.65605903	0.7547096	3.99613	0	0	0	3.676442	0	0	0	13.558049	0.59414208	155.198
50	10.10462	12.69412	0	0	22.79874	0.64278761	0.7660444	3.99613	0	0	0	3.676442	0	0	0	13.558049	0.59468405	155.2688
51	9.89317	12.87898	0	0	22.771	0.62932028	0.777146	3.99612	0	0	0	3.676442	0	0	0	13.558049	0.59540854	155.3633

Figure-2. Programmed data sheet for wind loads.

Proposed Plan of Mobile Bunkhouse

This study met the minimum requirements of the National Building Code of the Philippines. The proposed floor plan for this wheeled structure model is 42 square meters or 6m x 7m. The structure includes a kitchen, a restroom, a site office, a storage area, and a dormitory-styled bedroom. The dormitory-style bedroom can accommodate twenty (20) workers.

Ceiling heights are governed by Section 805 of the National Building Code of the Philippines [9]. The ceiling heights of habitable rooms with artificial ventilation shall be no less than 2.40 meters measured

from the floor to the ceiling for a single storey building. The maximum height used in this study is 2.50 m. Also, for the size and dimension of rooms, under Section 806, the kitchen must have 3.0 square meters with the least dimension of 1.50 meters, and the toilet and bath must have 1.20 square meters with the least dimension of 0.90 meters. The proposed kitchen, toilet, and bath floor areas are 3.75 and 2.40 square meters, respectively. Moreover, in Section 808 of the Code, window openings must be ten (10) percent of the room's floor area. Hence, such window shall open directly to a court, yard, public street or alley, or open water courses doing this project an advocate of



green architecture. Also, the mobile bunkhouse meets the minimum criteria of green architecture design, such as conservation of energy, the reuse and safety of building materials, and the siting of the building with consideration of its impact on the environment. This mobile bunkhouse can access an open courtyard, for it is a movable structure.

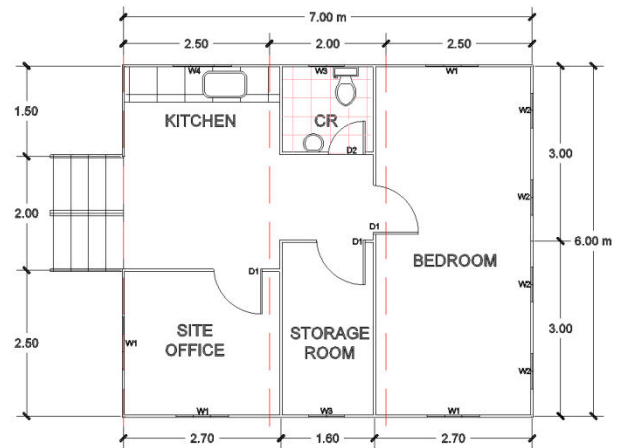


Figure-3. Floor plan of the mobile bunkhouse.

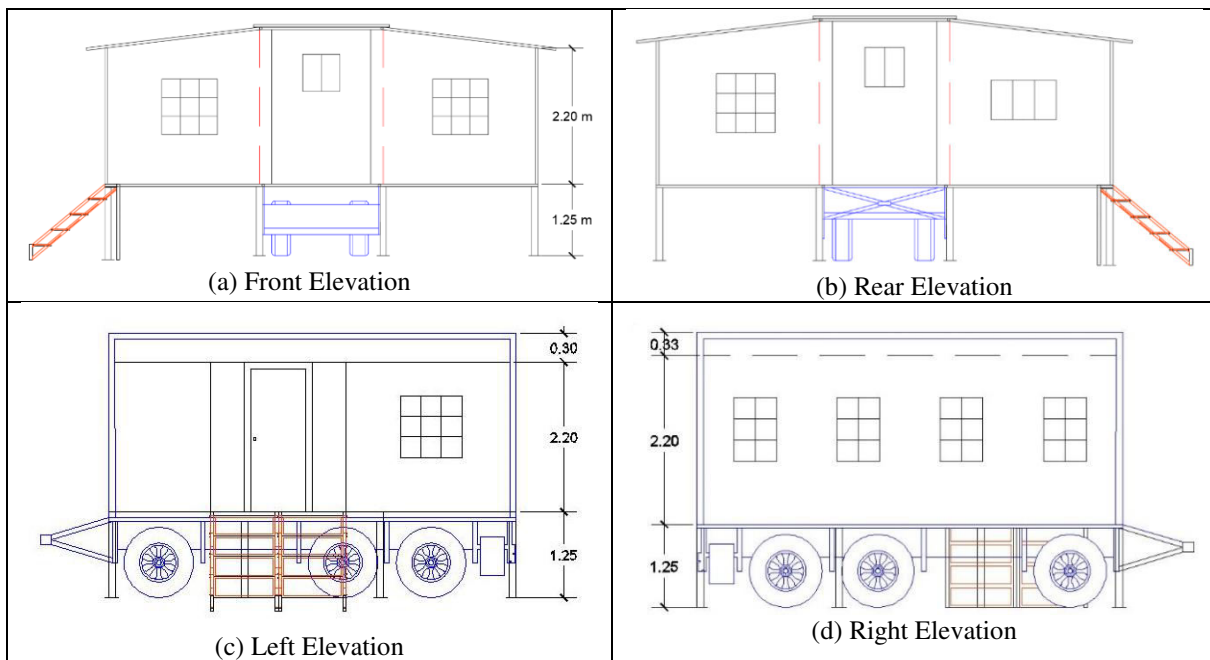


Figure-4. Elevation of the mobile bunkhouse.

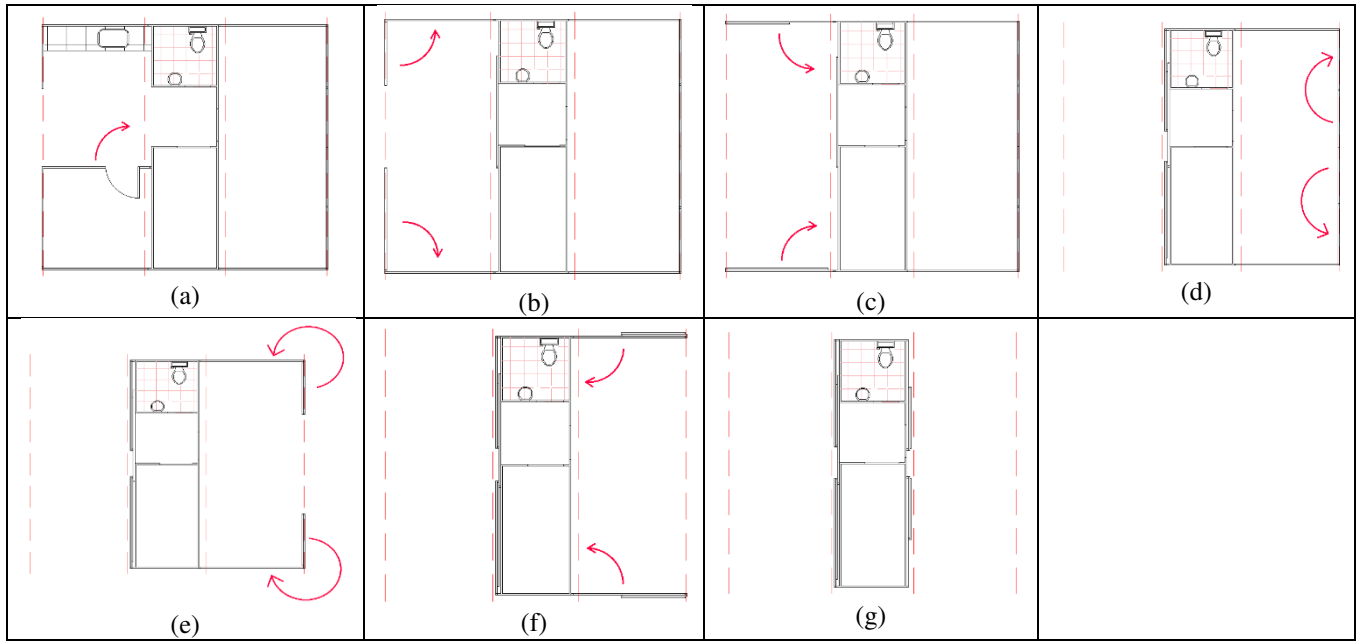


Figure-5. Step-by-step process of folding the walls of the bunkhouse.

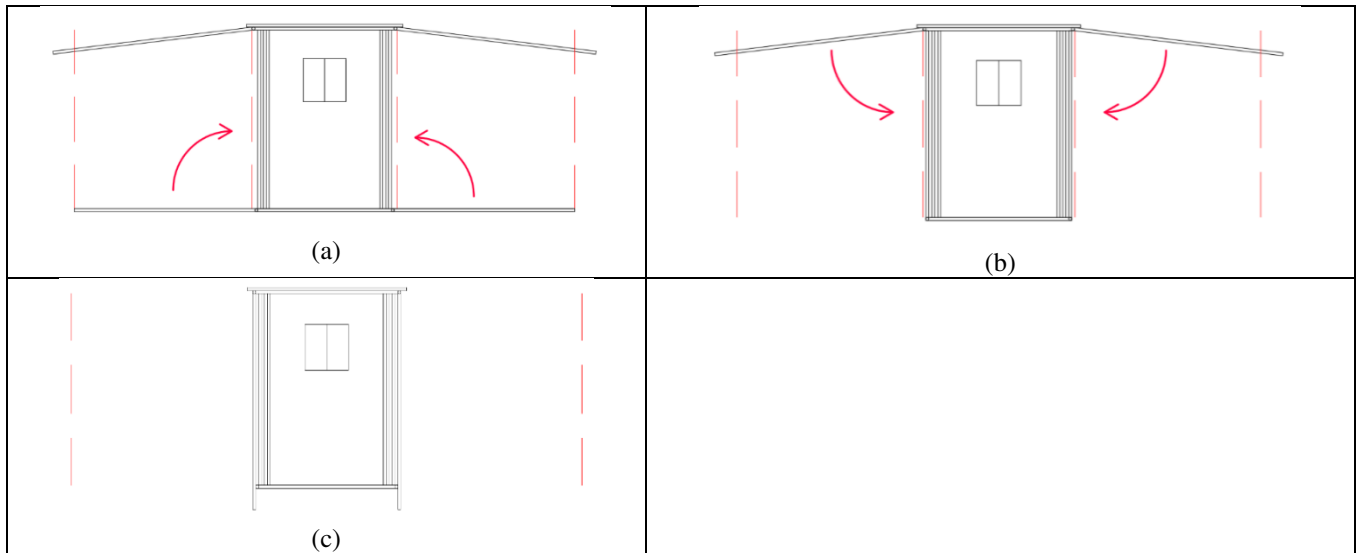


Figure-6. Step-by-step process of folding the floor and roof segments.

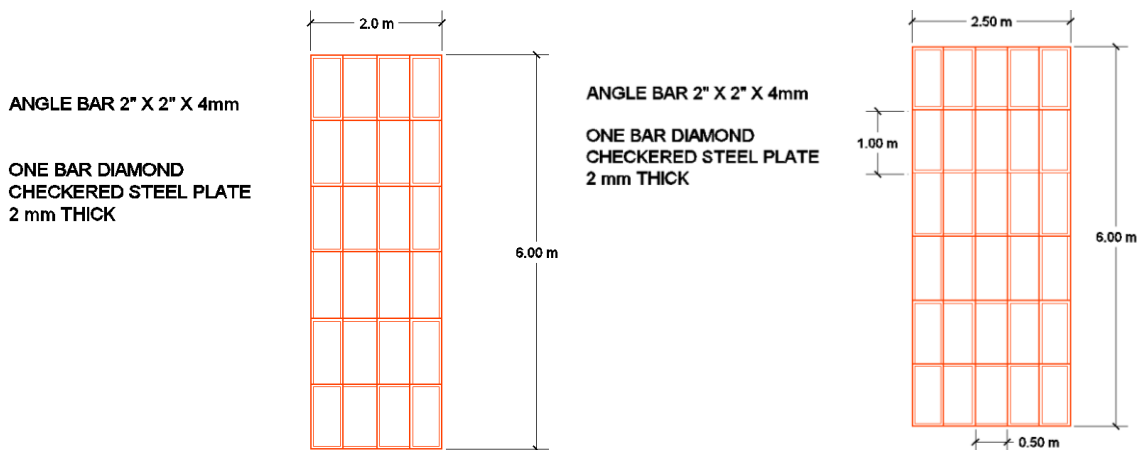


Figure-7. Floor details at the center (left) and wing side (right).

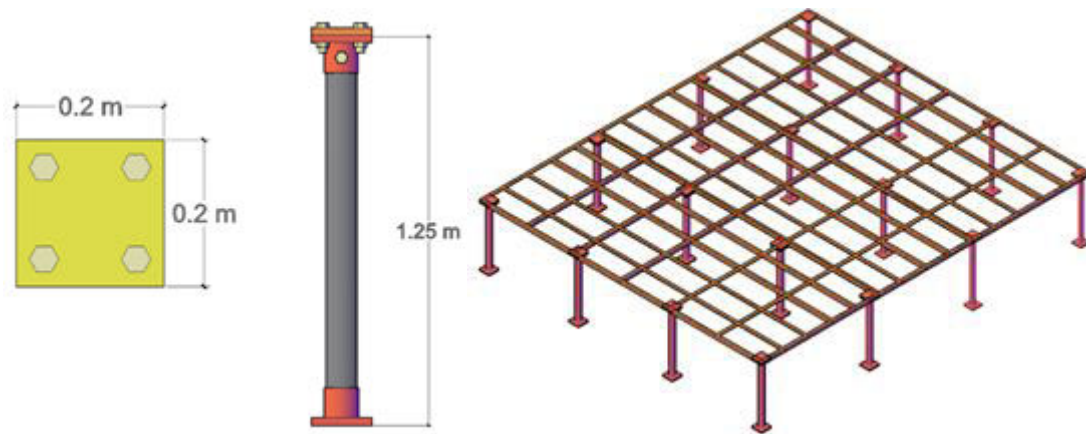


Figure-8. 16 pcs- 4” diameter galvanized iron support.

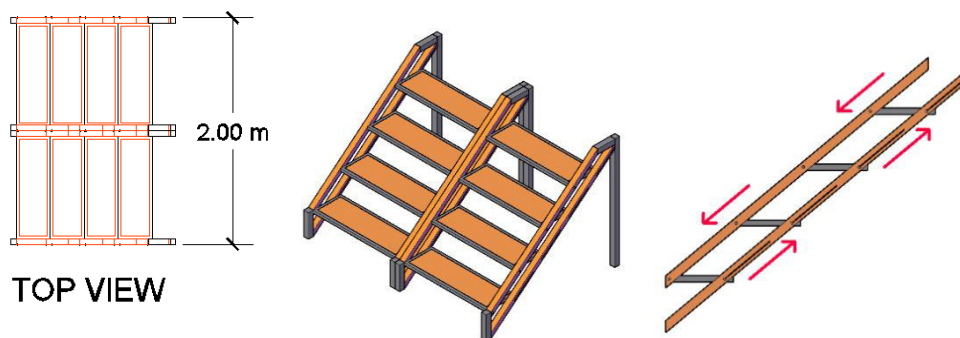


Figure-9. Staircase detail.

All frames of steps will be made of GI tube with the size of 1 inch by 1 inch; with one bar diamond checkered steel plate as the material in the steps. As support, 2 x 4 inches GI tube will be used. The staircase structure is a two-way stair with a removable support, and the staircase is also foldable.

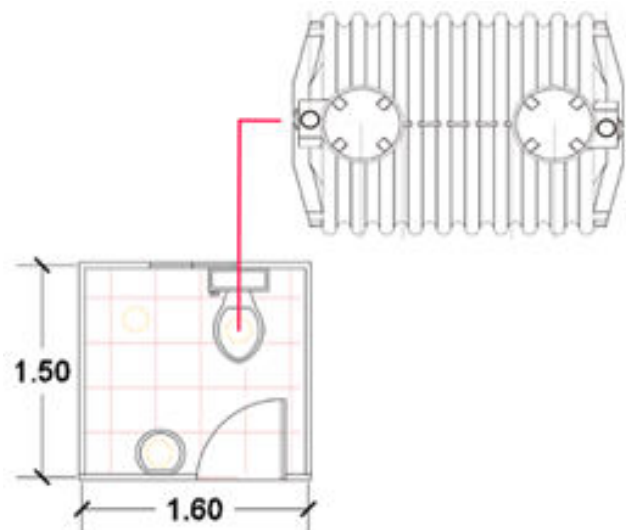


Figure-10. Floor plan of toilet and bath with septic tank.

The comfort room has a one-piece toilet and a lavatory. The lavatory stands 0.8m above the floor. Also, a removable plastic tank 2355 mm x 1210 mm x 1150 mm, 5 mm thick, with a capacity of 528 gallons will be used. The septic tank is mounted on the ground.

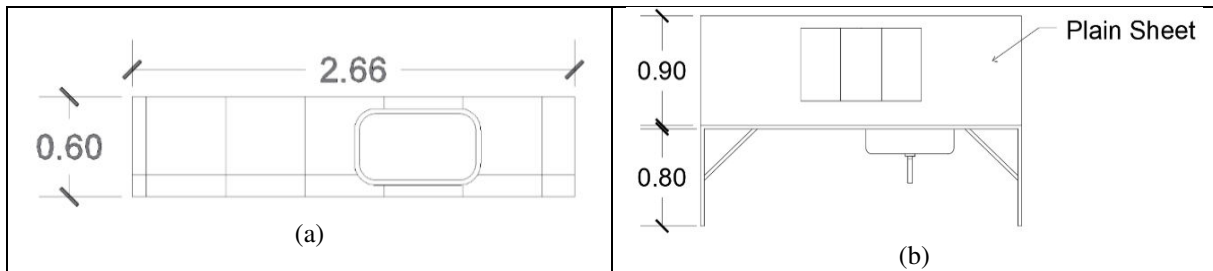


Figure-11. Plan of kitchen sink with foldable frame.

The dimensions of the kitchen top with a foldable frame are shown in the details. It measures 2.66m by 0.60m and stands 0.80m tall above the floor. In addition, the material to be used in the kitchen top and walls will be stainless steel.

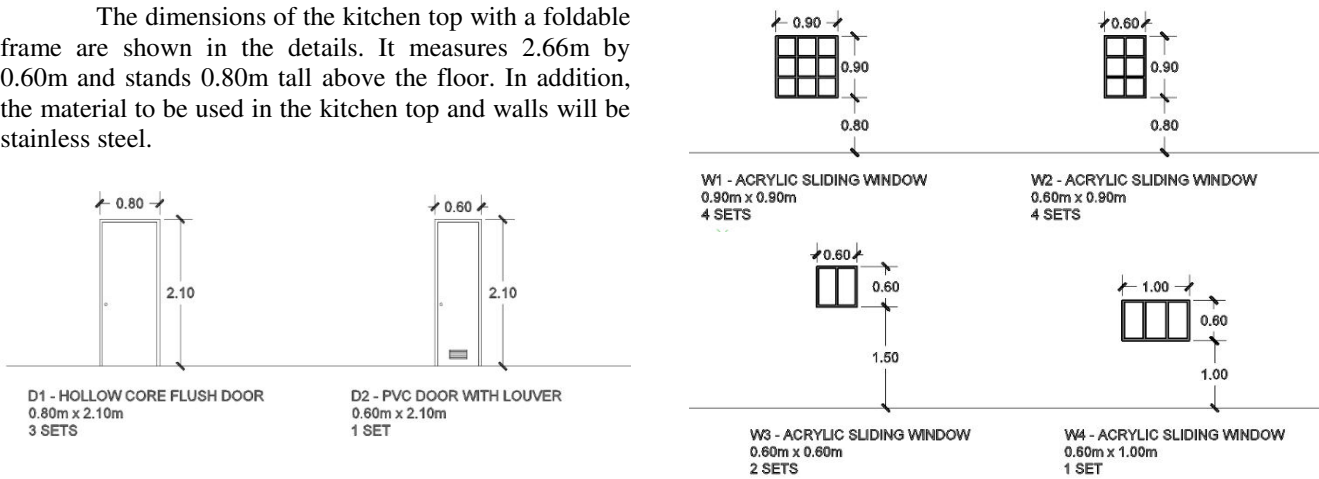


Figure-12. Schedule of doors and windows.

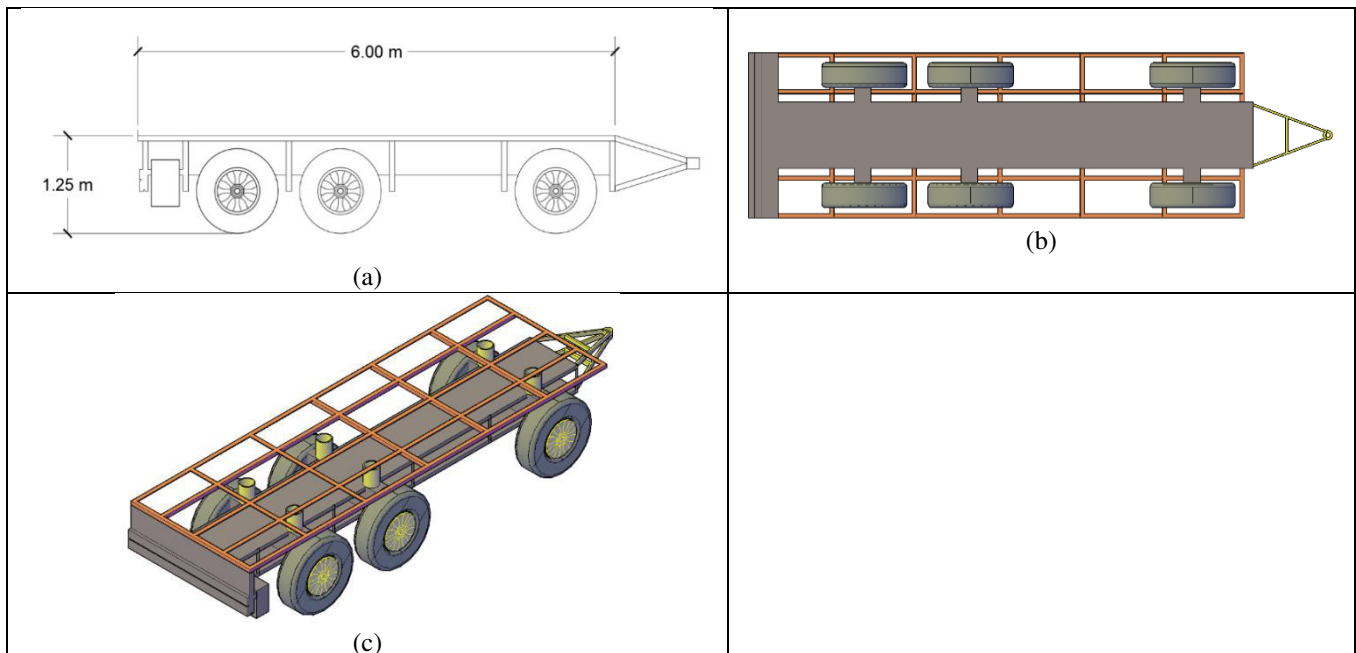


Figure-13. Exploded isometric view of the construction of the trailer.

A semi-trailer is a six-wheeled customized vehicle designed to transport the structure built on top of it-the trailer measures 6 meters long, 2 meters wide, and

1.25 meters tall. The trailer has an anchor attached to the mainframe serving as the structure's pulling point. The semi-trailer has a carrying capacity of three (3) tons.

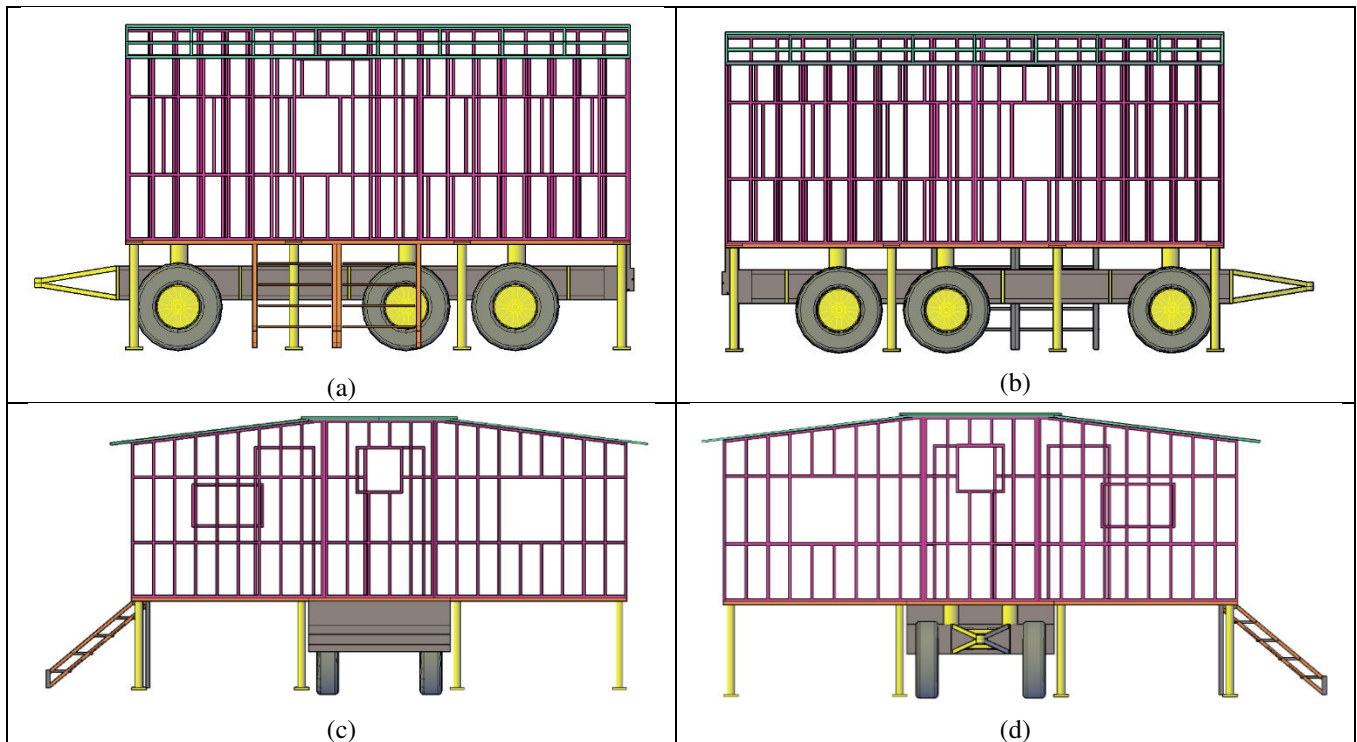


Figure-14. Wall studs

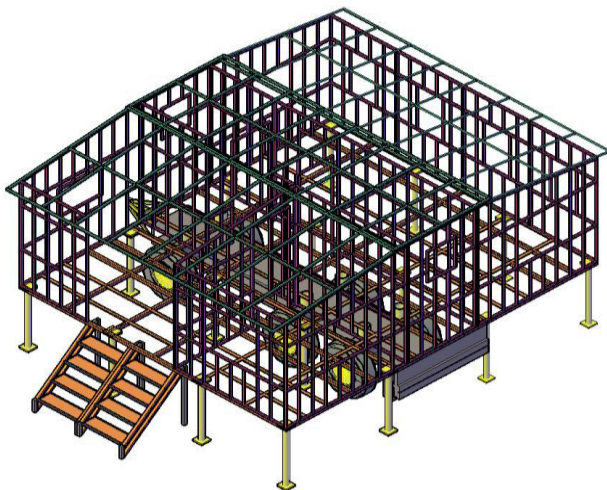


Figure-15. Exploded isometric view of the structure.

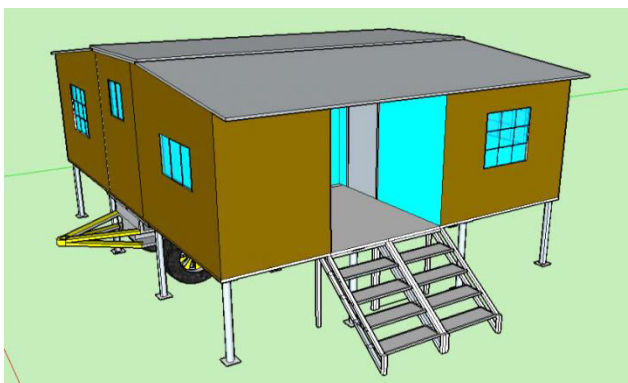


Figure-16. Perspective

Cost of Mobile Bunkhouse with the Temporary Bunkhouse

The estimated direct material cost is Php 308,661.80, and the direct labor cost is Php 138,897.80. The additional cost for a semi-trailer is Php 300,000.00. The total cost for the construction of a mobile bunkhouse is Php 747,559.60. Given the same area, the mobile bunkhouse is 75% more expensive than the temporary bunkhouse, amounting to Php 189,606.00. However, the return on investment is expected to be realized within one to two years. Given a 15% profit of the total project cost, the contractor needs to have at least three projects, each amounting to Php 1,700,000.00, to return the invested capital.

CONCLUSION AND RECOMMENDATIONS

Bunkhouses are temporary structures that must be demolished once the construction phase is completed. With this, physical wastes were generated after demolishing temporary structures. Before the construction of temporary structures, greenhouse emissions were released into the atmosphere as trees were cut down. Based on the findings of this study, the following recommendations are made; increase the dimensions of the floor area to allow a greater capacity because the Philippine Building Code of the Philippines requires habitable rooms to have at least 14.00 cubic meters of air space per person. Other lightweight materials may be used to reduce the overall weight of the wheeled structure.

Furthermore, temporary structures account for 1 to 3% of the total project cost. The cost could be minimized through a sustainable, eco-friendly, and disaster-proof bunkhouse model. Henceforward, this



model is designed to withstand a severe tropical depression with a wind speed of 89 - 117 kph to a typhoon category of not more than 155 kph wind speed and a maximum flood level of 1.20 m. The overall structure conformed to the standards set by the National Building Code of the Philippines and the National Structural Code of the Philippines. The result showed that a mobile bunkhouse is 75% more expensive than a temporary bunkhouse. However, it is expected that the return on investment will be realized within one to two years. With this, the problem of waste disposal could be addressed, which can positively impact the environment where construction wastes could be minimized after the project duration, as well as minimization of the cost of constructing temporary structures on the site.

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