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APPLICATION OF DESIGN FOR MANUFACTURING AND ASSEMBLY ON TEMPORARY SHELTERS IN THE PHILIPPINES

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ABSTRACT: The Philippines has experienced several tropical cyclones over the years. The most destructive disaster recorded in Philippine history was Typhoon Yolanda (Haiyan) in 2013, affecting 14 million people and deaths of at least 6,000. The number of internally displaced persons (IDP) has increased because of disasters from natural hazards. One of the challenges that people face during these times is the lack of durable and easy-to-build housing. As part of the disaster rehabilitation and recovery plan, a safe and durable house to protect people from the aggressive environment and ensure privacy to cope with emotional and mental health problems is essential in a disaster-prone country like the Philippines. Towards this end, the Design for Manufacturing and Assembly (DfMA) methodology was explored using sustainable materials like steel – cold-formed steel as the main structural components and screw piles for the foundation, of a previously designed shelter for the IDPs of Typhoon Yolanda. The application of the proposed scheme has shown a slight effect on project completion time but a significant benefit in terms of cost efficiency.

Keywords: DfMA, Temporary Shelter, Disaster, Philippines

1. INTRODUCTION

Annually, shelters in the Philippines are damaged by climate-related disasters, from tropical storms, flooding, earthquakes, and volcanic eruptions. On average, 300 shelters are affected by these catastrophes each year [1]. In 2013, Super Typhoon Yolanda (International Name: Haiyan) took the lives of about 6300 people and destroyed almost 1.14 million houses upon its landfall in Eastern Visayas [2]. In a more recent event, Typhoon Odette (International Name: Rai) wreaked havoc on December 16, 2021, in Southern Leyte and Caraga Region, affecting 9,800 families (approximately 40,300 IDPs), which as of March 2, 2022, have remained homeless, forcing them to seek shelter in either evacuation shelters or relatives' homes [3].

To address the housing concerns of displaced families, temporary shelters must be constructed; and, as such, guidelines for constructing these shelters have been developed. Considering the technical factors, it is suggested that the temporary shelters should be easy to erect and dismantled [4], has no complexities in their design since design complexities may cause delays in the timely construction of the shelter [5], could withstand and protect the inhabitants from subsequent calamities [6] and must be built from economical materials that are environmentally friendly, easy to manufacture and construct, and recyclable [7]. Several shelters have already been designed to match these guidelines. However, the developed designs also came with potential issues, which generally involve construction methodologies, site execution, and complexities due to numerous specifications [5] that would consume construction time.

To alleviate the potential issues stipulated in previous shelter designs, this paper explores the application of the Design for Manufacturing and Assembly (DfMA) to the temporary shelters developed in the Philippines. Previous studies have also applied DfMA in construction such as the construction of a light wall in 4-story houses [8], modules of cable-stayed towers [9], and student dormitory modules [10]. DfMA improves the overall standard of design by taking into account various facets of manufacturing and assembly processes [11], leading to a reduction in assembly and manufacturing costs and an improvement in quality of work and production time through simplification of the system [12]. To further explore the advantages of applying DfMA, this paper utilizes cold-formed steel (CFS) for the shelter framing system and screw piles serving as its foundation. CFS is selected as the primary structural material for the frame because of its optimized cost and high strength-to-weight ratio as a result of the cold-forming process [13]. As for the screw piles, related studies established that they are easy to install with the use of minimal equipment and manpower, and reusable on other sites [14]. The usage of these materials is similar to another shelter scheme used in Vietnam from the IFRC Eight Designs [15], but without the DfMA application.

2. RESEARCH SIGNIFICANCE

This study could provide a novel contribution to the present body of knowledge by unraveling the effects of integrating DfMA methodology in a structure made of CFS and supported by screw piles. The study can serve as a basis for local construction stakeholders and researchers looking into the usage of DfMA techniques for future construction projects. Further, the research application on temporary shelter would aid humanitarian organizations and government institutions explore other options for providing a more efficient temporary shelter to the affected population after a catastrophe.

3. METHODOLOGY

For this research, a case study was developed in collaboration with a local steel contractor, which specializes in the manufacturing and assembly of CFS sections and the installation of screw piles as the foundation. The case study covers the application of DfMA using CFS and screw piles on a selected shelter previously designed and constructed in the Philippines. The selected parameters for evaluating the generated CFS shelter design are the material cost and theoretical construction time.

3.1 Selection Of Shelter For DfMA

In this research, DfMA methodology using CFS and screw piles was applied to address the concerns in a previous temporary shelter design in the Philippines. The researchers chose the Philippine 2011 shelter from the International Federation of Red Cross and Red Crescent Societies' Ten Designs for Post Disaster Shelter [5]. In overview, the shelter is constructed using reinforced concrete columns and foundations, masonry and timber walls, and timber roof framing with a dimension of 4.0mx5.0m (Fig.1). Based on the front elevation (Fig.2), it has a gable roof with a braced column height of 2.40m. This shelter took 12 days to be built and has an anticipated lifespan of 5 years. In certain conditions, the shelter can adequately resist lateral wind and seismic loads, provided a proper connection between the timber wall to the lower masonry walls and truss framing exists. However, its performance analysis against hazards indicates the possibility of failure in resisting wind loads even at the reduced level, and non-compliance with the structural code requirements for seismic loads, indicating that it could only withstand seismic events at a reduced load level [5]. Moreover, the shelter weight is insufficient to respond against uplift forces from strong winds.

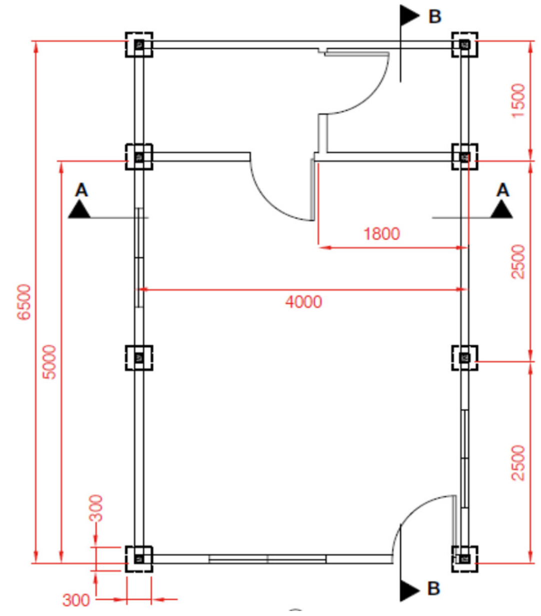


Fig.1 IFRC Philippine shelter 2013 plan [5]

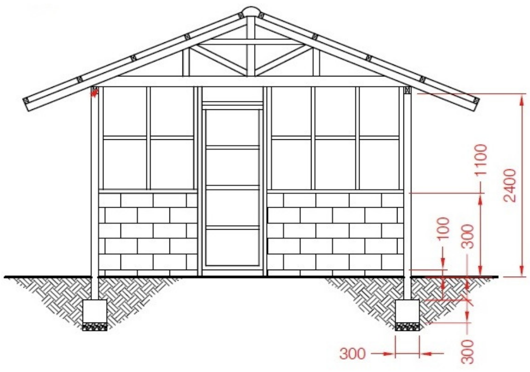


Fig.2 IFRC Philippine shelter 2013 elevation [5]

3.2 Initial Design Of The Structural System

3.2.1 Design of CFS frame

The selected shelter was prepared with an initial CFS framing and screw pile as a foundation complying with the design load requirements set by the National Structural Code of the Philippines (NSCP) requirements. The initial CFS frame was designed using the software STAAD by American Iron and Steel Institute (AISI) standards and imported to Vertex BD, a Building Information Modelling (BIM) software that facilitated the DfMA phase. For the design, the selected shelter was assumed to be situated in a hypothetical location in San Gerardo Subdivision, Tacloban City, Leyte. The wind and seismic parameters shown in Tables 1 and 2, respectively, were used in the design of the frame in STAAD.

Table 1 Wind load parameters

Parameter	Input Values
Wind Speed	290 kPh
Exposure Category	Exposure C

Table 2 Seismic load parameters

Parameter	Input Values
Soil Profile Type	S_D
Near Source Factors	Na = 1.0, Nv = 1.0
Seismic Zone Factor	0.40
Response Modification Factor, R	4.50 (Intermediate Moment Frame)

3.2.2 Design of screw piles

For the shallow screw piles in cohesionless soils, the cylindrical shear method was used for the design using the equations suggested by Nasr (2004) [16] for piles under compression, and Mitsch and Clemence (1985) [17] for tension/uplift, as shown in Eq. (1) and Eq. (2), respectively.

$$\boldsymbol{Q_c = \frac{1}{2}\pi D_a \gamma'\left(H_b^2 - H_t^2\right)K_s tan\varphi + \gamma' H A_H N_q + \frac{1}{2}P_s H_{eff}^2 \gamma' K_s tan\varphi} \quad (1)$$

where $\boldsymbol{D_a}$ = average helix diameter; $\boldsymbol{H_b}$ = depth to bottom helix; $\boldsymbol{H_t}$ = depth to top helix; $\boldsymbol{K_s}$ = coefficient of lateral earth pressure in compression loading; $\boldsymbol{P_s}$ = perimeter of the crew pile shaft; $\boldsymbol{A_H}$ = area of the bottom helix.

$$\boldsymbol{Q_t = \frac{1}{2}\pi D_a \gamma'\left(H_b^2 - H_t^2\right)K_u tan\varphi + \gamma' H A_H F_q} \quad (2)$$

where $\boldsymbol{K_u}$ = coefficient of lateral earth pressure in uplift for sand.

Shown in Table 3 are the soil parameters used in the design of the screw piles. The soil parameters are site-specific and were obtained from an available soil investigation report that generally assumes the parameters of the very dense sand of the selected site.

Table 3 Soil parameters

Parameter	Values
Internal Friction Angle, f	35°
Effective Unit Weight, g'	10.19 kN/m^3
Breakout Factor, Fq	10

3.3 Design Assessment Using DfMA Criteria

The scope of the research is limited to the application of DfMA as a design process and its consequent effect on the material cost and approximated theoretical time of installation of the prototype shelter with CFS and screw pile. In the design phase, DfMA criteria were utilized to optimize the production of the prototype by reducing installation and assembly time and costs while maintaining structural integrity and quality. The following criteria are as follows: (a) minimization of the number of parts, (b) ease of handling, (c) ease of insertion of parts, (d) standardized parts, (e) design for current process capabilities, and (f) maintain a margin for alternative design and assembly processes [11].

3.4 Usage Of Building Information Modelling (BIM)

Upon application of the DfMA criteria, the design output was imported to Vertex BD for the creation of the shop drawings of the CFS framing and connections, which were the basis of the material cost estimate and theoretical time of completion for assembly. After this, the obtained values were compared to the values of the original IFRC temporary shelter scheme. The original scheme was designated as IFRC and the new scheme applying DfMA with CFS and screw piles was designated as CFS.

4. DATA AND ANALYSIS

4.1 Structural Design Results

The STAAD models shown in Fig.3 for the trusses and Fig.4 for the frame reveal that the CFS sizes were designed according to the code specifications of AISI for CFS sections which assure the adequacy of its resistance against the wind and seismic loads. Since the structure is relatively lightweight, the governing load is the wind; thus, the sections, in majority, were designed against the wind load. Furthermore, due to the wind, the governing support reaction used in the design of the screw pile is an uplift force of 14 kN. The designed specification of the screw piles, as shown in Fig.5, mitigates the initial concern of the IFRC foundation of a possible uplift occurring during typhoons because of the impact of strong winds and inadequate shelter weight.

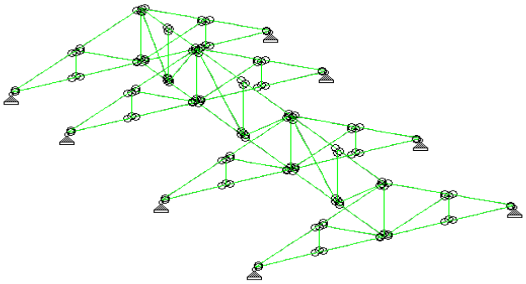


Fig.3 Trusses STAAD model

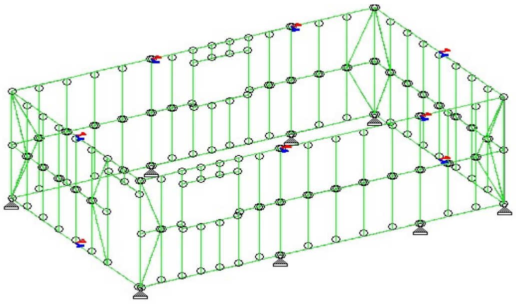


Fig.4 CFS Frame STAAD model

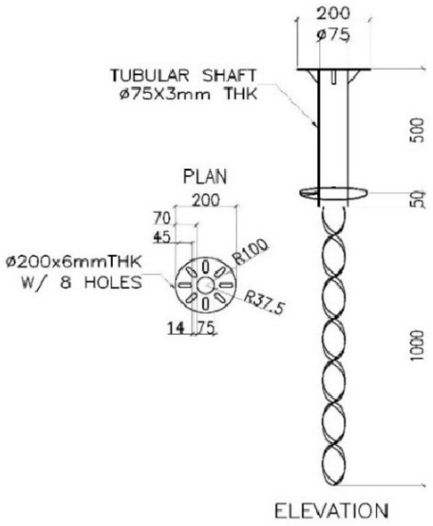


Fig.5 Screw pile design specification

4.2 Application Of DfMA

Following the structural design results, the criteria for DfMA were applied through the importation of the STAAD file to Vertex BD.

4.2.1 Minimization of the number of parts

The number of parts was already trimmed down to the required number of members based on structural requirements. Hence, the number of parts is already optimized. No further reduction of members is necessary as all parts are deemed essential.

4.2.2 Design for ease in handling

The Vertex BD output was readily imported to the roll-forming machine that would automatically manufacture the CFS sections according to the cutting list. Hence, this process eases the flat-pack packaging of the CFS. The sections were relatively light such that handling each section would require two persons only. Assembly is guided by the designations marked by the Vertex BD for each member of a panel. Shop drawings from Vertex BD include the specification of each member designation shown in Table 4 for the external wall framing and Table 5 for the truss. The respective designation of the parts of the wall and the truss are shown in Fig.6 and Fig.7, respectively.

Table 4 Vertex BD external wall framing specifications

Mark	Qty	Size	Use	Length (mm)
1	1	DH140-50-2.50	King Stud	2392
2	1	DH140-50-2.50	King Stud	2393
3	3	DH140-50-2.50	King Stud	292
5	1	DH140-50-2.50	King Stud	2391
6	4	DH140-50-2.50	Stud	2392
10	1	DH140-50-2.50	Stud	2392
13	1	DH140-50-2.50	Stud	2391
4	1	DH140-50-2.50	Header	1135
7	1	DH140-50-2.50	Bottom Track	4000
8	1	DH140-50-2.50	Top Track	4000
9	1	DH140-50-2.50	Noggin	2905
11	1	DH140-50-2.50	Diagonal Brace	1188
12	1	DH140-50-2.50	Diagonal Brace	1188

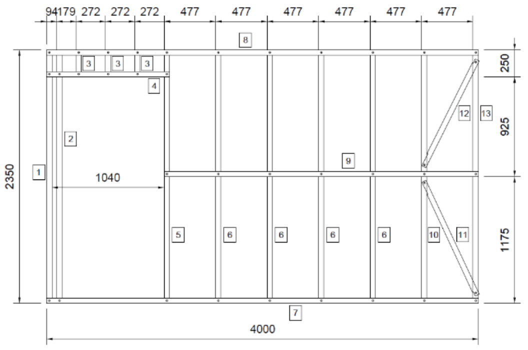


Fig.6 Vertex BD external wall framing designation

Table 5 Vertex BD truss parts specifications

Mark	Qty	Size	Use	Length (mm)
5	1	DH140-50-1.40	Jack	1193

Table 5 Vertex BD truss parts specifications

(Continuation)

Mark	Qty	Size	Use	Length (mm)
3	1	DH140-50-1.40	Web	1117
6	1	DH140-50-1.40	Web	1117
2	1	DH140-50-1.40	Web	643
7	1	DH140-50-1.40	Web	643
4	1	U140-50-1.40	Bottom Chord	4259
8	1	U140-50-1.40	Top Chord	2949
1	1	U140-50-1.40	Top Chord	2941

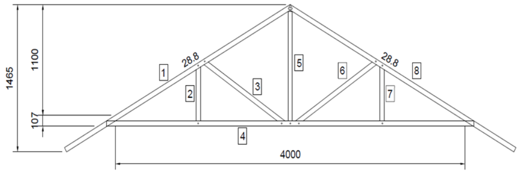


Fig.7 Vertex BD truss part designation

4.2.3 Design for ease in insertion and connections

Self-drilling screws are used for each connection. Each intersection would only require a single screw, as reflected in the shop drawings, and a dimple was already provided for each screw connection during the manufacturing process to lessen the amount of time spent in the fastening of members, as shown in Fig.8. The location of these screws is also indicated in the shop drawings created in the Vertex BD. These self-drilling screws possess relatively high strength, and their installation would only require a screw gun for fastening.

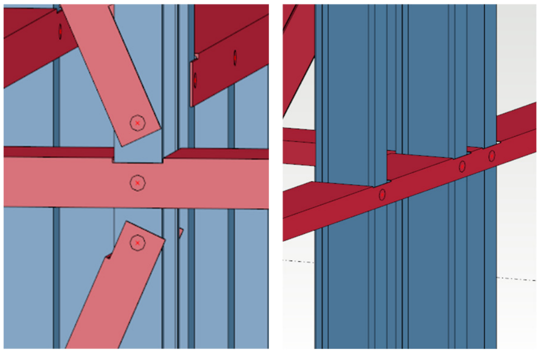


Fig.8 Single screw connections of CFS frame

4.2.4 Standardized parts

CFS components will be fabricated only by a single local manufacturer. Moreover, all of the parts of the frame were set to be constructed at the same length, size, and configuration. All frame connections were also standardized as single screw connections. The Vertex BD model was imported in the SketchUp software, as shown in Fig.9. From Tables 6 and 7, the quantity take-off of the standardized parts is shown, adding up to 129 parts.

Table 6 CFS frame parts

Size	Use	Length (mm)	Quantity (pcs)
DH140-50-1.40	Stud	2392.00	41.00
DH140-50-1.40	Stud	292.00	8.00
DH140-50-1.40	Stud	1092.00	5.00
U140-50-1.40	Header	1135.00	1.00
U140-50-1.40	Header	1345.00	2.00
U140-50-1.40	Sill	1345.00	2.00
U140-50-1.40	Diagonal Brace	1188.00	8.00
U140-50-2.50	Top Track	4000.00	2.00
U140-50-2.50	Bottom Track	4000.00	2.00
U140-50-2.50	Top Track	6212.00	2.00
U140-50-2.50	Bottom Track	6212.00	2.00
U140-50-1.40	Noggin	2905.00	1.00
U140-50-1.40	Noggin	1832.00	1.00
U140-50-1.40	Noggin	3995.00	1.00
U140-50-1.40	Noggin	476.00	1.00
U77-32-0.80	Top Track	3696.00	1.00
U77-32-0.80	Bottom Track	2696.00	1.00
U77-32-0.80	Noggin	2702.00	1.00
U77-32-0.80	Header	1031.00	1.00
U77-32-0.80	Top Track	1487.40	1.00
U77-32-0.80	Bottom Track	493.10	1.00
U77-32-0.80	Noggin	493.80	1.00

Table 6 CFS frame parts (Continuation)

Size	Use	Length (mm)	Qty (pcs)
U77-32-0.80	Header	1023.00	1.00
U77-32-0.80	Header	1031.00	1.00

Table 7 CFS truss parts

Size	Use	Length (mm)	Qty (pcs)
DH140-50-1.40	Top Chord	2252.80	4.00
DH140-50-1.40	Bottom Chord	4258.60	4.00
DH140-50-1.40	Web	1116.80	4.00
DH140-50-1.40	Web	643.30	4.00
DH140-50-1.40	Web	1193.00	4.00
U100-50-1.40	Top Chord	2224.40	2.00
U100-50-1.40	Bottom Chord	2224.40	2.00
U100-50-1.40	Web	1175.00	6.00
U100-50-1.40	Diagonal Brace	1501.00	4.00
U100-50-1.40	Top Chord	1463.10	1.00
U100-50-1.40	Bottom Chord	1463.00	1.00
U100-50-1.40	Web	1172.00	3.00
U100-50-1.40	Diagonal Brace	1294.00	2.00

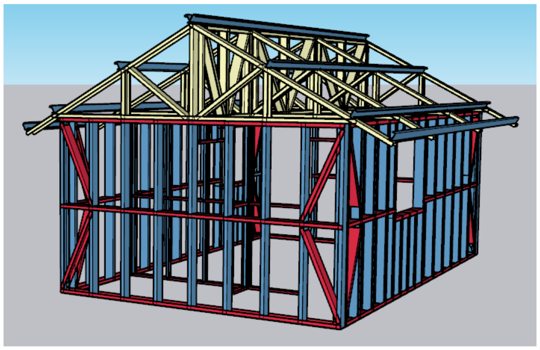


Fig.9 Imported Vertex BD model in SketchUp

4.2.5 Design for current process capabilities

A local CFS manufacturer was consulted regarding the application of the DfMA parameters for the frames. As such their current practices have been embedded in the application of DfMA.

4.2.6 Margin for alternative design and assembly process

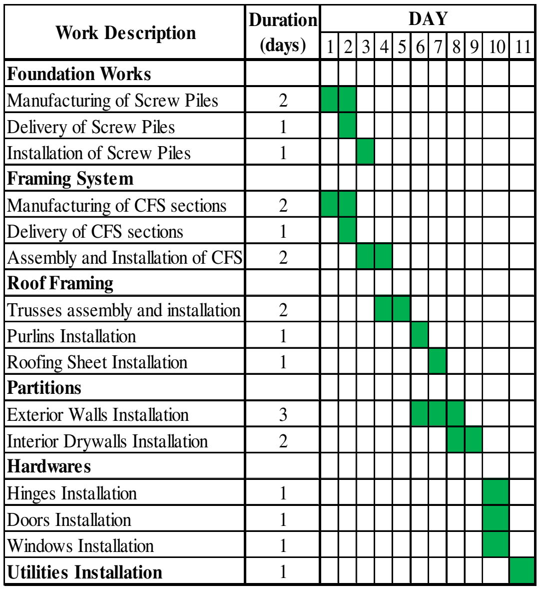
Exploration of modularization and 3D volumetric packaging options are suggested for future assemblies, as well as assessing the impact of adopting these methodologies.

4.3 Project Completion Time

The original IFRC shelter was recorded to be constructed in 12 days. Based on the Gantt Chart shown in Fig.10, the total number of days for construction was reduced to 11 days by applying the new scheme involving CFS and screw piles, saving only 1 day in the construction period. In the chart, manufacturing and delivery must be included in the scheduling since the CFS and screw piles specifications are not commercially available and are to be fabricated according to the design specifications, which, in the process, consumed 2 days of the overall schedule. Thus, if the CFS and screw piles are readily available, the construction period would only take 9 days to complete.

4.4 Project Cost

Using the quantities provided by the IFRC in the original scheme and the present unit costs of materials, the present estimated cost for the original IFRC increases by 98.99% in overall project cost when replaced with the CFS scheme as shown in Fig.11. Material cost is the primary contributor to the increase since the CFS scheme uses steel, a material known for expensive cost that escalates every year.



Work Description	Duration (days)	DAY										
		1	2	3	4	5	6	7	8	9	10	11
Foundation Works												
Manufacturing of Screw Piles	2	🟩	🟩									
Delivery of Screw Piles	1		🟩									
Installation of Screw Piles	1			🟩								
Framing System												
Manufacturing of CFS sections	2	🟩	🟩									
Delivery of CFS sections	1		🟩									
Assembly and Installation of CFS	2			🟩	🟩							
Roof Framing												
Trusses assembly and installation	2				🟩	🟩						
Purlins Installation	1						🟩					
Roofing Sheet Installation	1							🟩				
Partitions												
Exterior Walls Installation	3						🟩	🟩	🟩			
Interior Drywalls Installation	2								🟩	🟩		
Hardwares												
Hinges Installation	1										🟩	
Doors Installation	1										🟩	
Windows Installation	1										🟩	
Utilities Installation	1											🟩

Fig.10 CFS Gantt chart

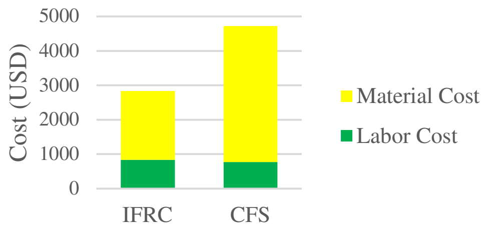


Fig.11 Estimated project cost of IFRC and CFS

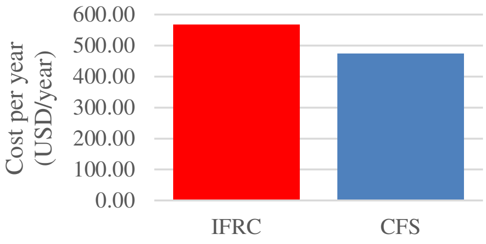


Fig.12 Cost per year of IFRC and CFS shelters

However, to appropriately assess the efficiency of using the CFS scheme, the anticipated lifespan of each scheme must be taken into consideration. The IFRC frame only has an anticipated lifespan of 5 years, whereas the CFS frame may last up to 30 years in lifespan [18]. On the other hand, Eurocode has set temporary structures to have a design life of 10 years [19] which will be the anticipated lifespan that will be taken into consideration for the CFS since it will be able to last the 10-year requirement due to its adequacy in design and documented anticipated service life. Therefore, to properly assess the cost efficiency of the two schemes, it would be appropriate to distribute the estimated cost over the indicative service life of both schemes which are 5 and 10 years for IFRC and CFS, respectively. As reflected in Fig.12, the IFRC incurs a higher annual cost at 567.75 USD per year compared to the CFS which only costs 472.75 USD per year which shows more favorable cost efficiency by saving about 20.10% yearly costs.

5. CONCLUSION

This paper shows the process and advantages of applying DfMA using CFS and screw piles in temporary shelters that could be utilized in the Philippines after a disaster. DfMA considers the manufacturing and assembly of the designed CFS sections in the design which in turn would facilitate ease in the construction process, cost, and completion. While the effect of using the proposed scheme on the completion time of the shelter was insignificant due to the addition of the manufacturing and delivery period of the parts, it was shown that the cost efficiency of using the proposed scheme is more favorable than the original scheme followed in constructing the shelter.

6. ACKNOWLEDGMENTS

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