Design of an Energy Container for Emergency Relief Preparedness and Provision of Humanitarian Aid

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Abstract. The conceptual design of an energy container is indirectly dealing with the most burning issues in our contemporary global society. Climate change and the destruction of nature cause major natural disasters such as, floods, earthquakes, tsunamis, or hurricanes which in turn lead to great damage and loss of life. Over and above that, international crisis leads to large scale conflicts with more and more nations getting involved into war with devastating consequences for infrastructure and citizens. Thus, disaster preparedness is a great necessity for relief and mitigation purposes to the affected population. Consequently, emergency relief preparedness includes all the needful actions taken to get ready and minimize the outcomes of disasters. It aims to anticipate, prevent, and mitigate the affection on vulnerable populations, and successfully deal with the consequences. Specifically, the purpose of this study is the designing of a 20-foot ISO energy container with the help of the sophisticated software of Solidworks 3D CAD system and the PVsyst 6.8.0 for the study, sizing and a data analysis of a complete off-grid photovoltaic system. This project will be a part of an integrated operations center for providing humanitarian assistance. The project aims at maximizing the production energy that could be generated by exploiting the available space of the container and constitute to integrated operations.

Keywords: case study, design, energy container, photovoltaics, disaster, recovery renewable energy.

1 INTRODUCTION

In the past two decades, the world has witnessed a steadily escalating humanitarian crisis, with the majority of affected individuals stemming from conflicts, and to a lesser extent, from the impacts of climate change and natural disasters, as recognized by the United Nations. The gravity of this situation becomes evident when examining the statistics, notably the surge in forcibly displaced people, which increased from 59.5 million in 2014 to 68.5 million in 2017. Additionally, natural disasters and climate change consistently affect an average of 350 million people each year, causing immense financial losses (OCHA, 2018). Rapid and immediate response is imperative to aid those affected at the onset of these crises.

The fundamental objective of Humanitarian Assistance (HA) is to safeguard the lives of individuals affected by disasters, both natural and man-made. Global HA intervenes when the governments of afflicted nations are unable to offer effective aid themselves. This assistance is extended in emergency situations to preserve and protect human life, mitigate the impacts of man-made catastrophes, and uphold human dignity (OCHA - Casey, E., 2003).

Containerization represents an ingenious system for intermodal freight transport, employing standardized shipping containers that seamlessly traverse various modes of transportation while safeguarding their contents (Hildebrand, 2018). These containers, characterized by their uniform dimensions, facilitate efficient loading and unloading from one transport medium to another.

This study is dedicated to addressing how the concept of the Energy Container can effectively meet the requirements of humanitarian aid, presenting a promising solution to enhance the immediate relief efforts in affected regions. Furthermore, it explores innovative approaches to equip the container's interior with pre-installed and pre-wired equipment. The study will illustrate the concept development process and the final project using the advanced Solidworks (Dassault Systemes, Villavoublay, France) CAD program, offering a comprehensive visual representation of this project.

2 METHODOLOGY

This study constitutes an integral yet distinct segment within the overarching cluster of container projects. It embodies a holistic approach and solution aimed at facilitating humanitarian assistance, enhancing emergency relief readiness, and bolstering the capacity for humanitarian aid provision.

The inquiries under examination in this study bear significant weight as they will substantially influence the structure and composition of the development project (Karl T. Ulrich, 2007). These inquiries encompass:

- The selection of an energy system type capable of generating the requisite power.
- The dimensioning of the energy system.
- The identification of necessary equipment for power generation, storage, and distribution.
- Ensuring the reliable operation of the energy system under adverse weather conditions.
- Sizing of supportive equipment to accommodate the energy system components.
- Preserving the initial intermodal characteristics of the converted container.
- Establishing interconnections with other purpose-specific containers (e.g., telecommunications, medical, water treatment, catering, and shelters).
- Adhering to international container standards.

The design principles guiding this product are closely aligned with user and stakeholder needs (Karl T. Ulrich, 2007). In terms of product development, it adopts a complex system perspective, necessitating the decomposition of the system into several subsystems and numerous components (Qiang Zhang, 2011). Furthermore, it can be categorized as a technology-driven product, driven by the integration of new technologies into its subsystems.

Within this study, project generation unfolds via a systematic process consisting of five distinct stages (Eppinger, 2000). These stages encompass problem clarification, external and internal investigation, systematic exploration, and result reflection.

Moreover, the analysis incorporates the FAST method, an acronym representing Function, Analysis, System, and Technique. This top-down approach aids in displaying functions logically, prioritizing them, and evaluating their interdependencies (Gavin Allanwood, 2014). The FAST method is employed in the following manner within the study:

- **Step 1:** *Clarify the problem*, involving a comprehensive understanding of the problem, breaking it down into simpler sub-problems using diagrams.
- **Step 2:** *Search externally*, which includes consulting experts, gathering technical information, and examining related products**.**
- **Step 3:** *Search internally*, focusing on idea generation and initial goal configuration through sketches and drawings.
- **Step 4:** *Explore systematically*, collecting concept fragments to synthesize a complete solution.
- **Step 5:** *Reflect on results*, ensuring the comprehensive exploration of the proposed solution, the thorough decomposition of the problem, and the consideration of alternative function diagrams.

3 APPLYING THE PRODUCT DEVELOPMENT PROJECT

In this section of the paper, the mission statement is introduced, highlighting the development of a self-supported intermodal container engineered to generate and store energy for the purpose of supporting existing containers deployed in telecommunications and medical treatment. To address this multifaceted challenge, a structured approach is employed, encompassing problem decomposition and the application of the FAST (Function, Analysis, System, Technique) model to prioritize functions and establish a logical sequence for project development, as figure 1 describes.

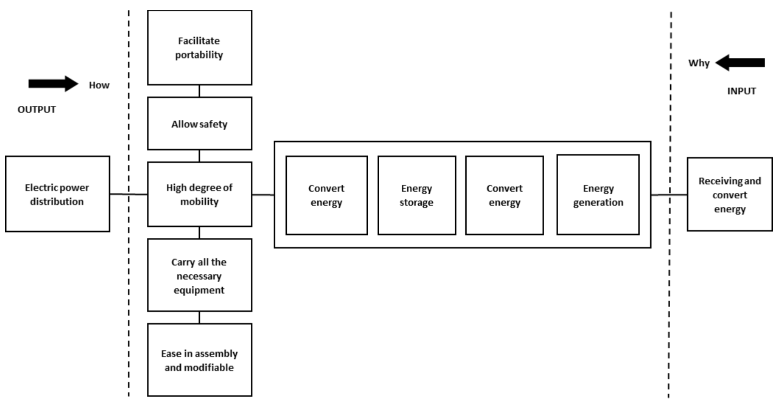

Figure 1. F.A.S.T MODEL for the Energy Container.

The concept generation phase is underscored as a critical component of the overall research process. Drawing upon external research and technology investigations, the objective is to adapt successful characteristics to this specific application while concurrently exploring innovative concepts to align with established requirements and specifications. Various methodologies are considered to facilitate the concept generation process.
Subsequently, the discussion focused on the establishment of initial characteristics for the Energy Container, with a specific emphasis on attributes like flexibility, reliability, and portability, especially in contexts susceptible to disasters or located in remote regions. The integration of photovoltaic panels, battery storage systems, and optionally, diesel generators, is elaborated upon, along with the practice of pre-assembly and pre-configuration to minimize on-site labour and cost implications. The paper concludes by highlighting the engineering trade-off encountered between the constrained internal space of the ISO container and the goal of optimizing energy production. Ultimately, the self-supported intermodal container is presented as a viable solution for powering telecommunications and medical treatment facilities, addressing the challenge posed by limited available space.

4 CONCEPT SELECTION FOR ENERGY CONTAINER DEVELOPMENT

External research revealed a consistent preference for renewable energy solutions in the context of these containers. Furthermore, to address potential safety concerns, conventional energy systems, specifically diesel generators, were commonly employed as supplementary measures The concept selection process is outlined as a pivotal decision-making stage, guided by user and stakeholder criteria. Concepts are rigorously evaluated, with their relative strengths and weaknesses considered. This process encompasses two key stages: concept screening and concept scoring, following Eppinger's framework (Eppinger, 2000). Concept screening involves filtering a pool of initial ideas and sketches, while concept scoring employs predefined criteria to rate and rank these concepts. Seven distinct concepts (labeled A to G) entered the concept development funnel, but only one emerged as the most promising, achieving the highest score, aligning with Karl T. Ulrich's approach (Karl T. Ulrich, 2007). Figure 2 presents a concept scoring matrix that details the evaluation criteria and ratings for each concept, offering a comprehensive view of the selection process.

	CONCEPT VARIANTS							
Selection Criteria	A	B	C	D	E	F	G	**REFERENCE**
energy output	-	+	+	+	+	+	+	0
energy storage	0	0	0	0	0	0	0	0
fixed tilt of PV array (or seasonaly adjustable)	0	0	0	0	0	+	+	0
single axis system	-	-	-	-	-	+	+	0
Dual axis system	-	-	-	-	-	-	+	0
intermodal transport	0	0	0	0	0	0	0	0
portability	0	0	0	0	0	0	-	0
quick set up on site (ease assembly)	0	0	0	0	0	+	-	0
safety	0	0	0	0	0	0	+	0
durabilty - (enegy production under harsh weather conditons)	-	-	-	-	-	-	+	0
re-installation	0	0	0	0	0	0	-	0
plug and play systems	0	0	0	0	0	0	0	0
pre-assembled pre-configured	0	0	0	0	0	0	0	0
PLUSES	0	1	1	1	1	4	6	
SAMES	9	9	9	9	9	7	4	
MINUSES	4	3	3	3	3	2	3	
NET	-4	-2	-2	-2	-2	2	3	
RANK	7	3	3	3	3	2	1	
CONTINUE	**NO**	**NO**	**NO**	**NO**	**NO**	**YES**	**YES**	

Figure 2. The concept scoring matrix.

5 ENERGY SYSTEM CALCULATION

The concept development initiated with the pivotal task of dimensioning the energy system. (Ramchandra Pode, 2011). This process generated vital parameters for each module, ensuring precision in the approach. To execute this task effectively, the sophisticated PVsyst V6.80 software (PVsyst SA, Satigny, Switzerland) tailored for photovoltaic systems was employed. Meteorological data and geographical coordinates from Thessaloniki's Mikra region were chosen to bolster result accuracy, acknowledging the importance of locale-specific data in energy system dimensioning. This encompassing dimensioning process involved establishing geographical site parameters, inputting orientation data, defining daily energy consumption patterns, configuring the solar battery bank, and selecting suitable PV modules. Table 1 systematically presents the energy system's characteristics, offering a consolidated overview of its performance and specifications.

Table 1. System characteristics.

Category	Characteristics
Energy System	Stand Alone system with batteries
Field Type	Dual axis trackers
Number of PV modules	72
Area occupied by the PV modules	144m^2
Power	3-phase
System production	35.9 MWh per year
Average daily energy	75KWh
Battery unit	2900Ah/2V
Battery	Number of units 48 (24 in parallel – 2 in series)
Battery Capacity	5900 Ah
Voltage	48V
Battery storage	227 KWh
Autonomy	Over two days of with 50% DoD
Battery lifetime	10 years

6 CONSTRUCTION CHARACTERISTICS AND DESIGN PROPOSAL

This chapter outlines the key characteristics of the construction resulting from the research conducted in this study. Concept G has been developed as a meticulous engineering project, guided by a trade-off equation that balances the available internal space of the energy container with the objective of maximizing energy production and storage. Furthermore, simplicity in construction is prioritized for ease of modification and maintenance. The Energy Container is aptly described as the "Sun in the Box," signifying its role in the production and storage of renewable energy harnessed from the sun. The system has been meticulously designed to deliver generated solar power on demand, with a focus on adapting a 20-foot shipping container to meet the requirements of humanitarian aid. The concept aims to optimize energy generation, mobility, transportation, and resilience to harsh weather conditions. The chapter provides visualizations of the 20-foot container's dimensions and the energy system, demonstrating a spatial arrangement that adheres to human factors and ergonomic principles. The main systems and sub-systems of the energy container installation are comprehensively depicted in figure 3, offering insights into the project's design. The standard ISO container featured in the study is sourced from the ISBU association, and the project leverages knowledge and resources related to shipping containers, including a handbook on container architecture and ISBU technology, which includes essential mechanical drawings used to create 3D renderings. Notably, 51 individual parts have been designed exclusively for the construction of the container, reflecting the meticulous planning and engineering involved in this effort.

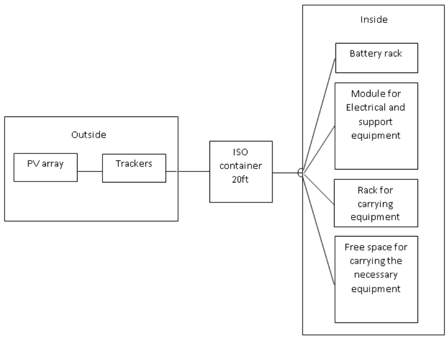

Figure 3. The main sub-systems of the project.

Within the energy container, several crucial infrastructure components have been carefully designed to ensure functionality and durability.

- *Modular Battery Rack*: One of the key components is the modular battery rack system, designed to accommodate appropriately sized batteries and withstand challenging transport conditions, including marine and helicopter transportation. The rack's dimensions were calculated based on the energy system's requirements, battery capacity, and the physical dimensions of the batteries, all while considering the space needed for other functions within the container.

- *Rack for Tracker Components*: Another essential element is the rack dedicated to housing the equipment required for assembling photovoltaic trackers. Constructed from structural steel components such as UPN channels, fish plates, tapered washers, high-strength bolts, and prevailing torque nuts, it features a standard UPN 140 channel, a readily available component often used in construction, ensuring ease of repair when necessary.
- *Electrical Module and Support Equipment*: The electrical module within the container facilitates the arrangement of devices according to manufacturer instructions (data sheets) to ensure correct positioning of the units. The module's design adheres to manufacturer guidelines, guaranteeing the proper functioning of the equipment.
- *Free Space for Equipment Transport*: Designing free space within the container was a critical consideration during development. This space is essential for transporting additional equipment, such as PV modules and tracker components. Specifically designed pallets optimize shipping durability and provide the necessary room to accommodate the required number of PV panels.

These foundational elements enhance the efficiency and durability of the energy container, guaranteeing its effective operation even in demanding transportation and deployment situations.

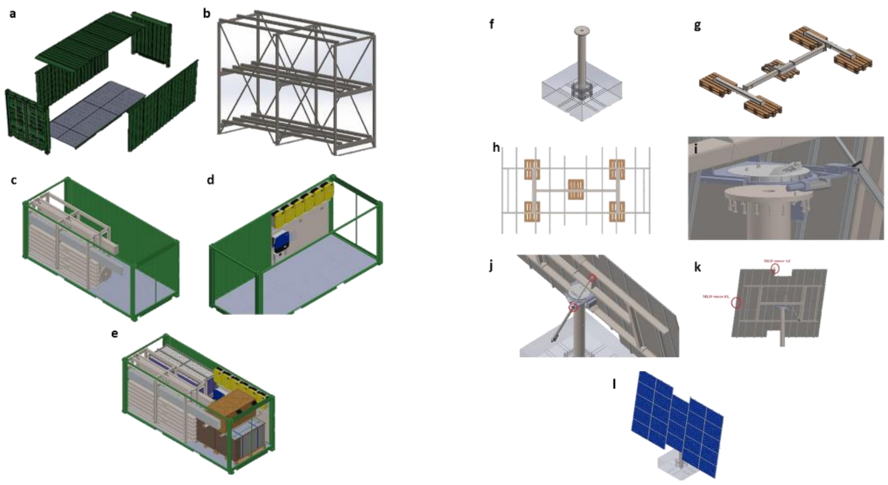

Figure 4. Key Stages in Container Design: ***a.*** Container, ***b.*** Battery Rack, ***c.*** Rack Placement, ***d.*** Electrical Module, ***e.*** Perspective View, and Solar Module Tracker Components: ***f.*** Mast and Foundation, ***g.*** Support structures, ***h.*** Aluminum Profiles, ***i.*** Base Frame, ***j.*** Elevation Drive, ***k.*** MLD Sensors, ***l.*** Photovoltaic Panel

Figure (4) provides a visual representation of different stages within the design process conducted via CAD software. This includes the design phases encompassing the container (a-e) and the configuration of the photovoltaic panels (f-l).
The concluding phases of the complete assembly involved the design phase of the tracker system as well as the principal design overview of the concept, including both the container and the tracker system within a relative open area.

- *The Tracker System***:** The chosen energy generation and PV module support system is the Deger tracker D60H, notable for its Dual-axis tracking capability and suitability for high-load regions, a key consideration in system selection. The Deger Tracker employs Maximum Light Detection (MLD) technology, ensuring precise, swift, and energy-efficient dual-axis orientation to maximize energy yield. Two MLD sensors identify the optimal position in the sky for maximum energy capture. These trackers optimize irradiation energy utilization, resulting in approximately a 45% yield increase for photovoltaic applications. The chapter provides a comprehensive presentation of assembly instructions for successful tracker system installation.
- *Design Overview of the Concept***:** Visual representations of the project are provided in Figure (5) through Solidworks visualization, offering a concise yet accurate portrayal of the entire concept. These visual aids offer insights into the design and layout of the energy container and its various components, aiding in a better understanding of the project's overall structure and functionality.

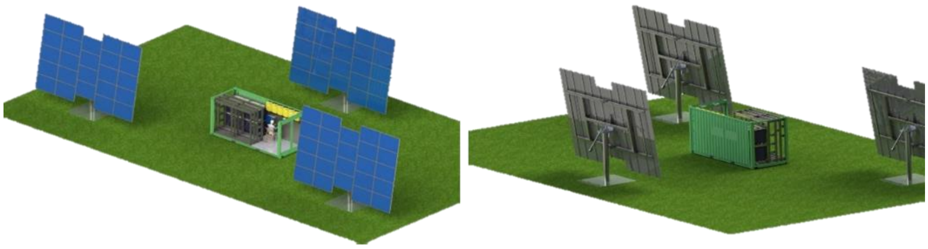

Figure 5. Front (left) and rear (right) views of the on-site Energy Container.

7 CONCLUSIONS

In summary, this research underscores the adaptability of shipping containers as versatile structures, capable of serving a wide range of functions such as hospitals, offices, classrooms, telecommunication stations, and energy units, among others. These repurposed containers are characterized by their enduring nature, offering substantial flexibility and mobility. Notably, we have demonstrated the successful conversion of a shipping container into an energy cube, equipped with photovoltaic solar cells that directly convert sunlight into electricity, which can be utilized or stored for later use. Our study has presented a novel approach and solution for energy containers, achieving the dual objectives of maximizing energy output and meeting intermodal requirements. Although the need for rapid assembly and disassembly for relocation is not a primary concern, given the prolonged stay of established camps, this research advocates for the deployment of large, stable structures due to their significant advantages in energy production and resilience against adverse weather conditions. This work highlights the promising potential of shipping containers as sustainable, adaptable, and efficient solutions across diverse applications and settings.

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