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Innovative Modular Emergency Shelters: A Sustainable Response to Crisis Situations in Cameroon

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Abstract:- The objective of this article is to propose a modular emergency shelter design tailored for crisis situations in Cameroon. It emphasizes the use of sustainable and adaptable construction techniques to address the urgent need for emergency housing while considering local climatic and geographic conditions. The research examines the integration of local materials, such as wood, for his cost-effectiveness and environmental benefits. Techniques like natural ventilation, rainwater management, and modular design strategies are explored as viable alternatives to more costly, less eco-friendly modern materials. Additionally, the financial feasibility of the project is evaluated at different scales, ensuring that it meets both immediate and long-term needs. This work offers a holistic approach to emergency shelter design, promoting sustainability, cultural adaptability, and durability, while addressing the specific socio-economic challenges in Cameroon. It provides a sustainable response to crises, contributing to the reflection on the future of emergency housing in African contexts.

***Keywords**:- Modular Emergency Shelter; Crisis Response; Sustainability; Cameroon.*

I. INTRODUCTION

David J. Mitchell asserts that "Architecture should be a servant of the people, meeting their needs and responding to the environment in a manner that is both functional and sustainable."[1] This principle underscores the urgent need to tackle the challenges presented by natural disasters and humanitarian crises. In Cameroon, where the demand for prompt and effective emergency responses is growing, the need for adaptable and durable shelter solutions is especially pressing. This article explores a proposal for modular emergency shelters specifically designed to address Cameroon’s unique socio-economic, climatic, and geographic conditions. By incorporating sustainable design strategies and local materials, this approach seeks to provide a swift yet resilient response to crises while minimizing environmental impact.

II. SITE

A. Morphology and Topography of Cameroon

Cameroon features extremely diverse morphology and topography, including mountains, plateaus, plains, and coastal areas. This diversity is crucial for designing solutions suited to different regions.

- Mountains: The Western Highlands, notably the Cameroon Mountains, have rugged terrain with elevations exceeding 2,000 meters. This terrain affects the climate, soil types, and construction methods.
- Plateaus: Plateaus like those in Adamaoua have moderate elevations, a temperate climate, and savannah vegetation. They are suitable for certain crops and renewable energy projects such as hydroelectricity.
- Plains: The vast plains, especially in the North, are characterized by a more arid climate and sandy soils. These areas require tailored solutions for water management and agriculture.
- Coastal Areas: Coastal regions, with low altitudes and proximity to the Atlantic Ocean, experience a humid tropical climate, which impacts infrastructure design and drainage systems.
- This varied morphology means solutions must be specifically tailored to the topographical characteristics of each region.”.

B. Climatic Analysis of Cameroon

Cameroon's climate is as varied as its topography, ranging from equatorial to Sahelian climates [2].

- Equatorial Climate: Found in coastal and southern regions, this climate is characterized by heavy rainfall, high temperatures, and high humidity. Solutions for these areas must address moisture resistance and rainwater management.
- Tropical Climate: In central regions and plateaus, the tropical climate features two distinct seasons: a rainy season and a dry season. Infrastructure in these areas needs to withstand significant seasonal variations.
- Sahelian Climate: Northern regions experience a Sahelian climate with high temperatures, low rainfall, and extended drought periods. Solutions here should include efficient water management systems and technologies suited to arid conditions.

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- Understanding these different climatic zones is crucial for designing sustainable solutions in areas such as building, agriculture, and transportation infrastructure.

C. Solar Orientation and Dominant Wind Directions in Cameroon

Solar orientation and the direction of dominant winds also vary by region, influencing building and infrastructure design.

- Solar Orientation: In Cameroon, close to the equator, the sun is nearly vertical year-round, following an east-west trajectory slightly southward. This characteristic must be considered to maximize energy efficiency in buildings by optimizing natural light and reducing cooling needs through appropriate solar shading.
- Dominant Wind Directions: Wind directions in Cameroon vary by season and region. For instance, in the Sahelian northern areas, the Harmattan winds from the northeast bring dry, dusty air, while coastal regions may experience maritime breezes from the Atlantic. Generally, during the rainy season, dominant winds come from the southwest, bringing moisture from the Atlantic, while during the dry season, Harmattan winds from the northeast prevail in northern regions.
- Understanding solar orientation and wind directions is crucial for bioclimatic design, enhancing energy efficiency, thermal comfort, and durability of buildings across different regions of Cameroon.

D. Site Selection and Location

In the context of our project, which does not require a localized intervention but rather the design of adaptable solutions for various regions of Cameroon, site selection focuses on flexibility and adaptability to different regional conditions. As a Central African country, Cameroon presents a wide range of geographic, climatic, and environmental contexts. Therefore, our approach must be sufficiently versatile to address the specific needs of each region.

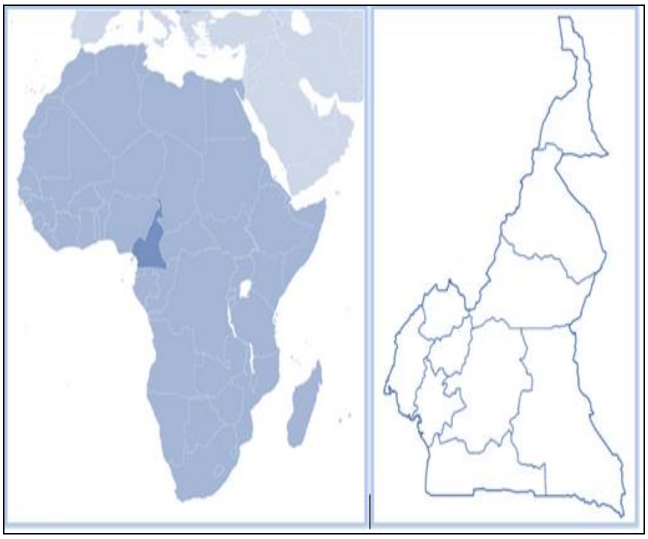

Fig 1: Location of Cameroon in Africa

➢ *Slope*

Our project requires a minimum of 18 m2 and a minimum width of 3 m, which can be maintained depending on the configuration. This implies that it could be adapted to flat sites as well as sites with a slope of less than 16.67%, corresponding to a maximum angle of inclination of 9.46°, calculated as follows:

$$\textbf{Maximum Slope} = (50\ cm) / (300\ cm) \times 100 \approx 16.67\% \quad (1)$$

$$\textbf{Maximum Angle of Inclination} = \arctan (50\ cm / 300\ cm) \approx 9.46° \quad (2)$$

Where 50 cm represents the vertical difference and 300 cm represents the horizontal distance.

➢ *Area*

The urban planning code specifies that 60% of the project site should be used for building placement [3]. The footprint of our project is 18 m² for a basic model accommodating four (04) people and 30 m² for an expandable model accommodating four (04) to six (06) people. The required areas for these models are calculated as follows:

$$\textbf{Required Area Basic Model} = (100 / 60) \times 18\ m^2 = 30\ m^2 \quad (3)$$

Thus, 30 m² for 04 people, or 7.50 m² per person.

$$\textbf{Required Area Expandable Model} = (100 / 60) \times 30\ m^2 = 50\ m^2 \quad (4)$$

Thus, 50 m² for 06 people, or 8.33 m² per person.

Our project is modular and applicable in both urban and rural areas, considering variations in topography, climate, and natural resources. In summary, our project can be implemented on any site where the spaces allocated to our model meet the criteria mentioned above.

III. PROJECT TARGETS AND OBJECTIVES

A. Target Audience

The target audience for our modular emergency shelter design project primarily includes vulnerable populations facing crisis situations, disasters, or epidemics. This group encompasses victims of natural or technological disasters, individuals displaced by armed conflicts and social crises, and those affected by epidemics or pandemics requiring isolation. The project also addresses humanitarian organizations and governments, who are often on the front lines providing temporary housing solutions in emergency contexts.

B. Project Objectives

Our approach aims to address the specific needs of individuals affected by emergencies by providing shelters that combine functionality, adaptability to local conditions, and material durability, while improving their living conditions.

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IV. ARCHITECTURAL DESIGN

A. Architectural Program

In a context where the need for emergency shelters is increasingly urgent, our architectural program proposes a modular and sustainable solution specifically designed to accommodate a family of five (two parents and three children). This project is centered around four main axes that address crucial issues of temporary housing while ensuring comfort and functionality.

- Space Efficiency: We have chosen a simple yet ingenious spatial organization that allows for optimal use of available surfaces. Every square meter is utilized to avoid unnecessary clutter, providing a living environment that is both practical and pleasant.
- Cost Optimization: Aware of the budget constraints often associated with emergency projects, we prioritize simple and cost-effective construction solutions without compromising on quality or durability.
- Modularity and Flexibility: To meet the evolving needs of the occupants, our shelter offers a flexible interior layout. This flexibility allows users to expand, customize, and modify the arrangement of spaces over time, ensuring a habitat that adapts to changing situations.
- Durability and Environmental Respect: By focusing on the rational use of resources, our program aims to minimize the carbon footprint. The selected materials are durable and recyclable, and the energy solutions are designed to reduce environmental impact.

This holistic and user-centered approach makes our emergency shelter a pragmatic response to current challenges, offering a viable, eco-friendly, and humane alternative for emergency housing needs. To achieve these objectives, we propose the following program outlined in Table I.

Table 1: Surface Program for the Housing Model

Level	Spaces	Module	Area
Ground Floor	Basic Model	Bedroom	$9m^2$
		Living	$9m^2$
		Total Basic Spaces	$18m^2$
	Expandable Spaces	Kitchen	$6m^2$
		Toilet	$3m^2$
		Terrace	$3m^2$
		Total Expandable Spaces	$12m^2$
	Expandable Model		$30m^2$
	Additional Spaces	Circulation	---
		Green Spaces	---
		Laundry Spaces	---
		Total Additional Spaces	$20m^2$
Dedicated Area for Expandable Model			$50m^2$

B. Functional Diagram

A functional diagram is an essential tool for visualizing and understanding the organization and interactions of various components within a system or project. It provides a clear and structured representation of information flows, relationships between functions, and key processes. To optimize space, improve circulation, clarify objective needs, and ensure coherence and cohesion between different functions, we have proposed the functional diagram illustrated in Figure 2.

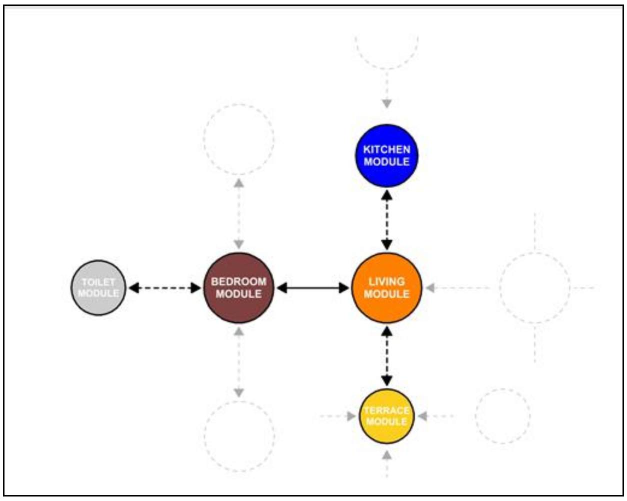

Fig 2: Functional Diagram for Basic and Expandable Models

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C. Architectural Concept

The architectural concept of our project revolves around an evolutionary and participatory approach. Designed to be adaptable and flexible, the shelter is based on a modular structure that allows users to actively participate in its assembly, customization, and development. The use of local and recyclable materials ensures its durability, while the modularity of the units allows for reorganization and adaptation according to changing needs. Thus, the shelter offers a temporary solution that can gradually evolve into a more permanent dwelling, integrating user involvement at every stage.

V. DESIGN STRATEGY

A. Model Orientation

For our project, we have carefully oriented the longest side of the building along an east-west axis, ensuring that the main façades face north and south.[4] This strategic orientation minimizes direct sun exposure on the longer façades, thereby reducing overheating in summer and maximizing energy efficiency. By also considering the direction of the prevailing winds, we have optimized natural ventilation throughout the shelter, ensuring a cooler and more comfortable interior without relying on mechanical systems. This approach not only enhances the sustainability of our solution but also increases its adaptability to various climates, while staying aligned with passive design principles. Figure 3 illustrates the orientation of our building.

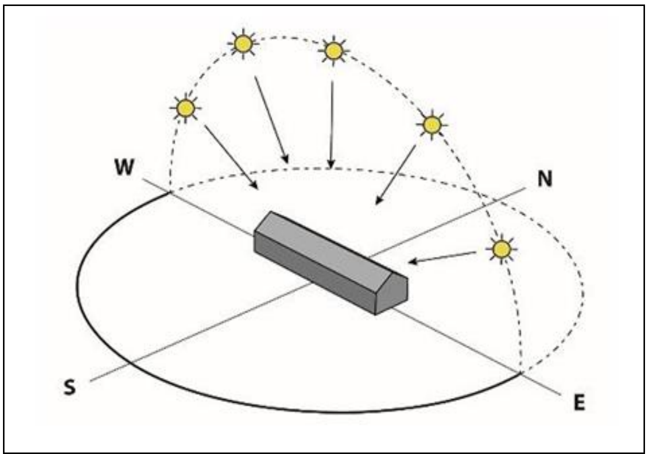

Fig 3: Model Orientation

B. Space Allocation

The shelter consists of several compact modules, designed to provide a functional and streamlined organization of spaces. Each module, either square or rectangular in shape, has been carefully planned to optimize the use of available space. The distribution of the modules is intended to ensure smooth circulation while meeting essential needs. The overall design prioritizes a minimalist approach, where each space serves a specific function without excess, ensuring maximum efficiency and essential comfort. This modularity creates a harmonious and cohesive environment, while adapting perfectly to spatial constraints.

- Bedroom Module: A private space, optimized for rest and storage. As illustrated in Figure 4.

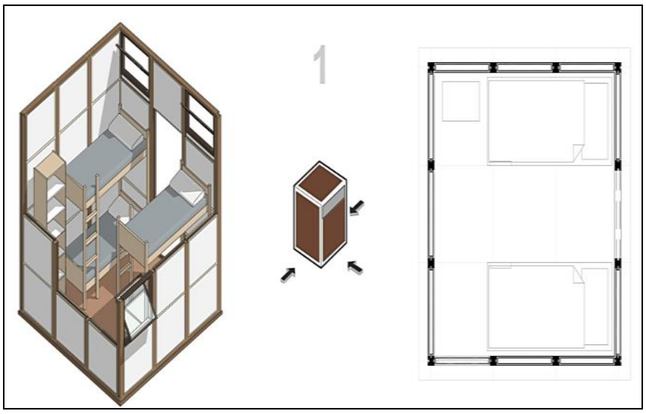

Fig 4: Bedroom Module 9m²

- Living Module: A central living area that serves as a gathering and relaxation space. As illustrated in Figure 5.

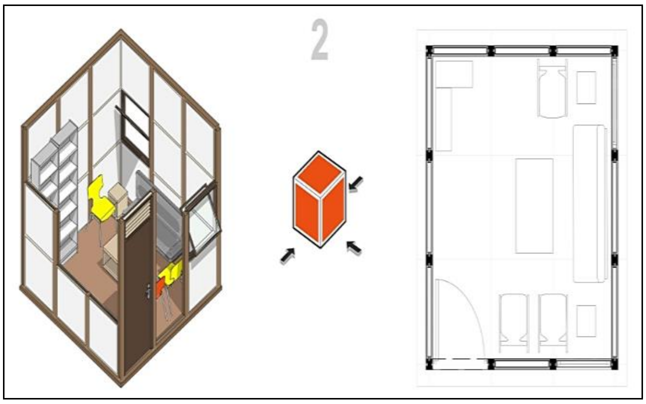

Fig 5: Living Module 9m²

- Kitchen Module: A functional space dedicated to meal preparation, with a minimalist yet practical layout. As illustrated in Figure 6.

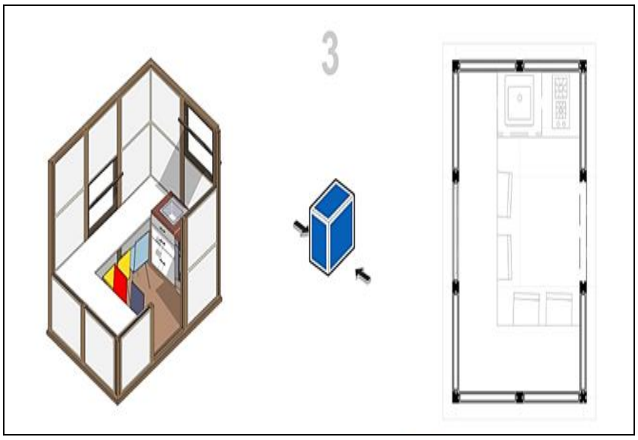

Fig 6: Kitchen Module 6m²

- Bathroom Module: A compact and well-organized space offering necessary amenities. As illustrated in Figure 7.

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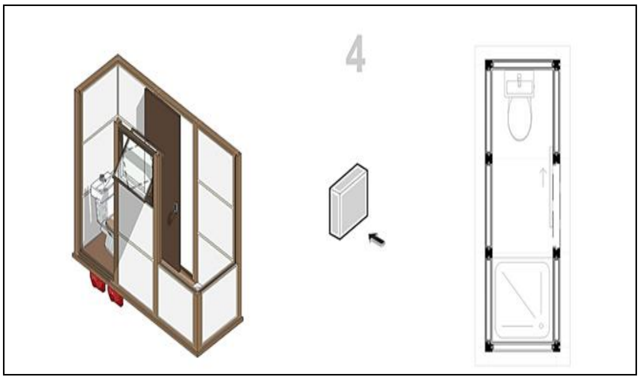

Fig 7: Toilet Module 3m²

- Terrace Module: An outdoor space extending the living area, allowing enjoyment of the surroundings. As illustrated in Figure 8.

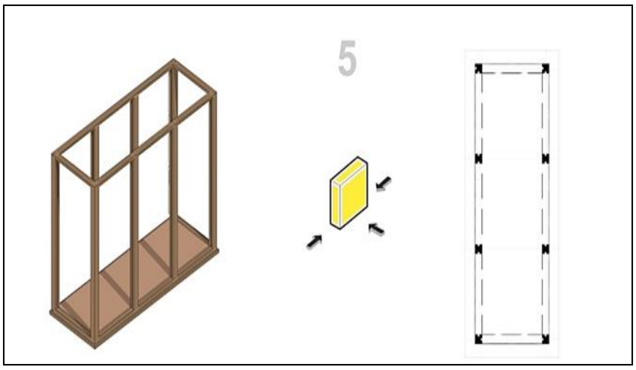

Fig 8: Terrace Module 3m²

C. Implementation and Evolution of the Model

In our project, which we have named evoNest, the basic model of the shelter consists of the initial assembly of the Living and Bedroom modules, thus forming the central core of the dwelling. This first setup is designed to meet essential needs, providing a minimal yet functional living and resting space as illustrated in Figure 9.

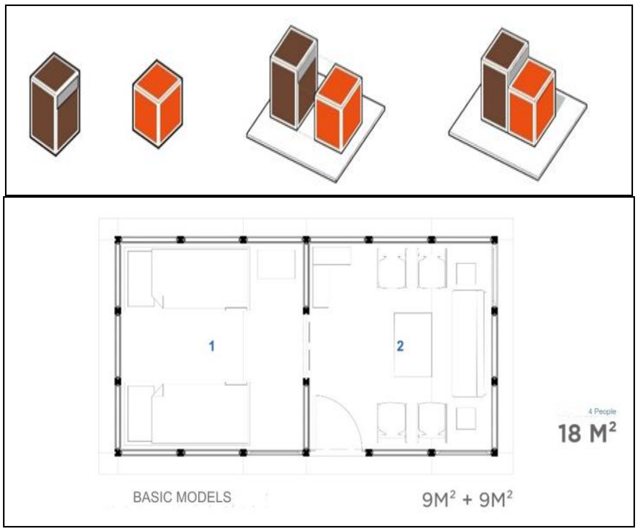

Fig 9: Living Module 9m²

The evolution of the model then proceeds through a modular and progressive approach, with the Kitchen, Bathroom, and Terrace modules being added to the central core. This expansion diversifies the functions of the shelter and enriches its use. With each addition, the expandable model takes shape, providing a complete and adaptable dwelling according to increasing needs or spatial constraints, as illustrated in Figure 10.

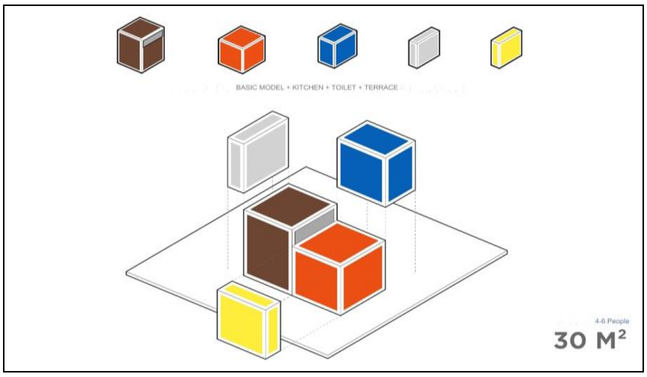

Fig 10: Expandable Model (04-06 People)

D. Modularity, Flexibility

Our evoNest shelter model embodies an innovative solution that combines modularity and flexibility, allowing for accommodating more people in a reduced space. Through clever design, the shelter optimizes the use of every square meter, while providing the ability to adapt spaces according to changing needs.

The modularity of evoNest is enhanced by the strategic arrangement of modules, which can be accessed from different façades as illustrated in Figure 11. This configuration allows for more efficient distribution of interior spaces and better circulation of people, while facilitating architectural adjustments according to site constraints or the preferences of the occupants. Figure 12 illustrates the modularity and flexibility diagrams of our model.

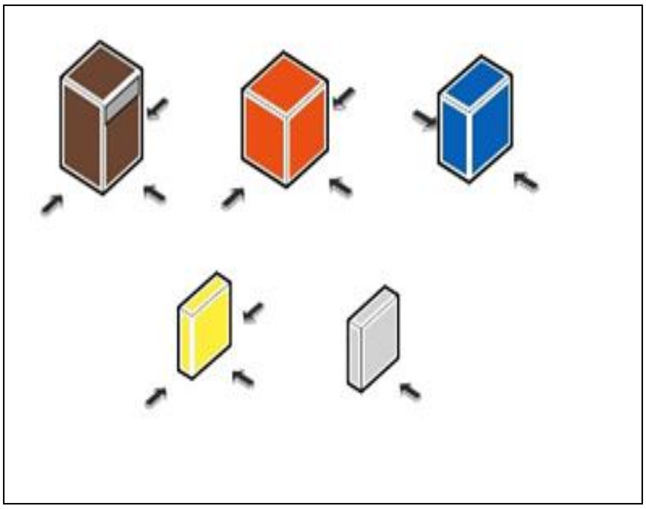
Fig 11: The Possible Access Points of the Different Modules

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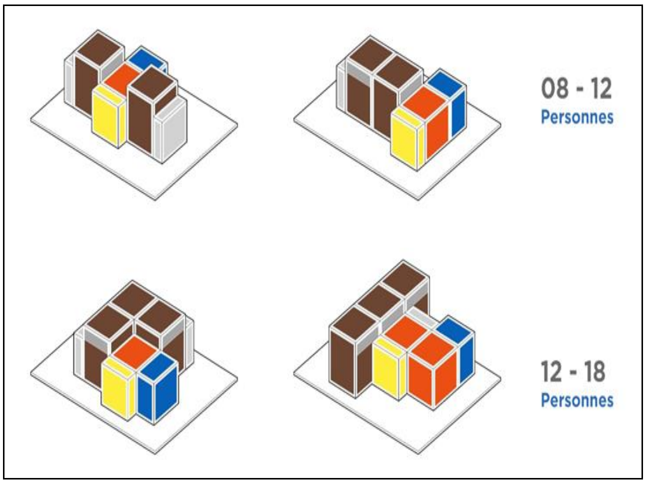

Fig 12: The Possible Access Points of the Different Modules

evoNest is designed to evolve over time. Additional modules can be added to the existing model to meet growing space or accommodation needs. This scalability allows for housing more people or addressing new functional requirements without compromising comfort or efficiency. Thus, evoNest stands out not only for its ability to maximize space but also for its flexibility to adapt to the needs of its occupants over time.

E. Openings

The evoNest shelter model stands out for its exceptional flexibility in terms of openings, allowing occupants to customize their environment according to their specific needs. With modular wall panels, doors, and windows can be placed at any location and height, enabling adaptation to site conditions and user preferences. This adaptability optimizes natural light entry, creating a bright and pleasant interior. Modular doors, in turn, facilitate interior arrangement and space organization, while improving circulation flow.

Additionally, ventilation can be finely controlled through reversible horizontal windows. These openings allow for adjusting fresh air intake based on climate conditions or specific needs, ensuring a comfortable and healthy indoor environment. This adaptability in openings makes evoNest a shelter capable of adjusting to various conditions while providing optimal comfort to its occupants.

Figures 13, 14, 15, and 16 show the arrangement of the openings and their modular possibilities.

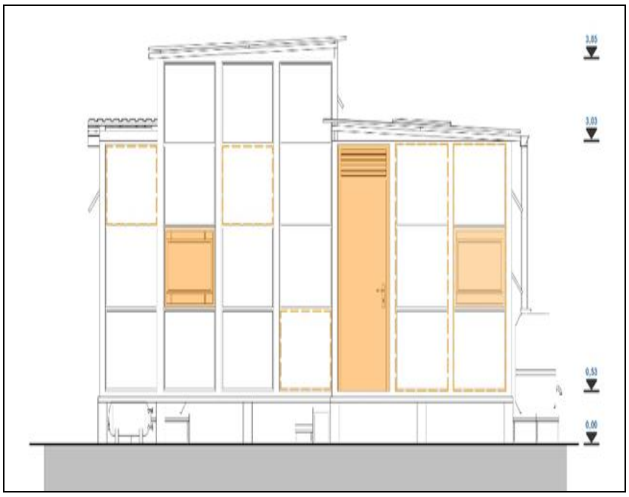

Fig 13: Openings on the South Façade

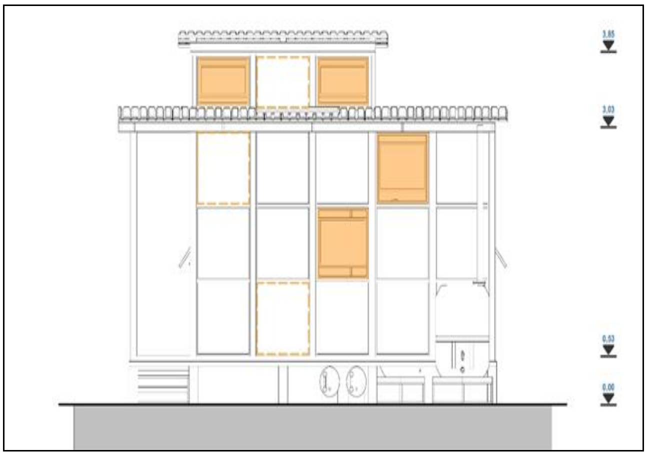

Fig 14: Openings on the East Façade

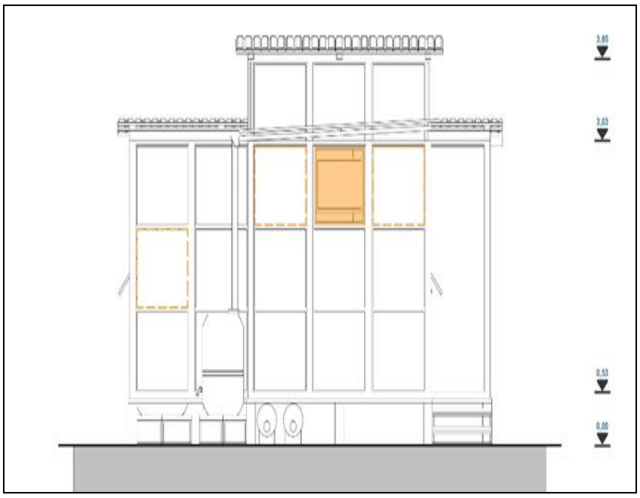

Fig 15: Openings on the West Façade

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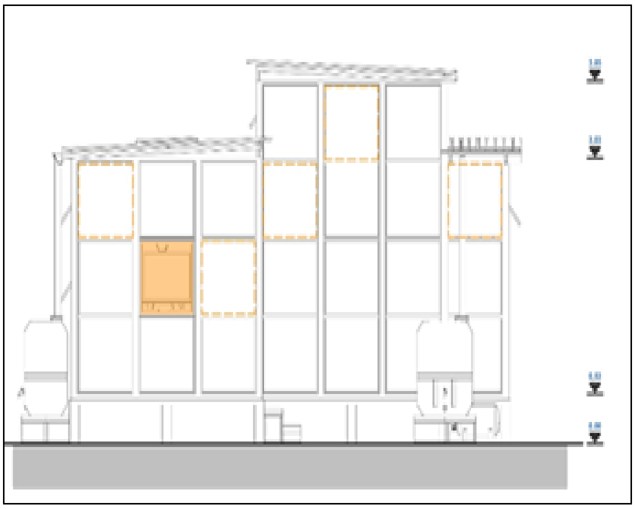

Fig 16: Openings on the North Façade

F. Natural Ventilation and Lighting

Cross-ventilation, both transverse and longitudinal, is ensured by pivoting windows located at a high level and by a stilt system that allows air to circulate under the structure, helping to naturally cool the interior by minimizing heat and moisture buildup. This system ensures efficient air circulation inside the building, as illustrated in Figure 17. Fresh air enters through the lower windows, while hot and stale air escapes through the upper windows and roof openings.

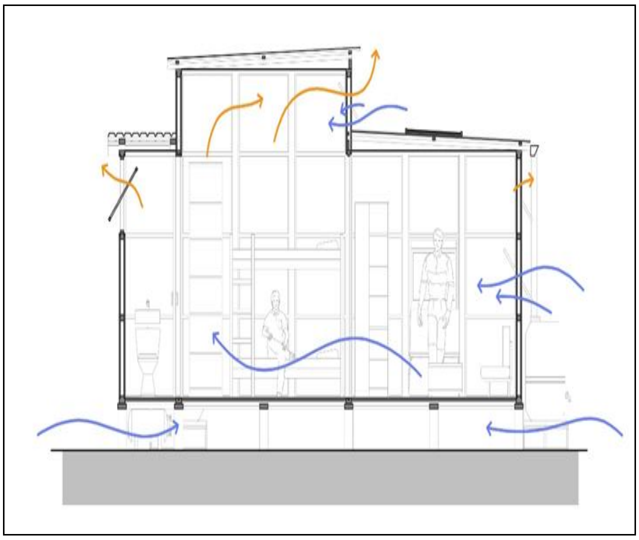

Fig 17: Natural Ventilation System

Each room in the building benefits from optimal natural lighting, which plays a key role in energy savings. The project is designed to maximize natural light throughout the day by taking advantage of the east-west orientation. This allows for full use of morning and evening light, ensuring a balanced distribution of light throughout the day. Additionally, this orientation contributes to better solar heat control, enhancing thermal comfort and reducing reliance on heating and cooling systems, as illustrated in Figure 18.

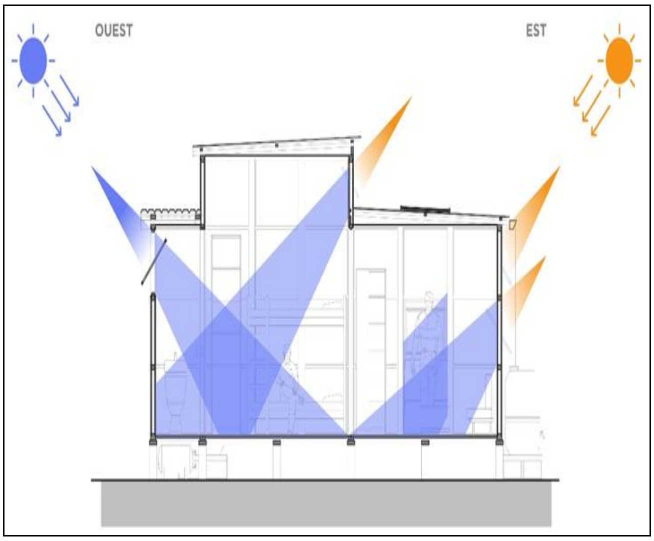

Fig 18: Natural Lighting System

G. Assembly and Material Selection

The construction modules are inherently modular, making their fabrication and assembly easy. Pre-designed and optimized for quick and simple installation, they can be assembled on-site by unskilled individuals using only basic hand tools, with no need for additional machinery.

The material selection was guided by environmental, economic, social, and cultural sustainability parameters, as well as modularity and flexibility, ensuring fast, efficient, durable, and adaptable implementation. Moreover, the selected materials are designed to facilitate assembly, reducing the time and effort required during construction. This ease of assembly contributes to quick installation while ensuring quality and durability. A breakdown of the basic model and the materials used for the housing model are illustrated in Figure 19.

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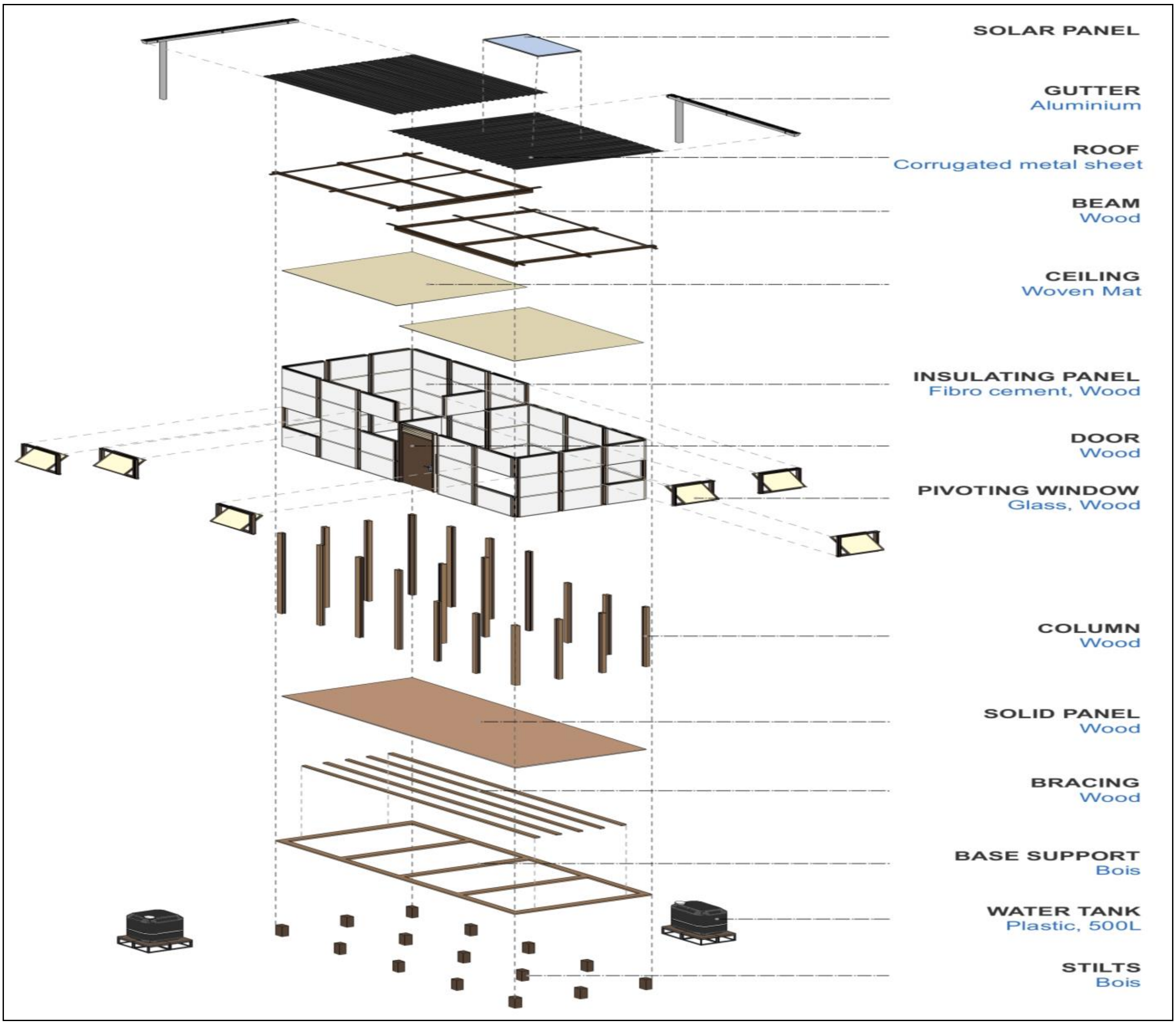

Fig 19: Exploded Axonometry and Materials

Designed with a wooden structure, the modules feature wall panels that are easy for a single person to transport and handle. The wooden panels and structure interlock using tongue-and-groove joints, allowing for fast and hassle-free construction. Figure 20 shows the details of the panel assembly.

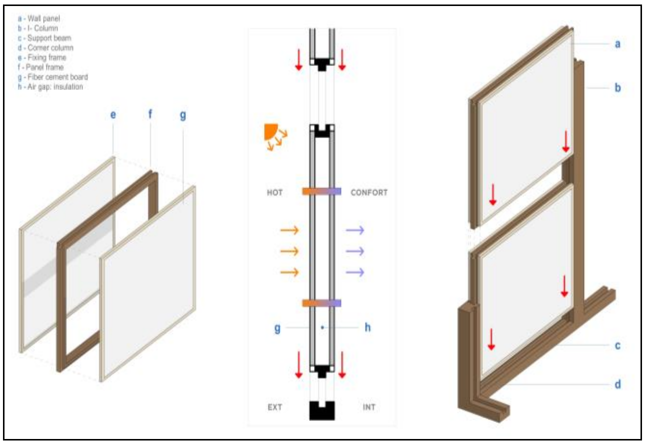

Fig 20: Wall Panel Assembly

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H. Renewable Energy

The integration of renewable energy, such as photovoltaic solar power, offers a cost-effective long-term solution for electricity generation. By adopting this technology, we can significantly reduce energy costs while decreasing our reliance on fossil fuels. Additionally, the use of solar energy contributes significantly to combating climate change by reducing greenhouse gas emissions. By choosing renewable energy sources, we not only promote financial savings but also play a crucial role in protecting the environment. Figure 21 illustrates renewable energy integration in our project.

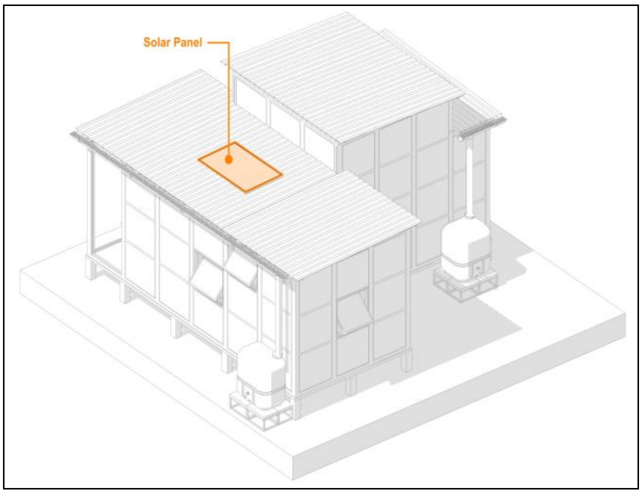

Fig 21: Renewable Energy Integration

I. Rainwater Management and Water Efficiency

Rainwater is collected and stored in water tanks and can be reused for laundry, gardening, and toilets, as illustrated in Figure 22.

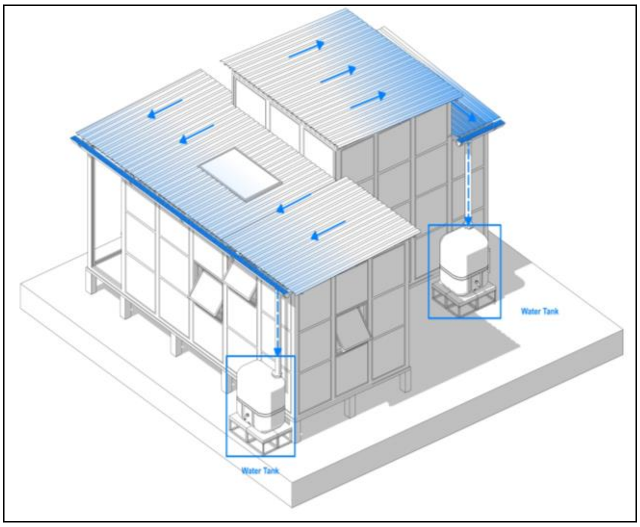

Fig 22: Renewable Energy Integration

Similarly, wastewater will be recovered and stored in drainable tanks and can be used in gardens, as shown in Figure 23.

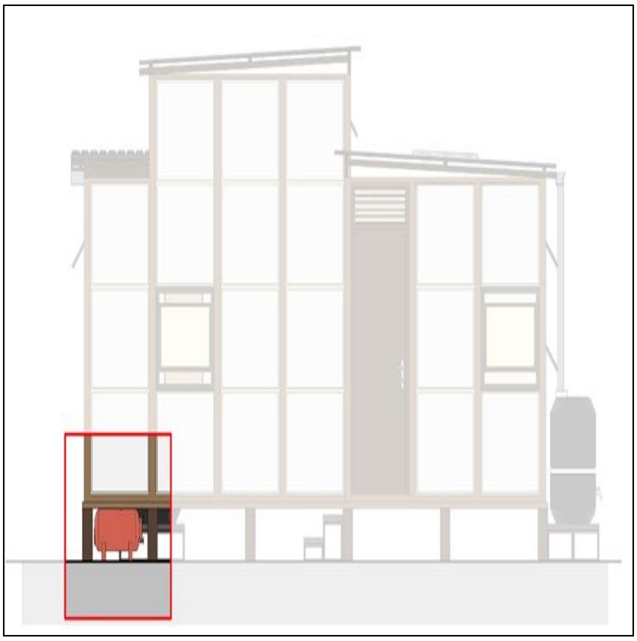
Fig 23: Wastewater Collection

To maximize water efficiency, we choose to install water-saving equipment such as low-flow faucets, showerheads, and low-flush toilets. Opting for water-efficient equipment in emergency shelters makes economic and environmental sense, allowing for financial savings, water resource preservation, and contributions to environmental sustainability.

J. Landscaping

The evoNest shelter model utilizes 60% of its allocated space, while the remaining 40% is dedicated to additional spaces: green courtyards to promote a healthy and pleasant environment, produce useful household vegetables, laundry spaces, and circulation areas.

- 60%: Main dedicated space (housing)
- 40%: Additional spaces including:
- ✓ 15%: Green courtyards for a healthy and pleasant environment, with vegetable production
- ✓ 15%: Laundry spaces
- ✓ 10%: Circulation (paths, corridors, etc.)

VI. PRELIMINARY COST EVALUATION

To calculate the costs of our project, we conducted a survey of local market prices. We studied the costs of materials available in the region and examined traditional construction techniques, relying on the expertise of local communities. This approach allowed us to arrive at a reliable estimate of the necessary expenses. Table II provides a summary of this overall evaluation for a basic evoNest.

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Table 2: Summary of Costs for a Basic Model

Description	Unit	Qty	U.P (FCFA)	T.P (FCFA)
Corrugated metal Sheets	m²	25	2,500	62,500
Wood	m³	1.136	250,000	284,000
Door	unit	1	30,000	30,000
Casement Window	unit	5	25,000	125,000
Insulating Panel	m²	63	10,000	630,000
Floor	m²	18	10,000	180,000
Woven Mat	m²	18	2,000	36,000
Total Building Materials				1,347,500
Water Tank 500L	unit	2	30,000	60,000
Bunk Bed	unit	2	50,000	100,000
Chair	unit	4	5,000	20,000
Table	unit	1	10,000	10,000
Total Equipment				190,000
TOTAL				1,537,500

The estimated total cost for our shelter model is approximately 1,537,500 CFA francs. This amount is provided as a rough estimate of the commercial value. A detailed quote will be prepared by measurement specialists before the start of the work.

VII. PROJECT IMPACT EVALUATION

The modular and durable emergency shelter project aims to provide rapid, sustainable, and adaptable housing solutions for populations in emergency situations. This impact assessment will analyze the potential effects of the project in environmental, social, and economic terms, as well as its short- and long-term implications.

A. *Environmental Impacts*

The environmental impact is central to this project, given the goal of sustainability.

- Resource Consumption: The project uses recycled and renewable materials, reducing the depletion of natural resources. However, the extraction and processing of some materials may have environmental impacts.
- Carbon Footprint Reduction: The modular design allows for local production, thereby decreasing transportation-related emissions. Additionally, integrating renewable energy solutions (solar panels, rainwater harvesting systems) helps reduce overall carbon emissions.
- Waste Management: The reusable and recyclable nature of the modules minimizes waste, but managing non-recyclable materials at the end of their life remains a challenge.

B. *Social Impacts*

Social impacts mainly concern the beneficiary communities and local populations involved in production.

- Improvement in Living Conditions: The shelters provide safe, dignified, and adaptable housing for people in crisis, thus enhancing their overall well-being.
- Local Community Involvement: Engaging local populations in the construction and installation of shelters creates job opportunities and strengthens community resilience.
- Cultural Acceptability: The modules need to be adapted to the cultural contexts of the beneficiaries to avoid conflicts and ensure smooth integration.

C. *Economic Impacts*

The economic impact assessment analyzes effects on costs, long-term benefits, and implications for the local economy.

- Initial Costs: Developing and producing the modules requires significant initial investment, but economies of scale and durability reduce long-term costs.
- Job Creation: Local production and installation of the modules create jobs, stimulating the local economy.
- Cost-Effectiveness: In the long term, the durability of materials and low maintenance ensure increased cost-effectiveness compared to traditional temporary shelter solutions.

D. *Risks and Mitigation Measures*

Risks include production delays, limited social acceptability, and unforeseen environmental impacts. Mitigation measures include participatory planning, regular environmental impact monitoring, and technological adjustments in response to user feedback.

E. *Projection Towards Modular Refugee Camps*

Projecting modular emergency shelters towards refugee camps opens new perspectives for managing humanitarian crises. Given the rising number of displaced persons worldwide, the need for rapid, effective, and sustainable housing solutions is more urgent than ever. Modular shelters offer unparalleled flexibility, allowing for rapid installation and easy adaptation to the changing needs of refugee populations. Integrating these shelters into camp planning can create living spaces that not only ensure the safety and dignity of residents but also provide some long-term stability. Modularity allows for space reconfiguration as needed, adding units for expansion or reorganizing according to demographic or climatic changes. Additionally, by using local materials and relying on traditional construction techniques, these camps can be set up more quickly while remaining cost-effective and environmentally friendly. This modular approach thus creates resilient refugee camps capable of evolving over time while providing decent living conditions for vulnerable populations. Figure 24 illustrates a possible layout of a refugee camp made up of modular shelters.

Fig 24: Refugee Camp Composed of Modular Shelters

VIII. STRENGTHS AND OPPORTUNITIES OF OUR PROJECT

The development of modular emergency shelters presents significant strengths and opportunities that enhance their relevance in the context of humanitarian crises. These key elements allow for evaluating the effectiveness of these structures in addressing the growing challenges of population displacement while exploring possibilities for improvement and large-scale expansion. Table III shows the analysis of the strengths of our project, and Table IV shows the analysis of the opportunities of our project.

Table 3: Strengths of Our Project

Strengths
• Durability: Use of recyclable and renewable materials, reduction of carbon footprint. • Modularity: Adaptability to various environments, crisis situations, and changing needs. • Flexibility: Response to growing needs for space or accommodation. • Rapid Deployment: Design allows for quick installation, essential in emergencies. • Long-term Cost Reduction: Increased cost-effectiveness due to durability and low maintenance.

Table 4: Opportunities of Our Project

Opportunities
• **Market Expansion:** Growth in the market for sustainable emergency shelters in the context of increasing humanitarian crises and population displacement. • **Technological Innovation:** Possibility of integrating advanced technologies (smart solutions) to further enhance the shelters. • **Strategic Partnerships:** Collaboration with NGOs, governments, and businesses to strengthen funding, research, and distribution. • **Growing Environmental Awareness:** Global trend towards more eco-friendly solutions, creating a favorable environment for the project.

IX. CONCLUSION

In summary, this article has allowed us to provide a thorough examination of our modular emergency shelter project, detailing the project's site characteristics and specific requirements. We traced the evolution of the architectural design, from initial concept to the development of a detailed qualitative and quantitative program. Our approach addressed both ecological and modularity needs, incorporating strategies for flexibility and energy efficiency while managing site-specific constraints. Finally, we synthesized the preliminary cost assessment and impact evaluation, setting the stage for further discussion on the project's feasibility and long-term benefits for emergency housing solutions.

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