U.P.B. Sci. Bull., Series D, Vol. 86, Iss. 4, 2024 ISSN 1454-2358

DESIGN OF DUAL-PURPOSE INDIVIDUAL SHELTERS FOR HOMELESSNESS AND EMERGENCY RESPONSE

Mircea Costin ENE[1]*, Ionel SIMION[2]

This article advocates the implementation of dual-purpose individual shelters in urban areas; they should help the homeless in the cold season and also serve as temporary emergency shelters in crisis situations such as earthquakes, floods, or others. By seamlessly transitioning from safety solutions to emergency response facilities, these shelters contribute to complete urban development. Dual functionality enhances the aesthetic appeal of cities while providing essential services, exemplifying the interconnectedness of community well-being and emergency preparedness. Successful implementation requires collaborative efforts between local governments, non-profit organizations and the private sector. This innovative approach not only addresses immediate challenges but also fosters resilience, creating communities that are both empathetic and well-prepared for various scenarios.

Key Words: Emergencies shelters, individual, urban development, dual functionality, industrial engineering

1. Introduction

In urban environments where homelessness persists as a pressing issue and the threat of emergencies such as earthquakes looms large, individual dual-purpose shelters have emerged as an innovative solution. Engineered with a multifaceted approach, these shelters address the immediate needs of the homeless population during harsh weather conditions while also serving as adaptable structures for temporary refuge during crises.

Research has shown the necessity of shelters for people without homes, especially during life-threatening weather conditions. Engineers and architects have been working on solutions for these individuals, as well as for those who avoid public shelters because of strict rules and prefer to find their own places to sleep.

The state-of-the-art project identified for this research is Ulmer Nest. This German-born project has set the target to help people stay warm during harsh

[1]* Eng., Department of Graphic Engineering and Industrial Design, National University of Science and Technology POLITEHNICA Bucharest, e-mail: mirceaene26@gmail.com (corresponding author)
[2] Prof., Department of Graphic Engineering and Industrial Design, National University of Science and Technology POLITEHNICA Bucharest, e-mail: ionel_simion@yahoo.com

conditions and has been implemented in the city of Ulm for those in need to use it whenever it is necessary.


Fig. 1 Ulmer Nest

Fig. 1 highlights the Ulmer Nest, a shelter hand-crafted for individuals who are unable to access conventional social shelters for various reasons. The Ulmer Nest is not meant to replace standard social shelters; instead, it acts as a 'last resort' to protect those at risk of exposure to harsh weather conditions. The final prototype is made from solid wood, selected for its robustness, insulating properties, and both economic and ecological advantages. Additionally, the structure includes powder-coated metal elements for easy and thorough cleaning. Key technologies integrated into the design include a heat exchanger for fresh air circulation, sensors, GPS, smoke alarms, and a motion detection system, ensuring safety and functionality. The design is also fireproof and features a secure locking mechanism.[1]

This paper proposes an improved design that integrates widely used materials known for their outstanding performance, high recyclability rates, and structural techniques ensuring durability and versatility. These include modular construction and tough materials tailored for urban resilience. The aim is to ensure efficient industrialization and streamlined processes for emergency readiness, providing safety and protection for those in need against the dangers of cold weather at a much lower cost of production and with a longer lifespan.

These shelters also feature essential yet indispensable amenities such as heating sources, ventilation control systems, and real-time monitoring. In this article, we delve into the technical details of individual dual-purpose shelters, from their primary purpose to deployment, highlighting their transformative potential in addressing both homelessness and disaster resilience in urban environments. Figure 2 below displays the potential and functional design of one assembly.

Fig. 2 Whole Assembly

2. **Reducing the number of homeless people and improving the urban space:**

Utilizing individual shelters as a solution to homelessness brings multifaceted benefits to urban areas, addressing critical social and infrastructural challenges. Primarily, it offers a secure and climate-controlled refuge for individuals facing homelessness, especially vital during severe weather conditions like the cold seasons. [2]

This proactive approach not only shields vulnerable populations from the detrimental effects of extreme weather but also mitigates the risk of associated health emergencies, thus potentially reducing the burden on healthcare services. Investing in such shelters represents a strategic allocation of resources, as preventing homeless individuals from succumbing to weather-related health issues can ultimately yield significant cost savings compared to the burden of treating them in hospitals for weeks or even months depending on the severity of health issue. [3]

In addition to meeting the basic needs of the homeless population, these shelters can help improve the urban landscape. In recent years, hostile designs such as spikes and benches with armrests, preventing people from lying down, have increasingly appeared on the main streets of cities. These measures aim to drive homeless people away without providing alternative solutions. Strategically located and thoughtfully designed shelters can offer a more humane approach, enticing homeless individuals away from the streets while simultaneously enhancing the overall appearance of the city. This will also help the mobile social services to locate them, to intervene to help, and to keep a better record of their state of health. This dual functionality aligns with the principles of inclusive urban development and fosters a sense of community care. [4]

3. Response in emergency situations and temporary shelters:

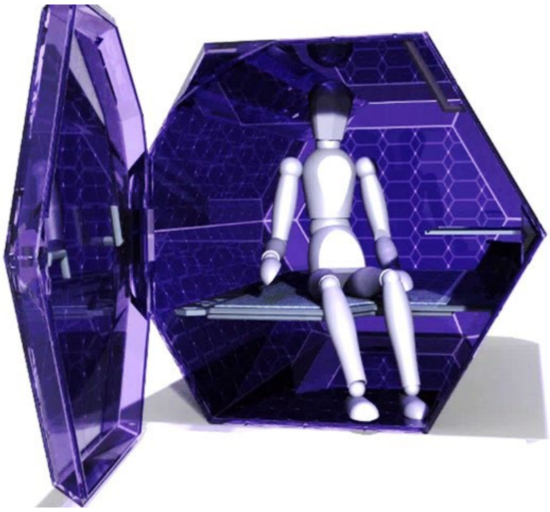

Fig. 3 Capsule and occupant

The adaptability of these shelters makes them invaluable in emergency situations. In the event of earthquakes or other crises requiring rapid evacuation, these individual shelters can seamlessly transition into temporary emergency shelters [5]. Figure 3 depicts one capsule and an occupant inside.

For example, the Central Disaster Prevention Council (CDPC) reports on the 2004 Niigata earthquake in Japan, for example, illustrate this dynamic. illustrate this dynamic. The number of evacuees peaked at over 100,000 on the fourth day after the earthquake but fell to around 10,000 by the end of the first month. This example highlights the importance of considering fluctuating shelter demands in post-earthquake planning. [6]

Loading 10 individual shelters, complete with the necessary framework and equipment, into a 12-meter-long shipping container facilitates rapid deployment by authorities to affected areas where people have lost their shelter. This temporary measure provides immediate relief until more permanent solutions can be implemented.

Dual-purpose shelters serve as evidence of the importance of proactive urban planning, emphasizing the interconnectedness of social well-being, infrastructure development, and emergency preparedness. By integrating these shelters into urban landscapes, cities can create a more resilient and compassionate environment that addresses immediate challenges while building a foundation for long-term community well-being. [7]

4. Simulation and analysis

For the shelters to be effective, especially in bad weather conditions and temperatures below 0 degrees Celsius, ensuring the interior of the capsules remains warm requires a reliable heating source and effective wall insulation The primary heating mechanism, seen in Figure 4, involves the bed surface, which operates similarly to a heated blanket with built-in electrical heating wires. Simulations in StarCCM+ have demonstrated that, even when subjected to strong, cold winds, the capsules can maintain a comfortable temperature under optimal conditions.

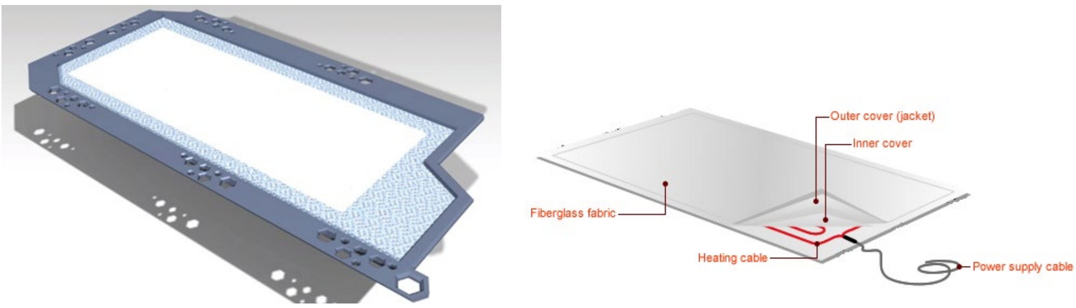

Fig. 4 Heating Source Inside Bed

Extensive testing was conducted across a range of temperatures, particularly focusing on sub-zero environments, to analyze how the shelters respond to different thermal conditions using fundamental engineering equations to determine its thermal performance under various environmental conditions.

a. Energy Balance Equation [8]:

$$Q\text{mannequin}+Q\text{heated bed}-Q\text{loss conduction}-Q\text{loss drainage hole} = 0 \qquad (1)$$

This equation governs the equilibrium between internal heat generation (Qmannequin and Qheated bed) and heat loss mechanisms, including conduction and ventilation.

b. Heat Loss due to Conduction [8]:

$$Q\text{loss conduction} = U \times A \times (T\text{inside} - T\text{outside}) \quad (2)$$

Here, U represents the overall heat transfer coefficient, A is the surface area of the capsule, and ΔT is the temperature difference between the inside and outside of the capsule.

c. Heat Loss due to drainage hole [9]:

$$Q\text{loss ventilation} = \dot{m}\text{air} \times cp \times (T\text{inside} - T\text{outside}) \quad (3)$$

In this equation, $\dot{m}$air denotes the mass flow rate of air through the hole, and cp is the specific heat capacity of air.

The input data used are shown in table 1:

Table 1

	Components	Density [kg/m3]	Cp [J/KG-k]	U [W/m-K]	Emissivity	Reflectivity
PMMA (Polymethyl methacrylate) [10]	Capsule walls, ventilation system, bed	1185	1466	0.2085	0.15	0.1
Air Solid	Pockets of air	1.18415	1003.62	0.0260305		
Human [11]	Mannequin	1000	3770	0.21	0.97	0.03
Concrete [12]	Seating surface	2240	750	0.53	0.94	0.06

These simulations aimed to replicate real-world scenarios, offering insights into the shelter's performance in diverse climates. For the best results, it is crucial to keep the heated bed at its highest setting and ensure that all ventilation is closed, leaving only the drainage hole at the bottom of the capsule open. Conditions used for this test are represented in the table 2 below.

Table 2

	Temp -8°C	Temp -15°C	Temp -18°C
Wind Speed	12m/s	12m/s	12m/s
Wind Dir.	Longitudinal	Longitudinal	Longitudinal

Mannequin [11]	33°C	33°C	33°C
Bed Temp	56°C	56°C	56°C
Ground temp [13]	-2°C	-2°C	-2°C

During the initial test, which took place at a temperature of -8°C — colder than Bucharest's average January temperature of -5°C [14] — the combination of a heated bed and well-insulated walls significantly increased the internal temperature, reaching an impressive 21°C as the diagram in Figure 5 shows. This result highlights the effectiveness of the shelter's heating system, especially in conditions that match or exceed the area's usual winter temperatures

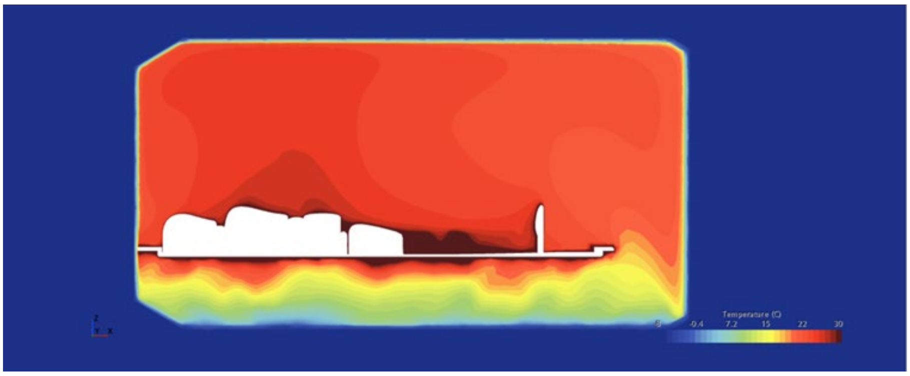

Fig. 5 Inside Temperature 21°C

In the second test, conducted at the average February temperature in Greenland, one of the coldest regions in Europe with an average of -15°C [14], the internal temperature still managed to reach 16°C as illustrated in Figure 6 diagram. This demonstrates the shelter's ability to maintain a warm environment even in such extreme cold conditions.

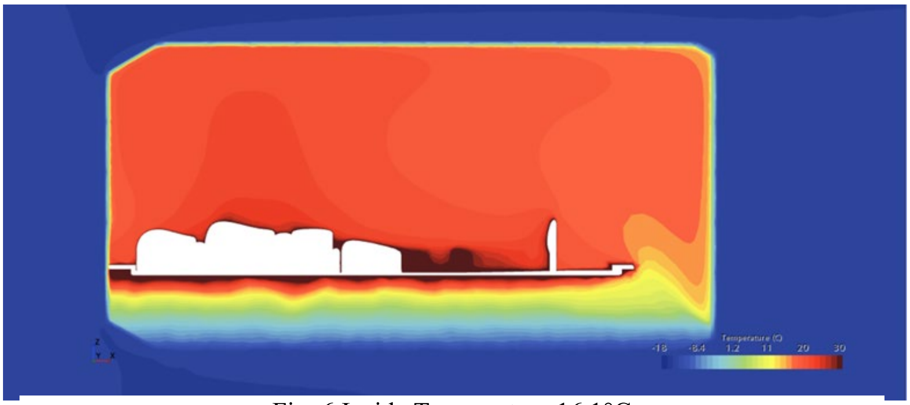

Fig. 6 Inside Temperature 16.1°C

The third and most rigorous test was performed at -18°C, a temperature often utilized in car manufacturers' defrosting tests. Impressively, despite these harsh conditions, in the diagram in Figure 7 we see that the internal temperature of the shelter rose to 14.3°C. This observed data highlights the shelter's strong thermal performance, establishing it as a feasible option for severe winter climates.

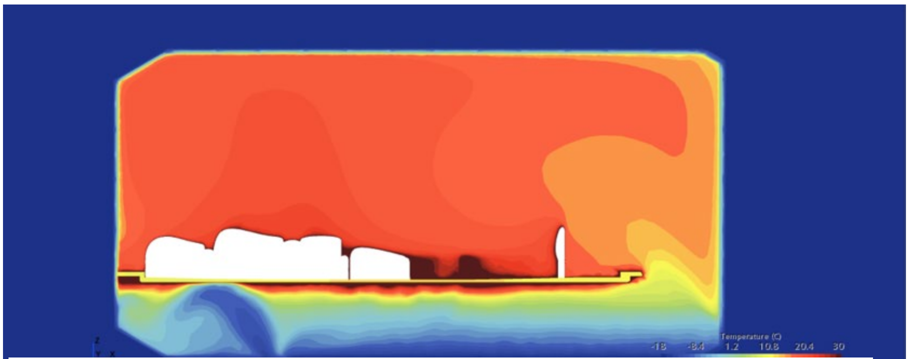

Fig. 7 Inside Temperature 14.3°C

These observations provide a critical basis for the academic study of the shelter's thermal dynamics, offering important insights for their practical application in various climatic conditions. All the results obtained from the simulations can be seen in Table 3 below.

Table 3

	Av. Temp. Inside	Max Temp Walls	Min. Temp Walls	Av. Air Speed Inside
Temp -8°C	21.1°C	56°C	-8°C	0.084
Temp -15°C	16.1°C	56°C	-15°C	0.083
Temp -18°C	14.3°C	56°C	-18°C	0.086

To facilitate easier future maintenance by public authorities, it is essential to limit the use of electronic components within the shelter design. Apart from the heating system already mentioned, the occupant is supplied with minimal electronic features, such as a light source and a phone charging outlet. When a direct connection to the electrical grid for each capsule isn't possible, an additional framework can be installed on top of the structure to provide the necessary power.

5. Design and modularity:

This article presents a new and improved design of such individual shelters that serve as a temporary refuge for those facing the temperatures of the cold seasons. Designed to be inspired by nature and friendly to the urban environment, the ensemble consisting of 5 individual capsules is intended to contribute to the improvement of the urban appearance and increase the quality of life.

. The design was created with the help of CATIA V5 from Dassault Systèmes CATIA is an industry standard in various sectors including automotive, aerospace, industrial equipment, and more.. This enables fast and efficient prototyping, ensuring a high level of precision and design optimization before final production.

The capsule itself comprises a single exterior shell with reinforced walls to enhance their structural integrity and create air pockets for prolonged heat retention. The enclosed air volume totals approximately 2.9 m^3, equivalent to 2900 liters. Considering the average human's equivalent air consumption of 66 liters, along with luggage volume, the available volume reduces to 2800 liters. Oxygen levels within the 2.8 cubic meters of air are contingent upon the initial concentration, typically around 21% at sea level. Therefore, the oxygen content would amount to:

$$(2{,}800)\ (21/100) = 588 \text{ liters} \tag{4}$$

To ascertain an individual's survivability in a sealed container with 2.8 cubic meters of air, factoring in an oxygen consumption rate of 0.5 l/min and carbon dioxide production, the following formula is applied [15]:

Time (minutes) = (588 liters of oxygen) / (oxygen consumption rate (l/min) + carbon dioxide production rate (l/min))

Assuming an oxygen consumption rate of 0.5 l/min and carbon dioxide production rate of 0.5 l/min, the calculation yields:

$$\text{Time (minutes)} = 588 / (0.5+0.5) = 588/1 = 588 \text{ minutes} \tag{5}$$

Thus, an individual can endure approximately 588 minutes, or close to 10 hours, in a sealed container with 2.8 cubic meters of air, under the specified conditions. To ensure adequate ventilation, the capsule will feature eight adjustable holes for air inflow, allowing occupants to regulate internal temperature as needed.

Following the installation and anchoring of the frame, the capsules can be randomly positioned within it as shown in Figure 8, accompanied by the abovementioned electronic components tailored for each capsule. To lift them, it is necessary to use a forklift or other equipment to minimize the risk of injury caused by the size and weight of the capsules. These components are engineered for effortless replacement or repair, ensuring seamless functionality and maintenance of the system.

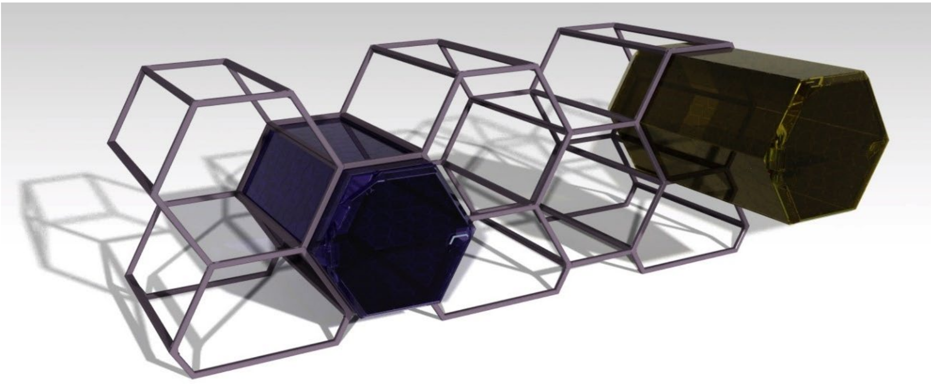

Fig. 8 Assembly Installation

Therefore, the assembly can be purchased in three configurations depending on the need, thus reducing costs if not all options are needed. It can be purchased in a first basic configuration, i.e., only with the 5 capsules presuming that the assembly can be connected to a power source as in Figure 9.

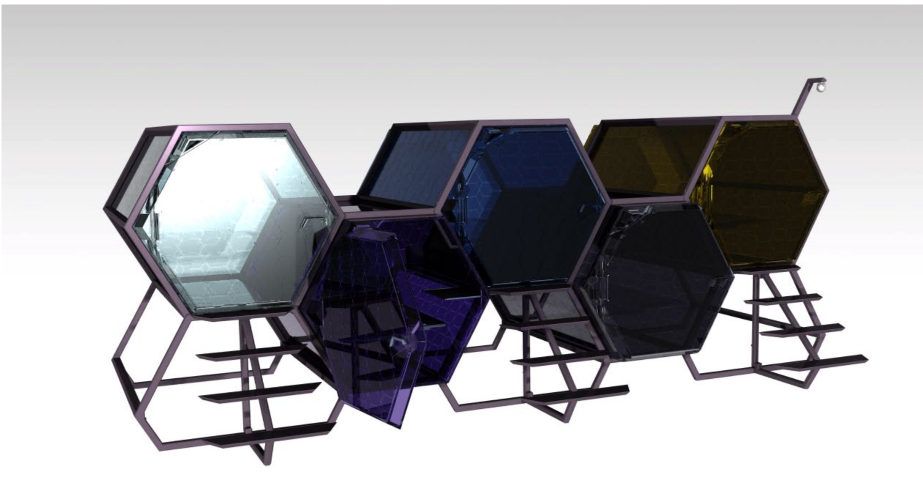

Fig. 9 Basic Configuration

A second configuration presents the purchase of extra storage space that is installed at the base of the assembly (Figure 10), and the third configuration is the one to which the photovoltaic system is added together with the service capsule plus related components and framework (Figure 11).

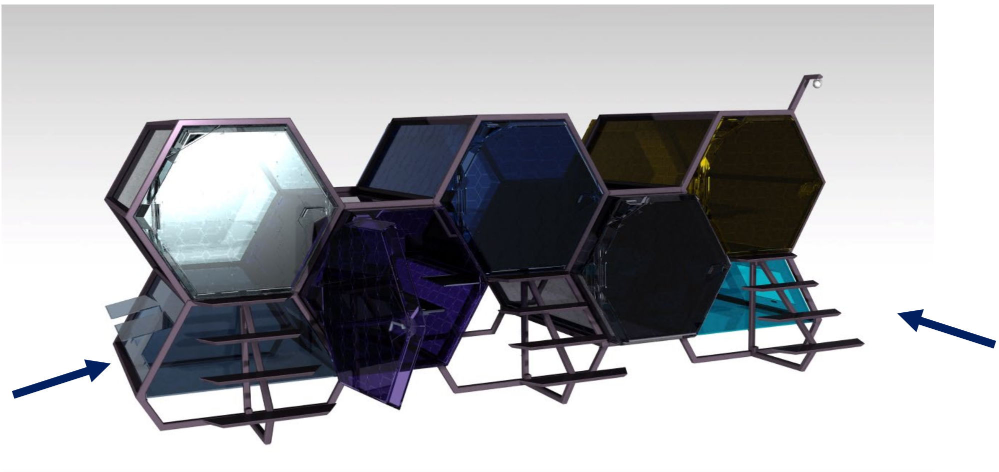

Fig. 10 Extra Storage Configuration

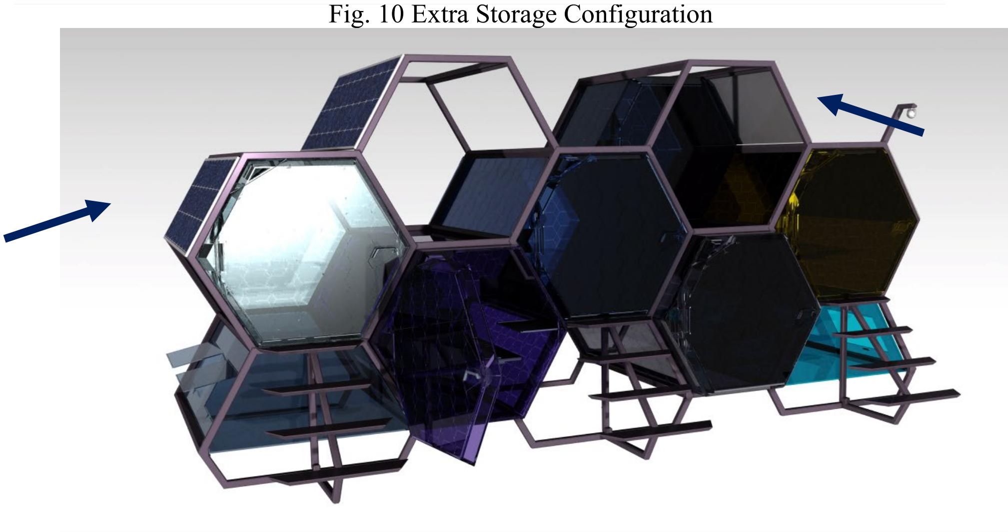

Fig. 11 Electrical independence Configuration

The modularity of the assembly consists not only in the freedom of installation in different forms or equipment levels, but also in the ease with which two such assemblies consisting of ten capsules and the additional parts can be loaded into a specially modified container so that after unloading and installing the assemblies, the container will transform into a sanitary unit with showers and toilets. Shipping containers are built to a standard size, making them compatible with international transport logistics. This ensures ease of loading, unloading, and handling across various modes of transportation, such as ships, trains, and trucks.

Unfortunately, either 2 assemblies can be loaded inside with the equipment for energy independence, or with extra storage space, Figure 12 depicts in different colors the assembly components inside.

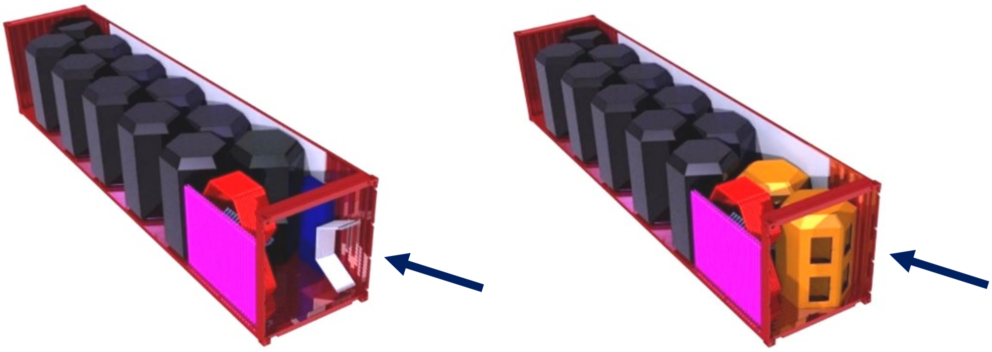

Fig. 12 Loaded Containers

These containers can be seamlessly transferred between different transportation methods (for example, from ship to rail to truck) without the need for unloading and reloading the contents, reducing the risk of damage and loss [16].

With pre-installed pliable walls, the process simply involves unloading the equipment inside and unfolding the walls to configure the cabins, as illustrated in the Figure 13 below.

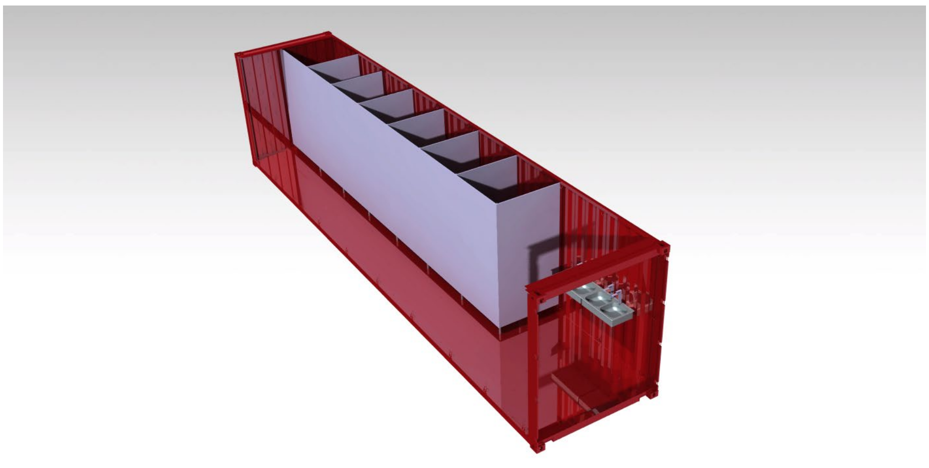

Fig. 13 Transformed Container

6. Conclusions

In conclusion, the integration of individual dual-purpose shelters offers a pragmatic and forward-looking approach to urban challenges. Beyond serving as shelters for street people during cold seasons, these structures embody a versatile strategy that responds to emerging crises such as earthquakes with efficiency and ingenuity.

The materials used in the construction are highly recyclable and durable, commonly utilized across various industries. Their widespread availability and ease of procurement contribute to keeping production costs much lower, enabling high-rate manufacturing. This not only ensures sustainability but also allows for the rapid deployment of emergency shelters, meeting the urgent needs of affected populations efficiently and cost-effectively.

The dual functionality of these shelters underlines the importance of adaptability in urban planning. By strategically incorporating shelters that address both immediate social needs and unforeseen emergencies, cities can optimize resources and increase overall resilience. This approach represents a rational response to the evolving dynamics of urban life, recognizing the need to address homelessness while preparing for unpredictable events.

The success of individual dual-purpose shelters relies on community engagement and collaboration between local authorities, non-profit organizations and the private sector. Establishing partnerships can lead to the creation of shelters that not only meet the basic needs of homeless people, but also contribute to the overall improvement of urban spaces.

R E F E R E N C E S

[1] *L. Myers,* Designboom, Patrick Kaczmarek, Florian Geiselhart, Falko Pross, Manuel Schall, Dirk Bayer, Kathrin Uhlig , 03 Feb 2021. [Online]. Available: https://www.designboom.com/architecture/ulmer-nest-solar-powered-shelter-protect-homeless-people-in-winter-02-03-2021/.

[2] *L. Pop*, National strategies to fight homelessness and housing exclusion Romania, *European Social Policy Network (ESPN),* p. 34, 2019.

[3] *L. H. F. David A. Sleet*, Homelessness and Public Health: A Focus on Strategies and Solutions, National Library of Medicine, 6 11 2021.

[4] NAEH, Would Adding More Emergency Shelter Help Reduce Unsheltered Homelessness? It's Complicated…, National Aliance to end Homlessness, 2018.

[5] *J. S. S. S. S. U. Ayusha Joshi*, Role of Architects in Building Disaster Resilient Communities, in IOE Graduate Conference, 2020.

[6] *L. Z. R. H. Q. H. Huiyong Li*, Hierarchical earthquake shelter planning in urban areas: A case for Shanghai in China, Sciences Direct, vol. 22, pp. Pages 431-446, 2017.

[7] *I. Team*, the utility industry's role in disaster preparedness, 2024. [Online]. Available: https://www.intterra.io/blog/utility-industry-role-in-disaster-preparedness/.

[8] *A. Dickerson*, Energy Balance for Closed Systems, University of Central Florida Pressbooks , 2019. [Online]. Available: https://pressbooks.online.ucf.edu/thermorit/chapter/energy-balance-for-closed-systems/. [Accessed 2024].

[9] *D. Mousdell,* Calculating Heat Loss - A Simple and Understandable Guide, h2x Engineering, [Online]. Available: https://www.h2xengineering.com/blogs/calculating-heat-loss-simple-understandable-guide/. [Accessed 2024].

[10] By Team Xometry, Everything You Need To Know About Acrylic (PMMA), 4 May 2022. [Online]. Available: https://www.xometry.com/resources/materials/acrylic-pmma/.

[11] J. P. R. Desikan Bharathan, Thermal-Properties-of-the-Human-Body, researchgate, 05 2005. [Online]. Available: https://www.researchgate.net/figure/Thermal-Properties-of-the-Human-Body_tbl1_228625768. [Accessed 2023].

[12] ennologic, Ultimate-Emissivity-Table, 2018. [Online]. Available: https://ennologic.com/wp-content/uploads/2018/07/Ultimate-Emissivity-Table.pdf. [Accessed 2022].

[13] *P. Knox*, How hot does pavement get, ga.edu, 12 05 2022. [Online]. Available: https://site.extension.uga.edu/climate/2022/05/how-hot-does-pavement-get/. [Accessed 2023].

[14] European State of Climate, 2021. [Online]. Available: https://climate.copernicus.eu/european-temperature.

[15] M. A. G. W. M. D. D. C. M. M. Joachim D. Pleil, The physics of human breathing: flow, timing, volume, and pressure parameters for normal, on-demand, and ventilator respiration, National Library of Medicine, 09 2022.

[16] A Guide to Shipping Container Sizes, BigBox, [Online]. Available: https://www.bigboxcontainers.co.za/blog/a-guide-to-shipping-container-sizes.

[17] European Observatory on Homelessness, Family Homelessness in Europe, Brussels, 2017.

[18] By Team Xometry, Everything You Need To Know About Acrylic (PMMA), 4 May 2022. [Online]. Available: https://www.xometry.com/resources/materials/acrylic-pmma/.

[19] European Parliament, How Parliament wants to end homelessness in the EU, 24 11 2020. [Online]. Available: https://www.europarl.europa.eu/news/en/headlines/society/20201119STO92006/how-parliament-wants-to-end-homelessness-in-the-eu.

[20] Fundation Abbé Pierre - FEANTSA, Fourth overview of housing exclusion in Europe, 2019.

[21] *B. Isabel and Eric Marlier*, Fighting homelessness and housing exclusion in Europe - A study of national policies, Brussels, 2019.

[22] Copernicus, European Parliament, [Online]. Available: https://climate.copernicus.eu/. [Accessed 2023].