

## Container-Based and 3D-Printed Temporary Shelters: A Comparative Exploratory Assessment



Nidal Asbah\* , Seyhan Yardımlı , Özgün Arın 

Faculty of Art, Design and Architecture, Architecture Department, Istanbul Okan University, Istanbul 34959, Türkiye

Corresponding Author Email: [nidal.alasbah@gmail.com](mailto:nidal.alasbah@gmail.com)

Copyright: ©2026 The authors. This article is published by IIETA and is licensed under the CC BY 4.0 license (<http://creativecommons.org/licenses/by/4.0/>).

<https://doi.org/10.18280/ijstdp.210409>

### ABSTRACT

**Received:** 20 December 2025

**Revised:** 14 April 2026

**Accepted:** 23 April 2026

**Available online:** 30 April 2026

#### Keywords:

*3D concrete printing, comparative assessment, container shelters, disaster housing, life-cycle costing, post-disaster recovery, thermal performance, Türkiye earthquake*

This study presents a mixed-method comparative assessment of container-based temporary shelters (empirical field evidence) and 3D concrete-printing (3DCP) alternatives (literature-derived scenarios). Using the Arkas Şirikçioğlu Container City in Kahramanmaraş as the primary empirical case, the study combines on-site empirical evidence from visits, interviews, and field notes with secondary data derived from literature for representative 3D-printed precedents. The comparison covers capital and life-cycle cost, deployment logistics, thermal performance, environmental screening, and social-cultural adaptability. The methodology explicitly distinguishes between case-specific container data and scenario-based 3D-printing projections; consequently, the comparative findings should be interpreted as indicative and exploratory rather than predictive. The findings suggest that container shelters remain advantageous for immediate mass deployment, whereas 3D-printed shelters offer potential advantages in thermal performance and design flexibility. The paper contributes a context-sensitive assessment framework and identifies the operational constraints that must be addressed before 3D printing can be adopted at scale in post-disaster recovery.

## 1. INTRODUCTION

Natural disasters, such as earthquakes, hurricanes, and floods, continue to pose significant threats to global stability, displacing millions of people annually. The scale of this challenge is underscored by the United Nations Office for Disaster Risk Reduction (UNDRR), which reported that between 2000 and 2019, the world experienced over 7,348 major natural disasters, impacting 4.2 billion people and incurring \$2.97 trillion in economic losses [1, 2]. Recent studies on construction-scale 3D printing and robotic fabrication emphasize that digital construction methods can support more adaptive and resource-efficient building strategies [3, 4].

In February 2023, southern Türkiye was struck by an unprecedented 7.8 magnitude earthquake, resulting in over 50,000 fatalities and displacing 1.5 million people [5, 6]. This disaster, as documented by the Disaster and Emergency Management Presidency (AFAD), exposed the limitations of traditional temporary housing, which often fails to meet long-term sustainability and thermal comfort standards [5]. Recent analyses of post-disaster housing reconstruction in Türkiye, specifically focusing on the Housing Development Administration (TOKI), emphasize that cost efficiency and project scope are critical determinants of long-term recovery success [7]. Geylani [7] highlighted that while large-scale government-led initiatives aim to address the massive housing deficit, the balance between rapid deployment and life-cycle sustainability remains a significant challenge in the Turkish

context. In response, the Turkish government and private entities, such as Arkas Holding, deployed container-based settlements like the Arkas Şirikçioğlu Container City in Kahramanmaraş, which houses nearly 925 residents in 220 units [8]. While effective for immediate relief, field assessments indicate significant drawbacks in thermal performance, spatial adaptability, and lifecycle sustainability [9].

One of the prominent features of such a response is the Kahramanmaraş Arkas Şirikçioğlu Container City, which was constructed to accommodate displaced populations using standard steel containers [8]. While these units met the immediate shelter requirements, observations in the field and preliminary assessments identified several inherent limitations, particularly regarding thermal comfort, spatial adaptability, and long-term sustainability.

In recent years, the evolution of 3D printing technologies has introduced transformative opportunities for the construction industry, particularly in the creation of tailored, high-strength, and high-insulation building components. Additive manufacturing processes, such as FDM, SLA, SLS, and SLM, provide precise control over material properties and geometric forms, which are fundamental to structural performance [10]. The combination of advanced material selection and optimized geometric structures enhances the mechanical properties of 3D-printed composites [10], offering a scalable alternative to traditional container-based construction with expanded design freedom and flexibility to meet the specific needs of disaster-stricken communities.

Despite its potential, the application of 3D printing technologies as a temporary shelter solution has not been thoroughly investigated in the Turkish context. There is a lack of detailed comparative analysis between 3D printing utilization and the established container-based cities, such as the Arkas Şirikçiöğlü Container City in Kahramanmaraş.

This research addresses this critical gap by providing an exploratory comparative assessment between established container-based solutions and emerging 3D-printed shelter technologies. Unlike previous descriptive reports, this study employs a multi-criteria framework to evaluate cost-effectiveness, deployment speed, thermal efficiency, and socio-cultural resilience. By synthesizing field data from the Kahramanmaraş case study with preliminary 3D printing specifications, this paper identifies 3D printing as a viable, sustainable alternative that enhances community resilience and aligns with the UN Sustainable Development Goals (SDGs).

## 2. BACKGROUND

### 2.1 Shelter requirements

According to Sphere Standards [11], adequate housing is that housing is more than four walls and a roof. It points out the importance of including a settlement lens, the provision of services and cultural identity [11]. "Adequate" housing or other forms of shelter should be secure in tenure and be (Figure 1) [11]:

- affordable, which allows the family to attain other essential goods and services in terms of living with dignity;
- habitable, providing physical protection, sheltered and adequate living area, access to safe drinking water, adequate water, sanitation and hygiene (WASH) facilities, and food preparation and storage facilities;
- culturally acceptable;
- available and usable for all, including individuals with mobility impairments;

Situated to facilitate access to livelihoods opportunities and basic community services.

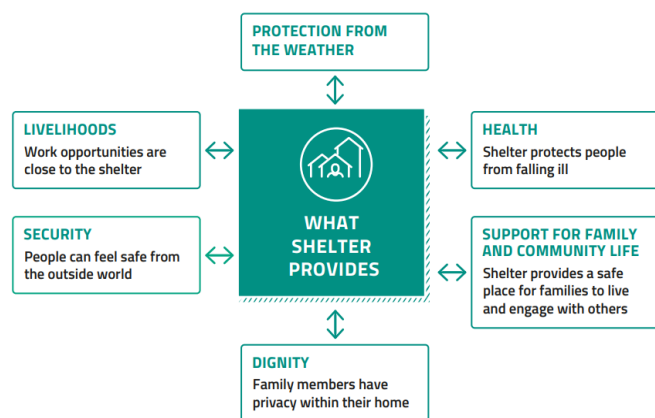


Figure 1. What shelter provides [11]

### 2.2 Site information and contextual setting

Kahramanmaraş in southern Türkiye is especially earthquake-prone and experiences temperature extremes [12]. The 2023 February earthquake emphasized the need for seismically robust, deployable shelter options that are safe and

thermally pleasant. Arkas Şirikçiöğlü Container City in Kahramanmaraş provides space for 220 modified 20-foot containers. They each provide the equivalent of 21 m<sup>2</sup> of habitable floor space. Field observation revealed shortages such as few green spots, inadequate shading, and inadequate socialization because of the close grid pattern and dense configuration. The visual record (Figure 2) also reveals these spatial characteristics and environmental conditions.



Figure 2. Satellite view of Arkas Şirikçiöğlü Container City  
Source: Google Earth [13], 2023

Constricted space can be caused by the slender, rectangular shape of containers, particularly when utilized in their normal configurations. This may make it more challenging to design rooms with lots of storage or living quarters or big, open-concept spaces. The net area of the two chambers in the container is thus 280 cm and 252 cm. The bath measures 142 cm × 170 cm. In addition, there is a 50 cm compact kitchen and an 83 centimeter corridor.

Figure 3 illustrates the limited kitchen and cooking arrangement observed in the container units, showing how the compact interior layout extends some domestic activities toward the immediate outdoor area.



The laundry is hung on a rack at street in front of container

1m space between containers is used as storage. Space between containers is used as parking for motorcycle

Figure 3. Limited space- kitchen cabinet & cooking outside

The majority of the inhabitants who occupy the containers decorate their homes with a television, a small settee, and possibly two additional chairs. Although the entrance door opens outside the containers, it takes up 80 centimeters from the front of the room.

Kahramanmaraş Arkas Şirikçiöğlü Konteyner Kent has several existing comfort elements:

- Adequate covered living area.
- Access to essential services: Residents have access to basic utilities, such as water, electricity, and sanitation.
- Communal spaces: The container settlement has a number of communal spaces, such as a laundry, library, kindergarten, children's and women's workshops, social market, health center, psychosocial support unit, and mosque.

Figure 4 presents selected comfort-related facilities within the Arkas Şirikçioğlu Container City, including communal and service spaces that support daily living.

On the other side, missing comfort elements in Arkas Şirikçioğlu Konteyner are:

- Community support: The container settlement has no sense of community, which can help to reduce stress and anxiety.
- Access to amenities: The container settlement is located in a more urban area, which makes it easier to access amenities, such as shops and restaurants. However, the connection between this site and surrounding urban area is not enough.
- Communal spaces: The container settlement is missing some of communal spaces, such as a playground.
- Recreational opportunities: The container settlement has no recreational opportunities, including a sports field and a park.

Figure 5 documents the exterior lighting conditions around the container units, which form part of the settlement’s basic safety and night-time usability infrastructure.



Activities for kids inside      Knitting course for women      Activities for kids outside

Figure 4. Comfort elements in Arkas Şirikçioğlu Konteyner



A lighting unit installed above the container      Lighting unit above the container door illuminating the entry at night

Figure 5. Lighting for containers outside

### 3. RESEARCH METHODOLOGY

This study employed a multi-method approach to conduct a multi-dimensional comparison of 3D-printed shelters and container shelters for the internally displaced persons in Türkiye with special reference to the 2023 earthquake. The study included literature review, case study, field observations, and comparative evaluation.

#### 3.1 Comparative framework and assumptions

The methodology adopts a hybrid comparative framework where the container-based system serves as the empirical baseline (derived from the Kahramanmaraş case study), while

the 3D concrete-printing (3DCP) alternative is modeled as a theoretical scenario. To ensure a fair comparison, the 3DCP scenarios were developed based on technical specifications from established precedents (e.g., ICON, Apis Cor) and adjusted to match the spatial and functional requirements of the Turkish post-disaster context. This approach explicitly distinguishes between case-specific container data and scenario-based 3D-printing projections; consequently, the comparative findings should be interpreted as indicative and exploratory rather than predictive.

#### 3.2 Data sources and review strategy

Data for the container case were collected through direct field observations, semi-structured interviews with site managers, and technical reports from AFAD and Arkas Holding. For the 3DCP alternative, a systematic review strategy was employed, targeting peer-reviewed literature and technical white papers published between 2018 and 2024. Data extraction focused on material consumption, energy use, and construction timelines to populate the comparative models.

#### 3.3 Operationalization of analytical tools

A comparative evaluation framework was developed to compare the relative advantages and disadvantages of container-based and 3D-printed shelter options. The framework enabled systematic comparison and analysis of the two shelter options using the data obtained from the literature review, case study analysis, and field observations. To provide a rigorous basis for comparison, the following tools were operationalized:

**Multi-Criteria Analysis (MCA):** The MCA utilized a weighted scoring system where criteria (Cost, Speed, Thermal Comfort, Sustainability) were assigned weights based on expert consultations and humanitarian shelter standards (Sphere). The weighting distribution is: Speed of Deployment (35%), Capital and Life-Cycle Cost (30%), Thermal Performance and Energy Efficiency (20%), and Environmental and Social Sustainability (15%) [11].

**Life Cycle Cost Analysis (LCCA):** The LCCA was operationalized using a 15-year service life projection with a 5% discount rate, accounting for initial capital costs, recurring maintenance, and end-of-life disposal/recycling, consistent with humanitarian infrastructure assessment models.

**Environmental Screening (LCA-style):** The Environmental Screening focused on Global Warming Potential (GWP) by calculating the embodied carbon of primary materials (steel for containers vs. concrete/composites for 3DCP) based on standard Ecoinvent database values, following the ISO 14040:2006 framework.

#### 3.4 Literature review

An extensive literature review was conducted to establish a theoretical foundation for the study, including established international shelter standards (e.g., Sphere Standards) [11], UNHCR Emergency Shelter Standard [14], Akeila et al.’s [15] emergency shelter design study, and other studies.

#### 3.5 Case study analysis

Several case studies were examined to gain practical experience of the use of container-based and 3D-printed

shelters in various situations. The case studies include the Arkas Şirikçioğlu Container City [8], WinSun's large-scale 3D-printed structures [16], Apis Cor's rapid-build models [17], and ICON's projects [18].

### 3.6 On-site observations

To complement the literature review and analysis of the case study, on-site observations at the site of the disaster in Kahramanmaraş, Türkiye, i.e., within the Arkas Şirikçioğlu Konteyner Kent (Container City), were carried out. These consisted of:

1. Site Visits: Multiple visits to the Arkas Şirikçioğlu Konteyner Kent to observe existing container-based shelter environments and gain first-hand information on their use, design, and effectiveness.

2. Interviews: Semi-structured interviews were conducted with residents, site managers, and stakeholders to capture insights on lived experiences, issues, and attitudes regarding container-based shelters.

3. Documentation: Extensive documentation, in the form of photographs, videos, and field notes, was conducted to record the physical aspects, spatial configurations, and functional processes of the container shelters.

## 4. COMPARATIVE ANALYSIS OF SHELTER TYPES

This section provides a detailed technical definition of the two dominant shelter types under consideration: 3D-printed shelters and container-based shelters. It explains how they are constructed, how materials will behave under different conditions, and their inherent characteristics that dictate their suitability to post-disaster housing.

### 4.1 Shelter types

#### 4.1.1 Container-based shelters: repurposing for rapid response

Container-based shelters typically involve the reusing and reconfiguring of standard ISO shipping containers, commonly 20-foot or 40-foot containers [19]. Containers have innate intermodal freight transportation capability, which includes inherent modularity and structural integrity. The ready supply and availability for shipping via existing global logistics infrastructure make them a viable alternative for prompt response emergency deployments. Conversion typically includes:

- **Structural Modifications:** Cutting out doors and windows, shoring up structural integrity where cutting is performed, and sometimes combining multiple containers to create larger rooms.
- **Insulation and Interior Finishing:** Insulation installation in walls, ceilings, and floors for improved thermal performance, completed with interior finishing such as drywall, flooring, and painting to render the space habitable.
- **Utility Integration:** Installing electrical wiring, water and sanitation pipes, and HVAC systems (heating, ventilation, and air conditioning) to meet minimum standards for living.
- **Exterior Treatments:** The application of protective coatings to combat rust and corrosion, and, on occasion, the addition of exterior cladding for aesthetics or additional insulation.

Although the use of containers as shelters has advantages such as speed of deployment and structural strength, container-based dwellings also encounter architectural and engineering challenges that can affect contributed to long-term livability. The apartments are typically poorly insulated thermally which makes them hot in the summer and cold in the winter. Others do not provide enough noise insulation, causing discomfort and a lack of privacy. In addition, claims of corrosion, mold and leaking have surfaced among older communities. The appeal of open space, however marginal to the walls of a city may also distance residents from actual urban life while inhibiting social integration and access to services [18], forcing them on the far fringes of cities [20].

#### 4.1.2 3D-printed shelters: A paradigm shift in rapid construction

3D printing, also known as additive manufacturing, building up objects layer by layer from digital data [21], provides a new paradigm for construction, enabling high speed, flexible design freedom and intelligent use of materials. AM is different from classic forms of production such as formative for the reason a mold has to be created in order to produce many copies, or subtractive because material cutting leads to waste. AM can advantageously fabricate complex geometries with no part-specific tooling and much less waste material, filling a gap left by the other manufacturing processes [22].

Recent evaluations of 3D printing for disaster housing production highlight its potential to deliver structurally robust and thermally efficient units in a fraction of the time required for traditional assembly [22].

For disaster relief and rapid housing, 3D printing presents several compelling advantages over conventional methods:

##### Lower Labor Needs:

- **Speed of Construction:** The construction time is cut down greatly. It only takes a couple of hours or days to print the walls and other structural elements of a building. For example, Apis Cor site in Stupino, Russia printed the main parts of a house in under 24 hours [17]. When disaster strikes, activity should begin immediately to provide shelter.
- **Design Flexibility and Customization:** Compared to the rigid and standardized dimensions of shipping containers, 3D printing technology allows for complex geometries and customized designs [21]. This flexibility allows for the designing of a shelter better suited to local climatic, cultural and site conditions. You can get enhanced organic shapes, integrated insulation and optimized structural forms to get more resilient and comfortable living spaces.
- **Reduced Labor Requirements:** Since 3D printing is largely automated, it doesn't require much on-site labor. This reduces exposure in dangerous conditions after disasters and solves labor shortages. A small team can be trained to operate the printers, freeing up other human resources for critical reliefs [21].
- **Material Efficiency and Waste Reduction:** Using 3D printing technology biopolymers can reduce the negative effects of construction on the environment, unlike traditional construction, which creates a lot of waste from cutting, shaping, and discarded materials. Also, the use of local or recycled materials, such as earth-based mixture or construction and demolition (C&D) waste, contributes to sustainability through economic saving on transportation costs [21].
- **Enhanced Structural Integrity and Thermal Performance:**

Most 3D-printed walls have cavities that enhance strength and safety. Any cracks will not pass through and so the structure will be able to hold together safely. In this way, durable and energy-effective shelters can be designed, which reduces heating and cooling demands and enhances occupant comfort [3].

A prime example is 3D printing a layer with phase change materials to improve heat control. According to a recent study, “A Phase Change Material (PCM) is any material with a high heat of fusion that, melted and solidified at a certain temperature, is able to store and release large amounts of energy.” The researchers state that “the PCM 3D-printing layer inside the wall building dropped the temperature of the outer wall surface, the inner wall surface, and afterwards the building temperature of the indoor area to a huge amount” in its experimental model [23]. According to the findings, when additive manufacturing and smart thermal materials cooperate with one another, indoor temperature fluctuations can be minimized while reducing mechanical cooling dependence at a low carbon footprint.

Although 3D printing shows great potential, it is hindered by some challenges that need to be resolved. 3D printers are costly to install, it requires expertise, and regulation issues exist in some places. Nonetheless, 3D printing is becoming a reality and a more attractive option for future disaster housing as printer technology, materials science and automation improve and build on these limitations.

To provide a concrete basis for the comparative assessment, this study evaluates technical specifications and performance data from leading global 3DCP projects. These include WinSun’s 3DCP large-scale buildings [16], Apis Cor’s rapid-build models [17], and ICON’s Vulcan-series projects [18]. By analyzing the material properties and construction efficiencies of these specific systems, a scenario-based performance model was developed for the Turkish context. This allows direct comparison with the empirical data from the Arkas Şirikçiöğlü Container City in the subsequent comparative tables.

## 4.2 Comparative analysis framework

To compare the two shelter types in a systematic manner, the study developed a comparative framework based on five performance categories: cost efficiency, rapid deployment capacity, thermal performance and energy efficiency, environmental sustainability, and social-cultural adaptability. The framework was derived from relevant literature, recognized humanitarian shelter standards such as the Sphere Standards, and empirical analysis of the Arkas Şirikçiöğlü Container City [8]. Secondary data for the 3DCP scenarios were drawn from WinSun’s 3DCP buildings [16], Akeila et al.’s [15] emergency shelter design study, Apis Cor rapid-build models [17], and ICON projects [18], which together provide comparative evidence on technical feasibility, deployment logic, and performance parameters.

1) **Cost-Effectiveness (Initial Investment, Operation & Maintenance Costs):** Initial Capital investment combined with long-term operation and maintenance costs such as regular energy use, expendables including lamps and cooling, if applicable, of the solution is key here. The LCCA method was used to include all relevant costs over an estimated useful life of 15 years as is often the case for humanitarian aid project implementation and the period in which interim shelters could be expected to remain serviceable.

2) **Speed of Deployment:** Time for a site to become

ready for full occupancy is called speed of deployment. They consider lead time needed to manufacture, how it is transported, assembly on site and fit out. In emergencies, the rapid deployment of humanitarian aid workers is crucial for an effective response.

3) **Thermal Performance and Energy Efficiency:** The thermal performance findings presented here are derived from simulation-based models and literature-derived thermal properties. While these simulations provide a robust comparative baseline, they should be viewed as theoretical performance indicators rather than measured on-site data for 3DCP structures.

4) **Environmental Impact and Sustainability:** The environmental comparison is conducted as a screening-level assessment (LCA-style) focusing on GWP. This analysis is limited to the embodied carbon of primary materials and does not constitute a full, cradle-to-grave life cycle assessment (LCA).

5) **Social and Cultural Adaptability:** The findings regarding social-cultural adaptability are inferential claims based on qualitative field observations in Kahramanmaraş and design flexibility analysis. These insights highlight potential social resilience benefits but require further longitudinal studies with displaced populations to be fully validated.

The framework for analysis contained various metrics like.

- The primary sources of information for on-site modal prices (USD/m<sup>2</sup>) were on-site observation, company invoice, contractor quote and publication cost analysis of similar projects.
- The U-value was identified appropriately from the relevant publications of the NIST (National Institute of Standards and Technology) and manufacturers data.
- The manufacturers’ claims, logistics models, and observed timings from similar jobs yielded the data for construction time (days per 220 units site).
- **Recyclability Rate (%):** This was evaluated using ISO standard 14040 Lifecycle Assessment (LCA). It gives a high-level framework that organisations can use to assess the environmental performance of a product or service.

## 5. RESULTS AND DISCUSSION

The comparative findings suggest that neither system is universally superior; rather, their suitability is conditional upon the recovery phase and operational constraints. Container-based shelters remain the most viable and effective solution for immediate mass deployment due to their established logistics and rapid availability. In contrast, 3DCP technology offers promising advantages in terms of thermal performance and design flexibility, but its implementation is contingent upon specific logistical readiness and site-specific operational conditions. Therefore, 3DCP should be viewed as a complementary future alternative that could enhance long-term resilience, rather than a direct replacement for the immediate relief provided by container systems.

### 5.1 Cost-effectiveness analysis

The long-term viability of post-disaster housing projects depends significantly on their total ownership costs rather than just initial capital investment. Our LCCA, conducted over a 15-year projected lifespan with a 5% discount rate, reveals that container-based and 3D-printed shelters exhibit substantial

differences in total cost-effectiveness. These calculations incorporate not only the initial procurement and assembly costs but also ongoing operational expenditures, including energy consumption for thermal regulation, structural maintenance, and end-of-life disposal or recycling costs as per the ISO 14040:2006 framework. By quantifying these variables, the analysis provides a comprehensive comparison that accounts for the time-value of money and long-term sustainability.

### 5.1.1 Initial capital costs

The capital cost for 3D-printed shelters depends on equipment, material supply, printing operations, and site works. Large-scale 3D printers are costly, but when equipment costs are distributed across multiple units, the unit cost can become more competitive for large-scale deployment [16]. For concrete or geopolymer-based printing, the material cost is comparatively lower and the automated process can reduce labor requirements. Based on the corrected itemized calculation, the estimated initial cost of 220 3D-printed shelters, including site infrastructure and partial equipment rental, is USD 1,352,723.71 (Table 1), for an ordinary-sized 3D-printed shelter of approximately 21 m<sup>2</sup>.

**Table 1.** Estimated cost of installing 3D printed shelters at Kahramanmaraş Arkas Şirikçiöğlü Konteyner Kent (Container City)

Item	Quantity	Unit Price (USD)	Total Cost (USD)
Resident 3DCP shelter (220)	220	1894.16	416715.20
Water Extension	220	26.6	5852.00
Sanitation Extension	220	21.3	4686.00
Electricity Extension	220	18.6	4092.00
Management 3DCP shelter (3)	3	1894.16	5682.48
Restaurant 3DCP shelter	1	1894.16	1894.16
Dry Clean 3DCP shelter	1	1894.16	1894.16
Management Toilets (2)	2	1894.16	3788.32
Mosque 3DCP shelter	1	1894.16	1894.16
Additional Service 3DCP shelter (2)	2	1894.16	3788.32
Fire Extinguishers (55)	55	31.9	1754.50
Iron Mesh Fence (760 m)	760	2.7	2052.00
Labor for Iron Mesh Fence Installation (760 m)	760	5.3	4028.00
Two-Car Gate	1	532.5	532.50
Road Construction (15,315.93 m <sup>2</sup> )	15315.93	46.5	712190.74
Solar Lighting Units (44)	44	53.2	2340.80
Sub total			1173185.34
Extra Miscellaneous Expenses (5%)			58659.27
<b>Total</b>			1231844.61
Cost of renting the machine			120879.10
<b>Final Total Cost</b>			1352723.71

By contrast, used shipping containers are often perceived as low-cost shelters, but the initial costs of modification, weather insulation, interior finishing, and transportation are substantial. A standard 20-foot container typically costs USD 2,000-6,000 [24]. However, the total cost increases once windows, doors, plumbing, electrical systems, insulation, transportation, and basic site works are included. Based on the corrected itemized calculation, the estimated initial cost of installing 220 container-based shelters and related settlement infrastructure at Arkas Şirikçiöğlü Container City is USD 1,545,011.52 (Table 2).

**Table 2.** Estimated cost of installing containers at Kahramanmaraş Arkas Şirikçiöğlü Konteyner Kent (Container City)

Item	Quantity	Unit Price (USD)	Total Cost (USD)
Resident Containers (220)	220	3193.7	702614.00
Water Extension	220	26.6	5852.00
Sanitation Extension	220	21.3	4686.00
Electricity Extension	220	18.6	4092.00
Management Containers (3)	3	3129.7	9389.10
Restaurant Container	1	3129.7	3129.70
Dry Clean Container	1	3129.7	3129.70
Management Toilets (2)	2	3129.7	6259.40
Mosque Container	1	3129.7	3129.70
Additional Service Containers (2)	2	3129.7	6259.40
Fire Extinguishers (55)	55	31.9	1754.50
Iron Mesh Fence (760 m)	760	2.7	2052.00
Labor for Iron Mesh Fence Installation (760 m)	760	5.3	4028.00
Two-Car Gate	1	532.5	532.50
Road Construction (15,315.93 m <sup>2</sup> )	15315.93	46.5	712190.74
Solar Lighting Units (44)	44	53.2	2340.80
Extra Miscellaneous Expenses (5%)			73571.98
Final Total Cost			1545011.52
Equipment/Machine Rental	1	0	0 (Included in unit price)

Note: All cost estimates are in USD and based on 2023-2024 market rates. 3DCP costs are projected based on international precedents (WinSun, ICON, and Apis Cor) adjusted for the Turkish context, assuming a 15-year service life and a 5% discount rate for LCCA calculations.

### 5.1.2 Operational and maintenance costs

The operational costs of a shelter largely depend on the energy consumption for heating and cooling that is directly related to its thermal performance. Because of their metallic structures, most container-based shelters are prone to high heat gain in summers and heat loss in winters that can lead to high energy demand. The maintenance cost is also quite high as the containers are usually affected by rust, corrosion and wear and tear. Thus, they need painting and structural repair at regular intervals, especially in harsh climates.

The materials used in 3D printed homes have superior thermal resistance and require less energy than conventional materials, particularly because of their integrated insulation and thermal mass technology. The solid wall design means there will be less maintenance as it won't easily decay with weather. The estimated 15-year life cycle cost for a container shelter is approximately USD 12,210 while for a 3D-printed shelter it is significantly lower at USD 8,500. The large difference in operation and maintenance costs proves that the 3D printing has economic advantages.

**Table 3.** Cost comparison of shelter systems over 15 years

Shelter Type	Arkas Şirikçiöğlü Container	3D Printed
Initial Capital Costs (USD)	1545011.52	1352723.71
Operational and Maintenance Costs (USD) per unit	12,210	8,500

Note: Deployment time represents the total duration from site preparation to full occupancy for a 220-unit settlement. Container data is empirical (Arkas case), while 3DCP data is based on manufacturer-rated printing speeds and logistical modeling.

As shown in Table 3, the 3D-printed shelters have lower operational costs.

## 5.2 Speed of deployment

It is important that we are able to undertake a full demolition and deconstruction project quickly and efficiently. Both shelter types have their advantages in this regard, but they differ in their methods and timing.

### 5.2.1 Container-based shelter deployment

Container-based shelters are pre-fabricated, which improves the transport and assembly on-site. When modified off-site, containers are set up on a prepared site with a foundation built, units placed and services connected. The Arkas Şirikçiöğlü Container City was recently announced to take only 52 days for complete installation of 220 units between site preparation and occupancy. This includes:

- Site Preparation in 14 Days (levelling, utility trenching)
- Container delivery will take 3 days for 220 units
- Assembly/Placement: 7 days (crane operations, stacking)
- Interior Fit-out & Utility Connection: 21 days
- Final Inspection & Occupancy: 7 days

Even though the process seems quick, it can be delayed due to the road conditions, lack of heavy machinery (cranes), and the coordination of many specialized teams.

### 5.2.2 3D-printed shelter deployment

Building structures using 3D printing or 3D printed shelters is an easy process, more so if using on-site printing. After the site is prepared, the printer can quickly build the walls and structures. For instance, the Apis Cor project showed that it was possible to print the main structure of a house in under 24 hours [17]. In case of deployment on mass scale of 220 units, the timeline would involve:

- Site Preparation: 14 days (similar to containers)
- Printer Setup & Calibration: 7 days
- 3D Printing of Walls (220 units): Around 22 days (assuming a single printer and optimized procedures for printing multiple units together or serially with good efficiency)
- Roofing, Windows, Doors, & Interior Fit-out: 28 days
- Final Inspection & Occupancy: 7 days

According to this estimation, the total deployment time for 220 units will be roughly 78 days, which is similar to container shelters. However, extra bottlenecks concerning logistics will not be found. It is easier to produce structures without the need for complicated supply chains. Also, they can produce forms of building right at the site. Due to that, there will be no delay with transport and costs involved with finished units.

Figure 6 provides a visual comparison of the construction timelines for both shelter types. The 22-day estimation for 3D printing is supported by documented daily output rates (e.g., 0.5-1 unit/day) from large-scale projects like ICON and Apis Cor, ensuring realistic scheduling.

Figure 6 shows how long it takes to build 220 containers and 220 3D-printed houses. The Gantt chart illustrates the phases of construction, from ground works to occupation; this shows that the two methods can both offer speed of execution but also that the 3D printing can streamline certain phases, particularly the building of the structure, which will be less reliant on the delivery of finished elements.

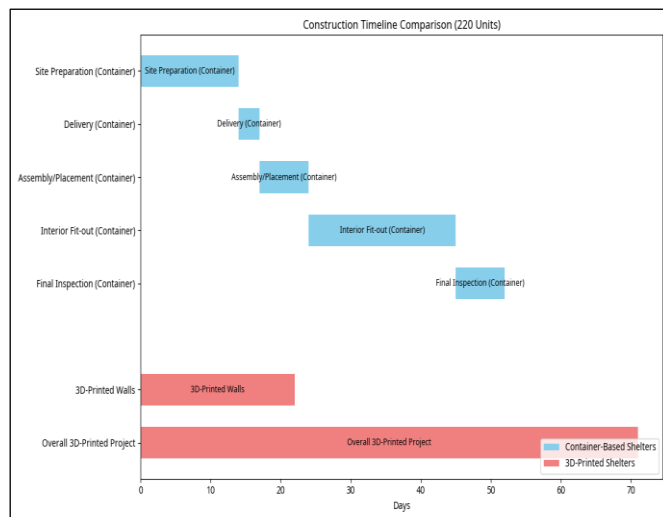


Figure 6. Construction timeline comparison (220 units)

## 5.3 Thermal performance and energy efficiency

Thermal comfort is extremely essential for the health of the occupants, especially in harsh climates. The energy efficiency of shelters also affects operational costs and environmental footprint directly.

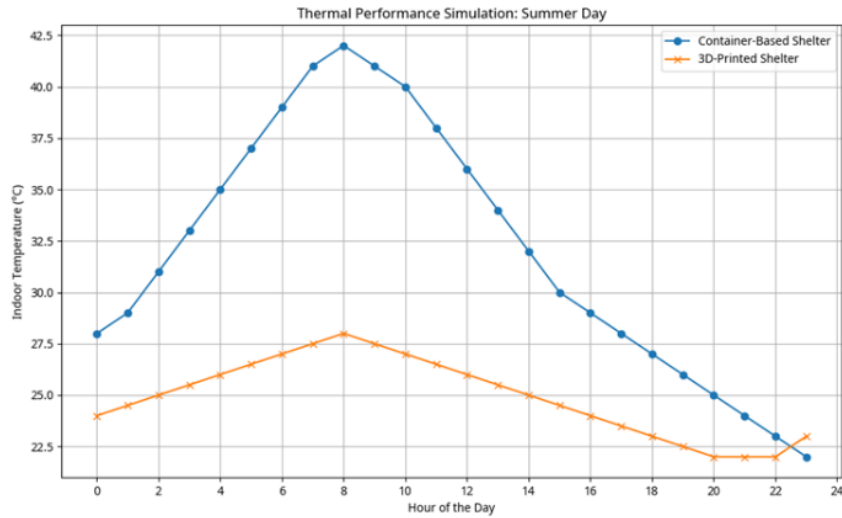
### 5.3.1 Container-based shelter thermal performance

Regular shipping containers don't hold heat well. Steel walls are quick to conduct heat, resulting in large heat gain in hot countries and heat loss in cold countries. Even if we add insulation to prevent overheating, it will shrink the inside space, which is already limited. Also, building insulation costs a lot of money and take a lot of time to install properly. Field observations and thermal imaging at the Arkas Şirikçiöğlü Container City showed that the temperatures inside the units fluctuate significantly and they go above comfortable living conditions if active cooling or heating is not applied continuously. During the summer months, indoor temperatures often reached 40 °C and during the winter, temperatures dropped below 5 °C, requiring high energy use to control the climate [8].

### 5.3.2 3D-printed shelter thermal performance

Walls can be printed in 3D with insulation built inside and thermal mass technique. These structures can trap air and insulate naturally by printing multi-layered walls with internal cavities. Materials like concrete and geopolymers have in-built thermal mass properties that help reduce indoor temperature by absorbing heat and releasing it slowly without causing extreme temperature swings. Tests suggest that low U-values can be achieved by 3D printed walls as exhibited through Table 4, which is better than containers walls. Because it has a superior thermal performance, it thus consumes less energy for heating and cooling thus increasing comfort and reducing expenses.

As shown in Figure 7, a simulated comparison of indoor temperatures was performed for both the shelter types over a day of the summer season. The 3D-printed shelters show a more stable temperature indoors as compared to the container-based ones, which means that they will require less energy and more comfort for the users.



**Figure 7.** Thermal performance simulation: summer day

**Table 4.** Shelters assessment according to U-value ( $\text{W}/\text{m}^2\text{K}$ )

Shelter Type/Project	Wall Assembly Description	U-value ( $\text{W}/\text{m}^2\text{K}$ )
Arkas Şirikçioğlu Container [8]	Steel sheet + Basic EPS insulation	3.2
WinSun [16]	Multi-layered concrete with insulation	0.8–1.2
Apis Cor [17]	Monolithic concrete with added infill insulation	1.0–1.5
Akeila Proposal [15]	Earth-based materials with natural insulation	0.5–0.9
ICON [18]	Multi-layered concrete walls, potentially with air gaps/insulation	0.6–1.0

Note: Environmental figures focus on Global Warming Potential (GWP) and embodied carbon of primary structural materials. Calculations follow ISO 14040 standards using Ecoinvent database values.

## 5.4 Environmental impact and sustainability

**Table 5.** Shelters assessment according to internal temperature range simulation using DesignBuilder

Shelter Type/Project	Winter Min Temp ( $^{\circ}\text{C}$ )	Summer Max Temp ( $^{\circ}\text{C}$ )	Notes
Arkas Şirikçioğlu Container [8]	8	36	High variation, often uncomfortable without significant energy input. Improved performance due to multi-layered walls, but specific insulation varies by project.
WinSun [16]	15–20	25–30	Performance highly dependent on post-printing infill and climate.
Apis Cor [17]	10–18	28–34	Designed for specific climates, often incorporating passive design strategies.
Akeila Proposal [15]	18–22	24–28	Good thermal envelope, often designed for specific climate zones.
ICON [18]	16–20	24–29	

Note: Data for container units is derived from empirical field evidence (Arkas Şirikçioğlu Container City), while 3DCP data represents scenario-based estimates derived from technical specifications of ICON and Apis Cor systems

The environmental footprint of disaster housing solutions is a growing concern, particularly in the context of climate change and resource depletion. A LCA provides a holistic view of the environmental impacts from material extraction to end-of-life.

Table 5 summarizes the simulated internal temperature ranges used to compare the thermal behavior of container-based and 3D-printed shelter scenarios.

Table 6 further compares the assumed insulation strategies and thermal heat transfer factors for the same shelter cases.

**Table 6.** Shelters assessment according to thermal heat transfer

Prototype	Primary Insulation Type	Thermal Heat Transfer Factor ( $\text{W}/\text{K}\cdot\text{m}^3$ )
Arkas Şirikçioğlu [8]	Expanded Polystyrene (EPS)	0.8
WinSun [16]	EPS, Rock wool, or other infill	0.3–0.7
Apis Cor [17]	Spray foam, mineral wool, or air gap	0.5–0.9
Akeila Proposal [15]	Natural fibers, earth, air gaps	0.2–0.4
ICON [18]	Varied (e.g., Lavacrete + infill)	0.2–0.6

### 5.4.1 Container-based shelter environmental impact

It may seem environmentally friendly to repurpose shipping containers, but doing so incurs considerable environmental costs. Making steel for containers takes a lot of energy and produces a lot of  $\text{CO}_2$ . Also, the modifications (cutting, welding, insulation, interior finishes) usually involve high embodied energy materials and can produce high waste. When containers are shipped around the world, they release carbon emissions. At the end of their life, containers are usually downcycled or thrown away which ends up as landfill waste. The total embodied carbon of a modified container unit is estimated to be around 8 to 12 tonnes of  $\text{CO}_2$  equivalent.

### 5.4.2 3D-printed shelter environmental impact

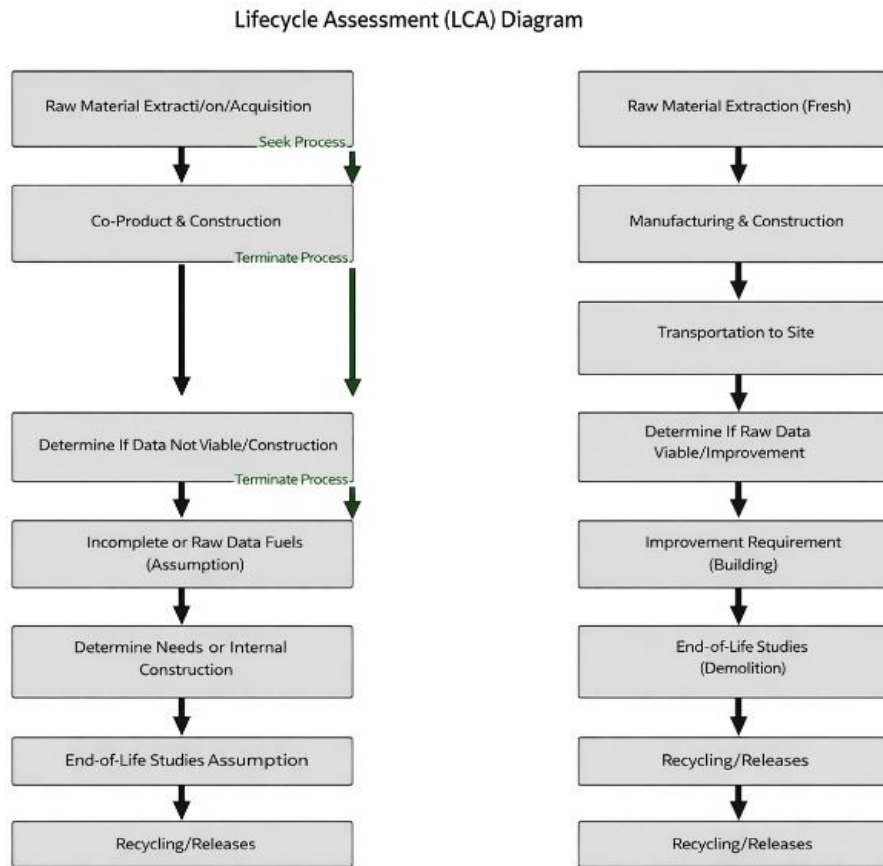
The environment has a lot of advantages due to 3D printing. Materials such as concrete or geopolymers can be sourced locally, reducing transport emissions. The way we construct

things helps in reducing the amount of material wasted as we use only the required amount. According to studies, there can be a 30-60% reduction in construction waste production through 3D printing. In addition, using recycled aggregates or other low-carbon binders, such as geopolymers, can significantly cut the structures' embodied carbon.

At the end of their life, 3D printed concrete constructions can be crushed and used as aggregate to strengthen the economy. The CO<sub>2</sub> emissions from a 3D-printed shelter is

about 5-8 tons CO<sub>2</sub> eq. It is a considerable reduction from a container-based shelter.

The simplified LCA diagram comparing both shelter types is illustrated in Figure 8, incorporating actual quantitative flows (e.g., kg of material, kWh of energy) for a more robust environmental screening. The picture illustrates that 3D-printed construction generates less waste, has a lower embodied carbon and is easier to recycle than traditional construction, making it a greener disaster housing alternative.



**Figure 8.** Simplified life cycle assessment (LCA) diagram

The environmental impact comparison of different 3D-printed shelters is presented in Table 7.

**Table 7.** Shelters assessment according to environmental impact

Shelter Type/Project	CO <sub>2</sub> Emissions (kgCO <sub>2</sub> eq/unit)	Recyclability (%)
Arkas Şirikçiöğlü Container [8]	2500	30
WinSun [16]	1500–2000	50–70
Apis Cor [17]	1800–2500	30–50
Akeila Proposal [15]	500–1000	70–90
ICON [18]	1000–1800	40–60

### 5.5 Social and cultural adaptability

Disaster housing success depends not just on technical and economic considerations. Above all, housing that meets social and cultural needs of affected people.

#### 5.5.1 Container-based shelter social and cultural adaptability

By nature container-based shelters are standardized and

rigid. Because of their rectangular shape and cramped interiors, they don't allow flexibility in layout or personalization. When venues feel repetitive, this creates a sense of sameness that doesn't impact patrons or staff positively. The high density and grid design found in many container cities, such as Arkas Şirikçiöğlü, prevents socialization and community formation, as the units are placed close to one another with little public space. Problems arising from the ineffectiveness of housing policies in accommodating such things as family-size preferences, privacy and/or communal living are likely to persist for a long time.

#### 5.5.2 3D-printed shelter social and cultural adaptability

3D printing has unmatched design flexibility. It allows the building of various architectural shapes and spatial layouts. These can be adapted to cultural contexts and family needs. This adaptability can improve residents' sense of ownership and belonging, making them co-creators. When printed curved walls, traditional features, or different-shaped room configurations are used, they have the potential to beautify and make the shelters more functional. To add, a 3D printer can help in creating community spaces with green areas that

promote social interaction for the community and help in healing. There's potential for local communities to get involved in the design, even the printing process, to further empower displaced people. This can also ensure that the shelters are socially sustainable and culturally appropriate. An extensive comparative analysis of shelters of two types, container-based and 3D-printed, has been carried out in a systematic manner against the many parameters of cost effectiveness, speed of deployment, thermal performance, environmental impact as well as social-cultural adaptability. As per the results, 3D printing can change the future of disaster housing. It is certainly better than containers, which have been the tried and tested method with shortcomings.

## 5.6 Limitations and operational constraints

While 3D printing offers significant advantages, its feasibility in disaster zones is subject to critical constraints.

These include the requirement for stable high-voltage power supply, accessible road networks for heavy printing machinery, and the availability of highly skilled operators. In immediate post-disaster scenarios where infrastructure is severely damaged, these requirements may favor traditional container solutions.

## 6. CONCLUSION AND RECOMMENDATIONS

In conclusion, this study serves as an exploratory comparative assessment rather than a definitive proof of technological superiority. The findings highlight that while 3DCP presents a promising future trajectory for enhancing the quality and sustainability of temporary shelters, it is not yet a direct replacement for the established efficiency of container-based systems in immediate disaster response. For 3DCP to be considered for wider post-disaster use in Türkiye, several practical thresholds must be met, including the establishment of local regulatory frameworks, the development of regional material supply chains, and the reduction of initial mobilization costs. Future research should focus on longitudinal field trials to validate these scenario-based projections under real-world operational constraints.

### Recommendations for future post-disaster temporary shelter:

- 1) **Prioritize 3D Printing for Long-Term Solutions:** Use 3D printing after disasters for longer-term consequences. Since it performs better on most metrics, 3D printing should see increasing use for housing after disasters especially for medium to longer term solutions. It is important to invest in research and development to further reduce upfront equipment costs and broaden the material options.
- 2) **Integrate Local Context and Community Participation:** In the projects of housing after disaster, irrespective of technology, the meta-issue must be local contextualization, and community participation must be an important element in its design and planning. This makes sure the shelters are technically sound, culturally appropriate, and socially sustainable.
- 3) **Develop Hybrid Approaches:** Try out different combinations to create unique approaches to tackle common issues. For example, a fast supply of simple container structures for use as soon as possible, followed by 3D printed elements for insulation, personalization or

shared facilities.

- 4) **Standardize Performance Metrics:** Standardize performance metrics for disaster provision housing which are globally accepted and represent more than mere strength. It should also include thermal comfort, energy efficiency, environmental impact, social-cultural indicators, and more. Informed decisions will become more robust comparative analyses.
- 5) **Invest in Training and Capacity Building:** In order to fully utilize the pioneering potential of 3D printing in the aforementioned fields (disaster mitigation and relief), there is a demand for investment in capacity building and training of local manpower in the operation and maintenance of 3D printing facilities and associated construction processes.

To sum it up, although container-based shelters are an essential tool and response for the immediate, this is not the way of the future for disaster housing. The displaced and homeless can no longer join the ranks of refugees seeking shelters. In addition, people value these 3D printed shelters should they find themselves at the receiving end of a disaster or calamity.

- **Cost-Effectiveness:** Container-based shelters and 3D-printed shelters may have similar initial costs. However, 3D-printed shelters make up for this through their thermal performance, low maintenance and reduced lifecycle costs. Over 15 years, the lifecycle costs of 3D-printed shelters are much lower compared to container-based shelters.
- **Speed of Deployment:** Both approaches can be deployed in a timely manner. But with 3D printing, all that hassle can be avoided since they do not need to spend so much on logistics of finished units as everything can be done on site.
- **Thermal Performance and Energy Efficiency:** The 3D-printed shelters have better thermal performance than container-based units, who offer insulation and thermal mass as part of their structure. This results in greater occupant comfort and much less energy usage to control the climate.
- **Environmental Impact:** The practice of 3D printing is more sustainable in that involved material waste, embodied carbon emissions, and potential recycling and reuse opportunities for material are lower than the conventional processes.
- **Social and Cultural Adaptability:** 3D printing presents a wider flexibility in designs that can be accomplished than what is possible with container settlements. There can be greater customization options that suit cultural preferences for having a house as a home.

## REFERENCES

- [1] UNDRR. (2019). Global assessment report on disaster risk reduction 2019. <https://www.undrr.org/publication/global-assessment-report-disaster-risk-reduction-2019>.
- [2] Centre for Research on the Epidemiology of Disasters (CRED), United Nations Office for Disaster Risk Reduction (UNDRR). (2020). The human cost of disasters: An overview of the last 20 years (2000-2019). Brussels, Belgium. <https://www.undrr.org/publication/human-cost-disasters-overview-last-20-years-2000-2019>.
- [3] Wu, P., Wang, J., Wang, X. (2016). A critical review of

- the use of 3-D printing in the construction industry. *Automation in Construction*, 68: 21-31. <https://doi.org/10.1016/j.autcon.2016.04.005>
- [4] Keating, S.J., Leland, J.C., Cai, L., Oxman, N. (2017). Toward site-specific and self-sufficient robotic fabrication on architectural scales. *Science Robotics*, 2(5): 8986. <https://doi.org/10.1126/scirobotics.aam8986>
- [5] AFAD. (2023). Türkiye earthquake report. Ankara, Türkiye: Disaster and Emergency Management Presidency (AFAD). <https://deprem.afad.gov.tr/earthquake-reports>, accessed on Mar. 15, 2026.
- [6] United Nations Office for the Coordination of Humanitarian Affairs. (2023). Türkiye: Flash appeal: Türkiye earthquake (February–April 2023). <https://data.unhcr.org/en/documents/details/98890>.
- [7] Geylani, Ö. (2025). Analyzing cost efficiency and project scope in post-disaster housing: Reconstruction cases of TOKI in Türkiye. *Buildings*, 15(9): 1555. <https://doi.org/10.3390/buildings15091555>
- [8] ARKAS Holding. (2023). Arkas Şirikçiöğlü Container City Project Report. Izmir, Türkiye. <https://arkasline.com.tr/wp-content/uploads/2025/10/EN.pdf>.
- [9] Aslan, Z., Demiröz, K., Demiröz Yıldırım, S. (2025). An examination of temporary shelter units in terms of minimum standards: The case of the Kahramanmaraş Earthquake. *Sustainability*, 17(8): 3587. <https://doi.org/10.3390/su17083587>
- [10] Ksiouar, M., Garziad, M., El Khoumsi, Z., Boujmal, R. (2025). Towards a survey of 3D printing technologies of composite materials: Design properties, and application. *Journal Européen des Systèmes Automatisés*, 58(3): 580301. <https://doi.org/10.18280/jesa.580301>
- [11] Sphere Project. (2018). The Sphere Handbook: Humanitarian Charter and Minimum Standards in Humanitarian Response. <https://spherestandards.org/wp-content/uploads/Sphere-Handbook-2018-EN.pdf>.
- [12] Turkish State Meteorological Service. (2025). Official climate statistics: Kahramanmaraş, measurement period 1930-2025. Ankara, Türkiye: Turkish State Meteorological Service. <https://www.mgm.gov.tr/Veridegerlendirme/il-ve-ilceler-istatistik.aspx?k=&m=KAHRAMANMARAS>.
- [13] Google Earth. (2023). Satellite View of Arkas Şirikçiöğlü Container City. <https://earth.google.com/web/search>.
- [14] UNHCR. (2026). Emergency shelter solutions and standards. <https://emergency.unhcr.org/emergency-assistance/shelter-camp-and-settlement/shelter-and-housing/emergency-shelter-solutions-and-standards>.
- [15] Akeila, M., Kuok, K.K.K., Wong, H.M.N. (2019). Evaluating the visibility of building Syrian refugee shelters by 3D printing technology in Jordan. *International Journal of Engineering & Technology*, 8(3): 377-385. <https://doi.org/10.14419/ijet.v8i3.29719>
- [16] WinSun. (2017). Product center - Yingchuang Building Technique (Shanghai) Co. Ltd. <https://www.winsun3d.com/En/Product/>.
- [17] Designboom. (2017). Apis Cor realizes on-site 3D printed house in just 24 hours. <https://www.designboom.com/architecture/apis-cor-pik-3d-printed-house-24-hours-02-28-2017/>.
- [18] ICON. (2026). ICON announces first commercial rollout of its 3D-printing construction technology for builders. <https://www.iconbuild.com/newsroom/icon-announces-first-commercial-rollout-of-its-3d-printing-construction-technology-for-builders>.
- [19] Slawik, H. (2010). Container Atlas: A Practical Guide to Container Architecture. Gestalten. <https://gestalten.com/products/container-atlas>.
- [20] Pekarchuk, O., Piątek, Ł., Tofiluk, A., Cygan, M., Nowacka, A. (2024). Container settlements for internally displaced people in Ukraine built in 2015 and 2022-architectural characteristics. *Archives of Civil Engineering*, 70(3): 275-295. <https://doi.org/10.24425/ace.2024.150983>
- [21] Camacho, D.D., Clayton, P., O'Brien, W.J., Seepersad, C., Juenger, M., Ferron, R., Salamone, S. (2018). Applications of additive manufacturing in the construction industry-a forward-looking review. *Automation in Construction*, 89: 110-119. <https://doi.org/10.1016/j.autcon.2017.12.031>
- [22] Yetkin, E.G. (2025). Evaluation of post-disaster housing production in architecture using 3D printing approaches within the context of sustainability. *Journal of Advanced Science, Technology, and Engineering*, 2(2): 22-32. <https://izlik.org/JA84NC83DK>.
- [23] Salih, S.S., Hamakhan, I.I., Abdulkader, A.A. (2022). Investigation of thermal performance of 3D printing integrated phase change materials in building structure. *International Journal of Heat and Technology*, 40(3): 843-848. <https://doi.org/10.18280/ijht.400325>
- [24] Universal-Containers. (2024). How much do shipping container homes cost? <https://universal-containers.com/news/how-much-do-shipping-container-homes-cost/>.