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Model Proposal for the Use of Pneumatic (Inflatable) Structures in the Case of Earthquake Disaster

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Abstract

Earthquake is natural disaster that can cause great destruction and loss of life and property. Temporary emergency structures, tents or containers, are used continuously until the reconstruction of the basic needs after the earthquake disaster. However today, with innovative structures, various systems that can offer more advantageous solutions to the needs of disaster victims can be proposed. In this study, the use of pneumatic (inflatable) structures for earthquake disasters is discussed. Since it is system that relatively little known and has wide variety of structural features, it is aimed to develop holistic fictional model that includes the process for making the most appropriate selection. Thus, as a result of the introduction of pneumatic structures and the creation of model for use; will be widespread by increasing the awareness of its positive qualities such as lightness, fast construction, easy storage in small volumes and transportation, flexibility and reusability in earthquake disasters.

Keywords: *Pneumatic (inflatable) structures, earthquake, emergency and temporary shelter, building selection model.*

Deprem Afeti Durumunda Pnömatik (Şişme) Strüktürlerin Kullanımına Yönelik Model Önerisi

Öz

Deprem, büyük yıkımlarla can ve mal kayıplarına sebep olabilen doğal bir afettir. Deprem afeti sonrasında temel ihtiyaç olan barınma mekânlarının yeniden inşasına kadar süregelen bir şekilde çadır veya konteyner benzerleri geçici acil durum yapıları kullanılmaktadır. Ancak günümüzde yenilikçi strüktürlerle birlikte afetzedelerin ihtiyaçlarına daha avantajlı çözümler sunabilen çeşitli sistemler önerilebilmektedir. Bu çalışma kapsamında pnömatik (şişme) strüktürlerin deprem afetine yönelik kullanımı ele alınmıştır. Görece az bilinen ve çok çeşitli yapısal nitelikleri bulunan bir sistem olması nedeniyle en uygun seçimin yapılmasına yönelik süreci içeren bütüncül kurgusal bir model geliştirmek hedeflenmiştir. Böylelikle pnömatik strüktürlerin tanıtılması ve kullanımına yönelik bir model oluşturulması sonucunda; deprem afetinde sağladığı hafiflik, hızlı inşa, küçük hacimlerde kolay depolanabilme ve taşıma, esneklik, tekrarlı kullanılabilme gibi olumlu niteliklerin bilinirliğinin artması sağlanarak kullanımı yaygınlaşabilecektir.

Anahtar Kelimeler: *Pnömatik (şişme) strüktürler, deprem, acil ve geçici barınma, yapı seçim modeli.*

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1. Introduction

Disasters in the world are catastrophes that can cause great loss of life and property. Earthquakes and natural disasters affect people negatively by destroying buildings. Although the construction of buildings against earthquakes is one of the first measures that can be taken, the design and development of temporary accommodation areas are important both physically and psychologically in case the structures collapse. Coburn & Spence (2002) stated that earthquake disasters can be very strong and cause psychological, economic, and sociological destruction in societies. He mentioned that it is inevitable to return to normal life after earthquakes that can occur at any time and cause great damage and that it is inevitable to learn about life with earthquakes. Especially geographies located in the earthquake zones such as our country need to develop structures for this disaster or emergency structures for disasters. In the light of his studies after the 17 August 1999 earthquake, Baradan (2002) determined the deficiencies in the design and use of temporary shelters built in case of emergency and evaluated the major problems experienced by the disaster victims in matters such as hygiene, technical support, and installation. For this reason, in the event of an earthquake disaster, emergency and temporary shelters gain importance due to the destruction of existing structures. The needs of the disaster victims should be resolved quickly.

Türkiye is a region that is frequently exposed to natural disasters such as earthquakes, landslides, floods, rockfalls and avalanches. According to the risk management index created to measure the risks of disasters, it is in the high-risk group with the 45th rank among 191 countries in the Global Risk Index. In terms of major earthquakes that have occurred since 1900, Türkiye ranks fourth with 77 earthquakes (AFAD, 2018). The intensity of the Erzican Earthquake, known as one of the biggest disasters in our country in 1939, was measured around 7.9. It is considered one of the biggest earthquakes in Anatolia since the 19th century. According to official data, 32,968 deaths and 116,720 buildings were destroyed in this earthquake (Haçin, 2014). The Gölcük-Kocaeli Earthquake with a magnitude of 7.4 that occurred on 17 August 1999 in the Marmara Region caused 18,373 deaths and damaged to 258,211 housing units (Yüksel & Hasırcı, 2012). A series of devastating earthquakes in 2023 caused approximately 50,000 casualties in Kahramanmaraş and Hatay. Covering 11 provinces in the south and southeast of Türkiye, including Kahramanmaraş, Gaziantep, Şanlıurfa, Diyarbakır, Adana, Adıyaman, Osmaniye, Hatay, Kilis, Malatya and Elazığ, in a large region with a population of more than 15 million, it has caused the displacement of 3.3 million people. 2.3 million people sheltered in tent camps and container settlements (UNDP, 2023). Here, a few earthquakes and the loss of life and property experienced by the geography of Türkiye are shown. The problems experienced in the emergency or temporary shelter areas, which are necessary in case of destruction because the buildings are not earthquake resistant, have been seen together with these earthquakes. After earthquakes, tents and containers were generally used for emergency and temporary shelter. The settlements created with tent and container units used in the Kahramanmaraş Earthquake latest incident that occurred on February 6, 2023, are shown (Figure 1 a-b). For this reason, within the scope of this study, pneumatic structures and their model, which is an innovative system that can be a solution to these problems, have been developed.

(a) (b)

Figure 1. Temporary shelter units established after the Kahramanmaraş earthquakes **a.** Tent example (İHA, 2023), **b.** Container example (AA, 2023)

The most basic unit in Maslow's hierarchy of human needs is shelter, which is found in physiological needs. Earthquake disasters can also cause damage or even destruction of shelters, which are the most basic needs. The loss of the place where the most basic human need is met, reveals the need for temporary emergency shelters until the construction of new ones. Temporary shelters are usually provided through tents and containers. However, today, after an earthquake, it is seen that shelters can offer more advantageous solutions to various needs with many innovative systems. The original aspect of the study is to propose the use of pneumatic structures with their advantageous aspects for earthquake disasters. The original aspect of the study is to propose the use of pneumatic structures with their advantageous aspects for earthquake disasters. For this reason, within the scope of the study, a model study was conducted for the use of pneumatic (inflatable) structures in case of earthquake disasters. It aims to select the most optimum structure by providing the intersection and selection of various parameters in the use of the relatively little-known pneumatic structure for emergency temporary shelters by using the model method created as fiction during the earthquake disaster process. In this context, all environmental and structural elements that affect the pneumatic structure before, during, and after the earthquake and their effect on user comfort are discussed holistically. As a result, pneumatic systems are structures that can offer solutions for earthquake disasters thanks to their lightness, ease of use, fast installation, ease of storage and transportation in small volumes, repetitive use, and adaptable and flexible design features.

1.1. Emergency and Temporary Shelter in Case of Earthquake Disaster

According to the United Nations, disasters are natural, technological, or human-based events that cause physical, economic, and social losses for people, interrupt normal life and activities, and that society cannot overcome with its means (Ergünay, 2005). Occurring suddenly or untimely; causing physical, economic, and psychological losses; natural movements that affect human communities negatively by disrupting the normal flow of life are defined as disasters. In some regions where various disasters occur and are frequently encountered, the evaluation of the situations before, during, and after the disaster and the management style that is expected to develop systematically, namely disaster management is recommended (Tüzün, 2002). There is a wide variety of disasters that can be classified as geological, meteorological, biological and human origin. Geological causes are earthquakes, landslides, rockfalls, volcanic events and tsunamis; examples of meteorological are floods, floods, drought, tornadoes, hurricanes, avalanches and desertification (Şahin, 2009). Some disasters may occur suddenly, while others may occur over a long period. At the same time, the realization of some disasters can trigger other negative disasters. For this reason, disasters are events that can cause many loss of life and destruction as seen in the world and our country. For this reason, previously developed systems and structures for disasters, temporary or permanent solutions during disasters should be planned and strategies should be developed.

There is a need for space at the beginning of the actions and requirements that are necessary for the continuity of the routine daily life of the person. This space, which can also be called a shelter phenomenon, is the basic living space of people (Demirarslan, 2005). Earthquake disaster, which is also discussed within the scope of the study, is defined as the shaking that occurs due to the collision, convergence, or coming under each other of the moving tectonic plates that have occurred suddenly from the formation of the world to the present. This sudden disaster can cause great loss of life and property (Fidanboy, 2015). The destruction of shelters, which are the most basic places where people meet the need for shelter and are protected from external factors, is seen to be destroyed by earthquake disasters. In this case, the development of temporary shelters as a result of the loss of the most basic shelters for people in the destruction after the earthquake disaster is one of the fastest solutions. Thus, until new permanent shelters are built, places where they can stay will be created for the earthquake victims. After the disaster, there are some parameters that these temporary places should provide in terms of both psychological and human life.

Establishment of shelters provided to the victims during the transition period from short-term life in emergency or temporary shelter areas to permanent residences where long-term life is planned again after an earthquake disaster; It may take a long time due to the removal of the excavation, preparation of the environment, and efforts to find suitable and safe areas (Nocera, Castagneto &

Gagliano, 2020). Temporary shelters, which were developed with various design suggestions, were built to meet the basic needs of people who continue their lives after an earthquake disaster in the fastest and most convenient way (Shelter Centre, 2012). Issues such as security, privacy, standard of living, living space dimensions, providing optimum comfort conditions in terms of heat and sound, ventilation, lighting, and durability are important for the quality of temporary shelters and the comfort of the victims (Felix, Feio, Branco & Machado, 2013). Thus, it brings the necessity of considering and producing temporary housing holistically together with all environmental factors, architectural elements, user comfort, managerial decisions, and social benefit dimensions after an earthquake disaster. In addition, spaces not only for shelter but also for various functions such as food, health, education, storage and gathering are required until the construction of permanent new structures after the earthquake disaster.

Temporary accommodation must have certain qualifications to offer various solutions in case of disaster. According to Tekeli (2010), stated that in addition to shelter, which is one of the biggest problems that arise after disasters, basic needs such as cleanliness, resources such as food, clean water, and health services in the temporary shelter process should be met in these regions. A study conducted by Johnson (2008) mentioned the problem that temporary shelter solutions could not be produced in the earthquake area, the transportation of products or units from outside causes high costs, infrastructure expenses (water, road, electricity, sewerage, etc.) and the problem of realizing all these in a short time. For all these reasons, instead of the solutions used after the earthquake for a long time, the use of innovative structures that can provide solutions to the requirements can be more efficient. In this study, the temporary use of pneumatic structures, which can be used in many functions in architecture, and various functions in emergency shelters has been proposed.

1.2. Use of Pneumatic Structures for Various Functions in Earthquake Disaster

The first examples of pneumatic structures are tents dating back to prehistoric times. The development and emergence of pneumatic structures in today's sense depends on the use of membrane material in architecture as a result of the Industrial Revolution. Mechanization advances in technology, population growth, wide-span structures, and urbanization made more durable membrane material have reached a more widespread use. 1970 Osaka EXPO was held in Japan and examples of pneumatically structured systems were exhibited. Thus, pneumatic structures have become applicable today as construction systems that can be used for a wide variety of purposes, from emergency structures, pavilions, exhibition elements, and covers, to sustainable and energy-efficient facades.

Today, pneumatic (inflatable) systems are flexible structures that can be applied in various forms and functions in architecture. In architecture, pneumatic structures can be used as a carrier system, auxiliary building elements (wall, cover, roof or facade cladding, etc.), or formwork elements. Pneumatic (inflatable) systems can be built in unlimited shapes, sizes, and structures thanks to the flexibility of the membrane material and carrier. There are many application areas, from short-lived temporary structures to the facades of large stadiums, sports halls, or high-rise buildings. Thanks to these possibilities, pneumatic structures can be used in a wide variety of functions in architecture. In this context, pneumatic structures have examples of various functions such as; furniture, personal accommodation, art items, meeting and entertainment venues, exhibition elements (pavilion), emergency structures, space structures for extreme conditions, utopian idea projects, addition to historical buildings, hotel, museum, office, terminal, stadium, shopping centers, multi-story building facades, sports fields such as swimming or tennis, walls in terms of building elements, formwork, dam control element, tunnel formwork element and integrated with energy systems. At the same time, pneumatic structures can be built in integration with other carrier systems such as frames, struts, cables, space cages, reinforced concrete shells, or tensegrity. In this study, the use of pneumatic structures developed to be applied in emergency and disaster situations for earthquake disasters has been examined.

Pneumatic systems are balanced structures that are stabilized by using the pressure difference between the outside and the inside, thanks to the air pressure, to provide structural integrity

(Marcipar, Onate & Canet, 2005). Pneumatic structures, which become carriers as a result of pressurizing the membrane material with air, can be applied as single or double-walled (Özşen & Yamantürk, 1991). Sphere, cylinder, ellipsoid, or free-form pneumatic structures can be designed with a cable-reinforced membrane (Türkçü, 1997). At the same time, they are flexible structures that can be produced integrally with various carrier systems such as space frame structures, tensegrity, and cable. Bögle, Schlaich & Hartz (2009) evaluated the factors that pneumatic systems are affected by in terms of environmental factors, membrane material, pressure control, and their impact on the interior space. Environmental factors include wind, snow, rain, sun, temperature, air pressure and climatic factors. The type of membrane material affects the tensile forces, surface temperature and degree of hardness. Since it is a structure that becomes a carrier as a result of pressurization, leakage, damage, puncture or abrasion can adversely affect the carrier. As a result of all these parameters, the interior is decisive on the temperature, air pressure, thermo-dynamic behavior, and user comfort. All these elements affect the continuity and durability of the structure as a whole. Therefore, as a result, the planning of various parameters in the use of pneumatic structures in earthquake disasters can provide optimum user comfort conditions.

Emergency shelters, which are aimed to provide minimum living conditions for people affected by earthquake disasters, can be tent-type or pneumatic-type shelters that require easy installation by being delivered very quickly. After the disaster, the installation should be started immediately and it should quickly be ready for use. Practical shelter types are suggested, which are easy to store and can be more advantageous to be delivered to the disaster area (Beyatlı, 2010). In this context, pneumatic structures, which are lightweight, easy to use, fast to construct, and flexible systems that can adapt to various environments, can be used for earthquakes thanks to their advantageous structural features. Figure 2 shows the “Cloud” project designed by Monica Föster. It is an example of a pneumatic shelter that can be carried in a bag and can be ready for use in minutes. A single-walled pneumatic structure is also a useful suggestion for earthquakes. Its fast set-up and portability in small volumes have been demonstrated.

Figure 2. Cloud project (Krauel, 2013; p. 260-261)

The “Cocoon” project, one of the individual pneumatic shelter examples, is shown in Figure 3a. It provides a single-person living space, which is formed as a result of the activation of two pneumatic tubes by inflating. It is an example of use in earthquake disasters, thanks to its features such as fast installation, easy transportation in small volumes, and ease of use. The “Parasite” project is shown in Figure 3b. This project is primarily designed for homeless people living in the city. However, it is also a usable recommendation for earthquake disasters. This project, on the other hand, can be used as a parasite by meeting some structural requirements from existing buildings. It is made up of membrane material double-walled pneumatic structure consisting of tubes. This project, on the other hand, can provide a fast living space by using it together with the structures that remain intact in case of earthquake disaster.

(a) (b)

Figure 3. a. Cocoon project (Krauel, 2013; p. 271) **b.** Parasite project (Krauel, 2013; p. 255)

Tents and container units are traditionally used in earthquake disasters in Türkiye and many other countries around the world. While many innovative construction systems can be applied instead, pneumatic structures are one of them. Some examples of pneumatic structures applied in earthquakes around the world are given in Figure 4 below. Figure 4a shows a wide-span emergency structure used after the Kumamto earthquake. It consists of double-walled membrane surfaces. Structural stability is ensured by air support mechanisms. Thus, it is an example of a rapid structure that can temporarily provide a solution to the needs of disaster victims in the event of an earthquake emergency. Figure 4b shows a pneumatic structure with health function used in the Nepal earthquake. The tubes made of membrane material become carriers as a result of being pressurized with air. It provides a temporary solution in case of an earthquake, as collapsed health structures cannot be used.

(a) (b)

Figure 4. a. Pneumatic shelter used in the Kumamato earthquake (A-PAD, 2016) **b.** Pneumatic health structure used in the Nepal earthquake (Mundasad, 2015)

Pneumatic systems can also be used in water tanks or structures that provide health services, apart from functions such as individual shelters, gathering areas, and educational structures. Examples of pneumatic structures used in Kahramanmaraş Earthquakes are shown in Figure 5 below. Developed by Beren Kayalı, the pneumatic and concrete water tank installed in 48 hours can store 14,000 liters of water (Figure 5a). It is a project that can offer a very fast solution within hours to the problem of access to clean water in case of an earthquake disaster. Pneumatic structures can be used not only in user-oriented spaces but also in service-purpose reinforcement elements. In Figure 5b, the health structure consisting of double-walled pneumatic tubes transported by Russia by air and inflated in place is seen. In the event of an earthquake, it is ready for use within hours and can provide health services to disaster victims.

(a) (b)

Figure 5. a. Pneumatic water tank (Finney, 2023) **b.** Pneumatic health structure (Aydın, 2023)

As can be seen from Türkiye earthquakes and abroad in the sample projects examined, pneumatic structures can be applied in a wide variety of forms and functions. Inflatable systems thanks to their existing architectural structures can offer quick and easy solutions for earthquake disasters. For this reason, in this study, a model has been developed showing the stages for the use of pneumatic systems in earthquake disasters. The entire system is described in detail below.

2. Material and Method

After disasters such as earthquakes, solutions are developed for the victims by applying for temporary settlements. Generally, temporary structures such as tents and containers do not provide sufficient comfort for the living and needs of the victims. In this context, pneumatic structures have been proposed within the scope of the article study. Pneumatic systems provide advantageous structural features such as lightness, fast construction, easy transportation, and storage, producing large spaces with less material, and not requiring expertise for construction and reusability. In addition, pneumatic structures can change and transform with their modular adaptable structures and provide flexible uses. Thus, they are structures that can offer easy solutions in earthquakes. Contrary to these advantages, they can be weak in terms of fire safety, exposure to climatic factors, and material qualities. To evaluate all these elements and manage the parameters, a model proposal has been made for the use of a structure with a pneumatic system in case of an earthquake.

The developed model system proposes a holistic process including pre-earthquake, earthquake situation, and post-earthquake. The steps, headings and sub-parameters of the developed model were determined by literature analysis and inference from applied sample structures. The constructed model provides the selection of the most suitable type of pneumatic structures for the use of earthquake disaster victims, which are less known than other systems. This model accepts the choice of a pneumatic structure after an earthquake disaster and conveys the types and parameters of its structure.

In the event of an earthquake, it includes the structure selection parameters for all constructions with pneumatic structures for the victims, the factors affecting the structures, the suitability of the structures for the earthquake disaster, the expected qualities from the structures, the selection of the structure, the design of the structure and the risk analysis for all processes. The methods and steps followed in the formation of the model are shown schematically below (Figure 6). With this table, the proposal of pneumatic structures and model development for the structural need for emergency and temporary shelter after the earthquake are explained. The parameters and inputs of the developed fictional model were determined by collecting data. Then the steps of the model were created. The flow chart of the model is to determine the parameters that affect the selection of pneumatic structures in an earthquake disaster, the factors affecting the structures with a pneumatic system for earthquake disasters, the suitability of the use of structures with a pneumatic system in an earthquake, the expected qualities of a structure with a pneumatic system in case of an earthquake, the selection of a structure with a pneumatic system in case of an earthquake and the selection of a structure with a pneumatic system in case of an earthquake. It consists of several stages, including systematic building design. These stages and their sub-elements are explained later in the article.

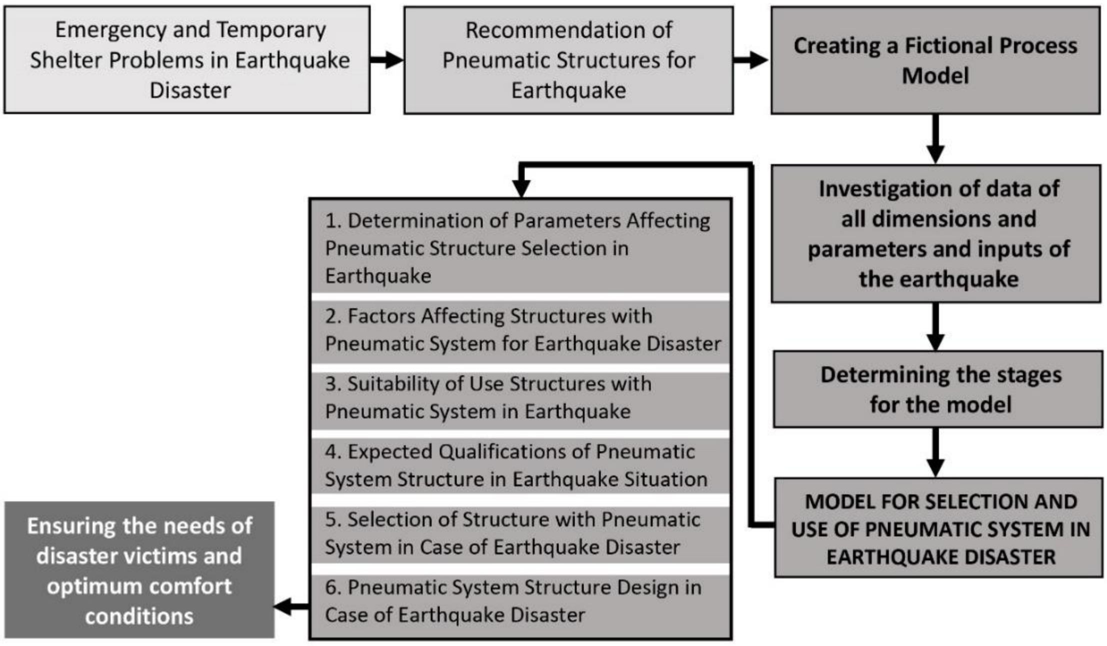

Figure 6. Method chart showing the steps followed in model creation

The aim of this model system is to select the structure with the most optimum features with a pneumatic system for any function or purpose to be used in case of an earthquake disaster. Because pneumatic systems can be produced and applied in many types and systems with exhibit very different features as structural characteristics. For example, pneumatic structures are separated from each other according to the number of layers and the pressure situation. Being single or double-walled also directly affects the requirements and structure of the structural system. For this reason, this model study has been carried out so that these structures can be separated from each other and dealt with systematically with parameters such as environmental, structural, and user dimensions in a certain order.

It is a fictionally created process model showing the selection of pneumatic structures for earthquake disasters. For all processes risk analysis and as a result, pneumatic structures can be earthquake-oriented is recommended. The selection of the structure with the pneumatic system, which provides the most suitable elements in all these processes from before the earthquake disaster to the realization and after the disaster, is provided through the model. The stages, sub-elements, and parameters in the flowchart of the model are explained in detail in the findings section of the study.

3. Findings and Discussion

In the findings and discussion section of the article, a model for the use of pneumatic structures, whose upper and lower titles have been developed in earthquake disasters has been presented. The model developed for the use of pneumatic systems in earthquake disasters and its stages are shown in Figure 7 below. The model has 6 main headings namely to determining the parameters that affect the selection of pneumatic structures in an earthquake disaster, covering all processes before, during, and after the disaster, the factors affecting the structures with pneumatic systems for earthquake disasters, the suitability of the use of structures with pneumatic systems in an earthquake, the expected qualities of the structure with a pneumatic system in case of an earthquake, selection of a structure with a pneumatic system and the design of a structure with a pneumatic system in case of an earthquake disaster. The suitability of the use of pneumatic system structures in earthquakes and the qualities expected from a pneumatic system structure in case of an earthquake are explained together.

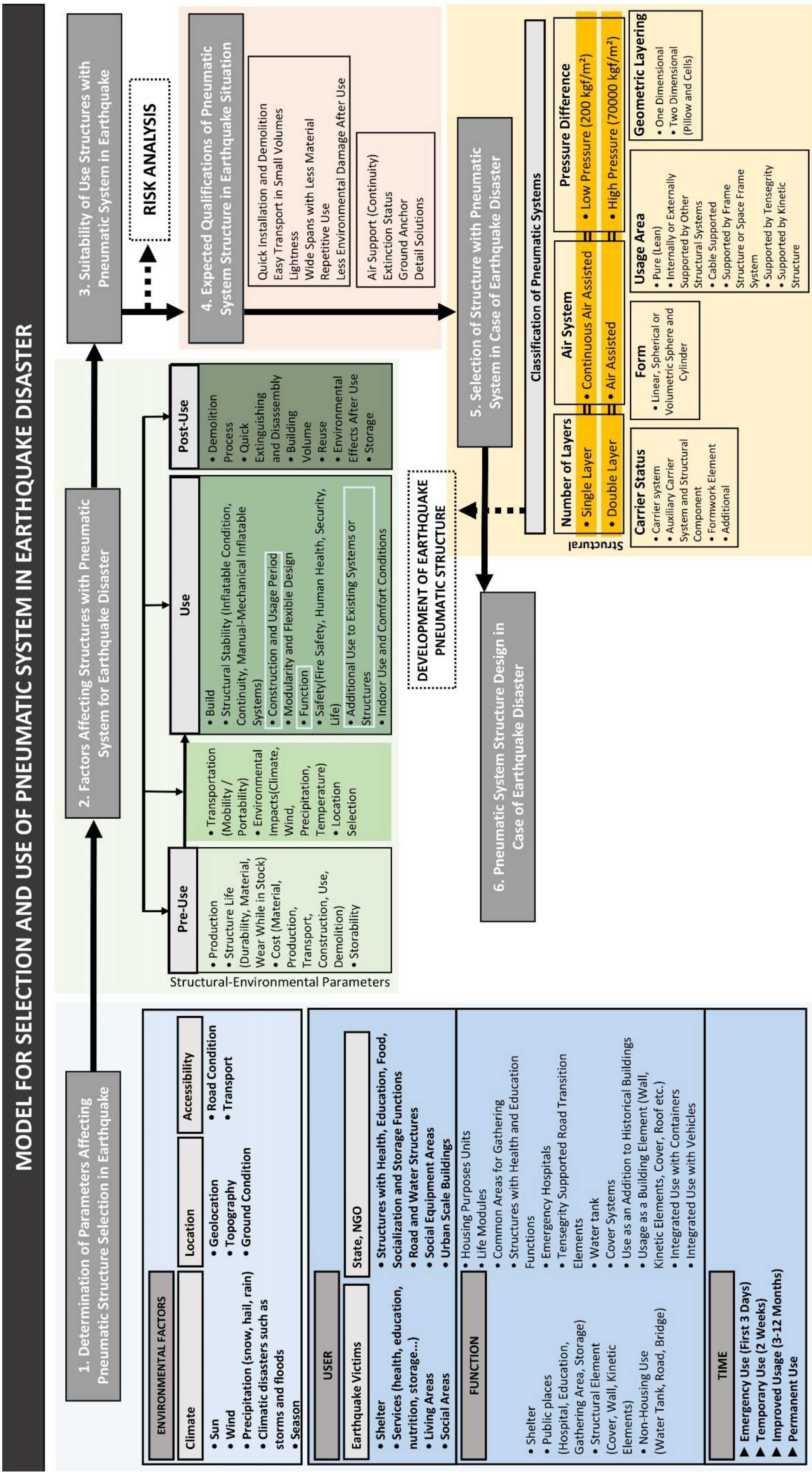

Figure 7. Model for the selection and use of pneumatic systems in case of earthquake disaster

3.1. Determination of Parameters Affecting Pneumatic Structure Selection in Earthquake Disaster

As seen in the Kahramanmaraş earthquakes in 2023 in Türkiye, in temporary construction after an earthquake disaster usually tents and containers are used provided by the government, non-governmental organizations, private sector, or aid. Tents are unsuitable for seasonal conditions and long-term use. Containers are high-cost and non-reusable structures (Yavuz, 2013). Although temporary shelters are designed for a short period, they are often of longer-term use than expected. Tent, container, paper tube temporary unit, polyurethane igloo, and temporary trailers used after various earthquakes in Türkiye; When evaluated in terms of structure, performance, and usage features, many negative data were obtained besides its positive qualities (Abanoz & Vural, 2023). For this reason, innovative structures and design strategies and the design of holistic temporary shelters centered on earthquake victims have gained importance.

Post-disaster sheltering is a phenomenon that needs to be designed and planned from an architectural point of view, as seen in disasters. Experts from various fields have carried out various studies on this subject. Such as Fuller (Fuller et al., 2008) and Pinero (Sorguç, Hagıwara & Arslan Selçuk, 2009) with the idea of designing temporary shelters for the victims in emergencies. Many designers, engineers and architects have done studies. They determined that the shelters developed for the locals did not comply with the global strategies. They proposed structures that were simple, sustainable, flexible, and self-constructed. In this context, pneumatic structures have been proposed in terms of the positive qualities they can provide thanks to their structural and architectural qualities. For this reason, emergency temporary shelters should be designed for disaster victims according to various parameters after an earthquake disaster. Climate, environmental factors, user, and architectural structure are also the most important factors. In terms of architecture, there are structural systems suitable for use in temporary accommodation. Surface deployable structures such as folded structures, inflatable structures, and telescopic structures are examples of these (Bajgiran, 2018).

After an earthquake disaster, there are certain guiding or restrictive parameters for environmental, structural, temporal, functional, and human factors. These are the issues that affect the choice of building for the requirements in case of an earthquake disaster. Building selection parameters in an earthquake disaster consist of four sub-components which are environmental factors, user, function, and time. Environmental factors; affect the choice of structure, the durability of the structure, its durability during use, the comfort conditions for the user and the choice of location. Climatic factors, sun, wind, precipitation (snow, hail, rain, etc.), natural events such as storms and floods, and seasons are the determining factors in terms of building selection. In addition, climatic factors also determine the required qualities of the buildings to be used in case of an earthquake disaster. Climatic factors vary from place to place. For example, the buildings to be proposed to the cold or hot climate regions, and the locations that receive a lot of precipitation or are dry require the implementation of different structures after the earthquake. Difficult conditions and risks such as storms or floods are important in terms of durability, anchoring to the ground, and structural stability of the structures to be used after the earthquake. Location is a parameter that specifies the properties of the place where the structure will be applied. In the event of an earthquake disaster, the geographical location, topography and ground conditions of the place where the structures will be applied are guiding in the selection of the structure. After the earthquake, temporary settlements may not always be in the designated gathering common areas for the disaster. For this reason, it is necessary to propose structures that can be adapted according to various characteristics of the place where the structures will be applied. The ground condition of the area where the temporary construction will be applied after the earthquake includes both topographic elements and the suitability of the ground or excavation after the earthquake. For example, the structures to be proposed for mountainous regions or wetlands, stone and rocky ground and soil ground have different structural features from each other. In addition to the condition of the ground, accessibility to temporary shelter areas after the earthquake is also a unique parameter for each place among environmental factors.

Accessibility covers road conditions and transportation after an earthquake disaster. Road conditions and transportation have an impact on the delivery of aid to the disaster victims, the continuity of the services, and the evacuation of the region when necessary. In addition to these, roads are the lines where disaster structures will be taken and transported for temporary shelter and social areas after an earthquake. In this case, the dimensions of the road and transportation structures can be decisive in the selection of the system to be the transportation method. At the same time, earthquake damages that may occur on the transportation roads can also limit post-disaster road conditions and accessibility. The "Highway Traffic Regulation" in Türkiye, contains restrictive laws regarding the weight of containers that can be transported on the highways, the vehicle to which the container will be transported, and its dimensions. In this context, transportation by highways becomes a structural constraint for the containers that are mostly preferred for temporary shelter after the earthquake in our country. It includes factors such as accessibility, size, weight, vehicle, and transportation system on road conditions, and transportation structure selection. Therefore, the choice of location and the environmental factors of the place; in terms of climate, location, and accessibility, is effective in the determination of the structural system that is planned to be implemented after the earthquake as a whole.

Pneumatic systems recommended for use in case of earthquake disasters within the scope of this study are also structures that can be directly affected by environmental factors. Considering that pneumatic systems become carriers through membrane surfaces that are pressurized with gas or liquid, usually with air, it is likely that climatic factors affect the carrier. In this context, the sun and seasons can cause structural or physical changes in the pressure and membrane material in pneumatic structures that are recommended to be used after an earthquake. The structural stability of the pneumatic system is directly dependent on the pressure difference. Ground anchors for light pneumatic structures such as rains, harsh weather conditions, and storms, are decisive on the elements developed for the detailed solutions and durability of the system. It is seen that pneumatic systems generally offer adaptable solutions regarding the location and choice of location in case of an earthquake. Pneumatic structures, which can be affected by climatic factors, offer advantageous qualities in terms of accessibility and transportation due to their light weight and ability to be transported in very small volumes.

Another parameter that affects the building selection in case of an earthquake is the user. In this study, the user dimension is explained in two groups disaster victims and the state, its institutions, and non-governmental organizations. Although victims are users of all structures, they are the main factor in the housing situation in terms of systems that they can implement and make ready for use. The state, state institutions, and non-governmental organizations are the units that provide all the equipment for the disaster victims. Structures developed for needs common and gathering areas such as health, education, food, socialization, storage, structures that are expected to provide roads and water, social reinforcement areas, and urban-scale structures are the areas that serve the disaster victims after the earthquake disaster. For this reason, it is expected that the structures that provide solutions for the needs in case of earthquakes will be implemented by the disaster victim or by the state and non-governmental organizations. When the user dimension is considered in terms of pneumatic systems, fast and easy installation can be achieved for all individuals or institutions after an earthquake disaster.

In Türkiye, legal studies have been carried out to prevent disaster damages developed by the government from the past to the present. As can be seen from the earthquakes experienced, it has been observed that there are some inadequacies. Legal regulations should be developed both for the improvement of existing structures, making them earthquake-resistant and rehabilitating, and for temporary settlements after an earthquake. These studies should be applied not only to residential buildings but also to social and technical infrastructure (Kepenek & Gençel, 2016). For this reason, another parameter is a function, which includes the usability of structures for various purposes. That affects the choice of building in case of an earthquake disaster, pneumatic systems are used for purposes such as shelter, common areas (hospital, education, gathering area, warehouse), building elements (cover, wall, kinetic elements), and non-shelter water tank, road, bridge. In this context, pneumatic structures can be adapted to various construction systems, structural elements, vehicles, or containers with modular and flexible designs. As a result of the examinations on the functional areas of use of pneumatic systems, accommodation units, living modules, common areas for gathering, buildings with health and education functions, emergency hospitals, tensegrity supported road crossing elements, water tank, cover systems, additional use to historical buildings (walls, kinetic elements, cover, roof, etc.), exemplary uses such as integrated use in containers or vehicles have been reached. What is expected from temporary shelter structures for difficult conditions such as earthquake disasters is a flexible, transformable, or integrated system. From a structural point of view, the pneumatic structure must be selected as a holistic function-oriented system throughout the design, use, and post-use process. Thus, pneumatic structures can be applied for a wide variety of purposes and functions in case of earthquake disasters.

The time parameter, which affects the selection of the structure in case of an earthquake, indicates the qualities that the pneumatic structure must-have for the period in which it will be applied. Various comfort, energy, or secondary-use resources are added to the pneumatic structure selected for emergency use for the first 3 days after the earthquake, temporary use for 2 weeks, enhanced use for the range of 3-12 months, and permanent use. As a result, environmental factors, user, function, and time parameters that affect the selection of pneumatic structures in earthquake disasters should be fully planned in the design, application, use and even post-use stages and the characteristics of the structure should be determined.

3.2. Factors Affecting Structures with Pneumatic System for Earthquake Disaster

There are three approaches for temporary shelter in an earthquake disaster: design, material, and survivor earthquake victims approaches. The design approach is to creatively develop suitable and efficient structural types and materials. The choice of structure is important in terms of increasing efficiency. Because it provides the state of being self-constructed. The material approach focuses on providing temporary shelter for the long term. It includes the use of materials in terms of energy saving and sustainability. Materials may be locally available, recycled from waste, or designed for earthquake disasters. The Survivors approach, on the other hand, includes the participation of earthquake victims in temporary construction at the highest level. It proposes shelters that can easily be made ready for use by the public on their own (Keen, 2008). Thus, pre-use, use, and post-use stages should be developed holistically within the design, material, and survivor's approach in terms of temporary emergency shelters in earthquake disasters.

Pneumatic structures proposed for earthquake disasters are affected and affected by various factors in the process. A holistic process should be followed in the implementation of a structure for earthquakes, from design to use and even after use. Each of the structural, environmental, financial, accessibility, user, comfort, and safety aspects should be planned and the advantageous or disadvantageous qualities of the building should be evaluated. The main material of pneumatic systems is membrane; it can be recycled, reused, or used in demolition after use without causing any harm to the environment. Thus, it will be possible to propose the most optimum structure and construction system for earthquake disasters. The aspects of the pneumatic systems proposed within the scope of this study for the sudden-onset earthquake disaster using structure stages for the process are described. The factors affecting the pneumatic system structure are explained below for the three processes determined as pre-use, use, and post-use.

3.2.1. Pre-use

An earthquake is a natural disaster that can not be predicted, develops suddenly, and can cause great loss of life and property. The most basic precaution that can be taken is the planning and manufacturing of structures that are robust against earthquakes and by the regulations. However, as can be seen in earthquake disasters, great destruction can be experienced in earthquake disasters. For this reason; the production, design, placement, and application of temporary shelters and social facilities after an earthquake should be planned. The pre-use phase includes elements such as production, structure life (durability, material, wear while in stock), cost (material, production, transportation, construction, use, demolition), and storability of temporary structures to be produced for disaster and risks. The production phase includes accessibility to raw materials, availability of materials, mass production, and fast and easy manufacturing. The life of the structure;

characterizes the stability of the structure, the life of the material, and its durability against wear and tear throughout the entire process from the production stage to use and after use. For a construction system that can offer repetitive use, such as pneumatic structures, the type and life of the membrane material directly determines the life of the structure. At the same time, another material element is material, labor, and service costs, which will cover all stages such as production, transportation, construction, use, and demolition. Evaluating the performance of buildings in terms of cost is important in the life of the building. For example, a single-walled pneumatic structure requires continuous air support throughout the use phase. In this case, energy and machinery expenses will affect the cost continuously. As can be seen, the structural characteristics of pneumatic structures directly affect many parameters such as production, structure life, cost, and storability. Pneumatic structures can be stored in very small volumes. This facilitates the storage of large numbers of buildings in small volumes, accessibility, transportation, and transportation by vehicles. This issue, which can also reduce the cost, can quickly be a solution to the need for shelter in case of an earthquake disaster.

In the transition from the pre-use stage to the use stage with the realization of the earthquake disaster, the stages of transporting the pneumatic structures to the selected places in the disaster area, choosing the location, and the effects of the environmental factors of the location on the pneumatic structures are passed. Environmental effects include components such as climate, wind, precipitation, or temperature. It should be produced and designed by taking precautions in terms of pneumatic structure, detail analysis, anchorage systems, and materials in terms of high wind speed and temperatures, adhesions, and all climatic and seasonal factors. In this way, optimum comfort conditions can be provided for the user.

3.2.2. Use

During the earthquake period, victims generally provide shelter in three different ways. The buildings of their first destroyed house are to create a living space. The power plant is in large public buildings, either closed or open, away from their demolished houses. The third is the campsites, which are the ones living for life as a group away from the demolished houses and where they will stay for an unknown duration (Fallahi, 2008). For this reason, temporary structures gain importance in terms of the comfort of the victims. This is where it comes into play as an alternative to the tent and container traditionally used in pneumatic structures. After the earthquake disaster occurs, the use process begins with the construction of the pneumatic structure. It becomes available quickly without requiring expertise for construction. The person, institution, or organization that will build it may vary according to the purpose of use and the function of the building. In any case, however, pneumatic structures can be built quickly and easily. Since it is a structure that becomes carrier with pressure after it is built, the swelling state, continuity, and manual-mechanical inflation systems should be kept in certain balances to maintain stability. Thus, structures with pneumatic systems can be used in a certain continuity for the required time.

Pneumatic systems can be used in many functions such as shelter, health, education, road elements, cover, and water tanks in earthquake disasters. It can also be used by integrating with other structures or vehicles. In this context, the structural system should also be chosen for its function and intended use. Pneumatic structures, which can also provide modular or adaptable use, can be easily changed and transformed thanks to their flexible design. The building directly affects indoor use and comfort conditions. For example, a single-walled pneumatic structure with a membrane and impermeable structure may not provide optimum thermal comfort conditions indoors in hot summer weather conditions. In this context, the holistic selection of the building for all factors including location, environment, comfort, and safety gains importance. In terms of safety, fire safety, human health, and living conditions emerge. Flammability, toxic gas emission, flammability, and flame conductivity, which are very variable according to the characteristics of the membrane material, are important in terms of fire safety. For this reason, the pneumatic structure and material selection should be carried out before use, taking into account all the elements in the use phase.

3.2.3. Post-use

After completing the temporary use phase of the pneumatic structure after an earthquake disaster, the demolition or extinguishing process takes place. Pneumatic structures can be quickly deflated and dismantled, just as in their installation. It can be stored again by returning to its original volume and it can be used repeatedly despite another earthquake disaster. In addition, since it is an inflated and deflated system, it can be restored after use without causing any harm to the environment or leaving any residue. Thus, pneumatic systems can be evaluated for purpose and function through the model, taking into account their weaknesses along with earthquake-friendly solutions during the pre-use, use, and post-use stages.

3.3. Appropriateness of Use of Pneumatic System in Earthquake Disaster and Expected Qualifications

Temporary constructions should provide optimum conditions in terms of storage, transportation, installation, and material efficiency for all disaster victims' needs that may occur in an earthquake disaster. Post-disaster shelters used by International Organizations and in Türkiye generally are tents and containers (Yamalı, Akgün & Karaveli, 2015). For this reason, the use of pneumatic structures which is one of the innovative systems, for earthquake disasters has been suggested in this study. The suitability of the use of pneumatic structures that can provide quick solutions to emergency shelters, structures with other functions, and requirements for earthquake disasters, and the expected qualities are within the scope of this title. Pneumatic systems are suitable for use against earthquakes thanks to their structural features. It has advantageous features such as fast installation and demolition, no need for re-planning after demolition, no waste, reusability, easy transportation in small volumes, lightness, wide openings with less material, and less damage to the environment after use. Thus, in case of an earthquake disaster, it can be quickly taken to the disaster area, where the construction is completed and ready for use. Due to its structural characteristics, air support is required continuously in single-walled structures, any puncture, abrasion, or tearing in the membrane material, problems may occur in the case of extinction, ground anchorage, and detail solutions. However, these can also be solved by planning at the design stage. For this reason, what is expected from pneumatic structures is to quickly and easily create a space and make it ready for use in case of an earthquake disaster.

3.4. Selection of Structure with Pneumatic System in Case of Earthquake Disaster

Pneumatic systems are structures that become carriers as a result of pressurizing the membrane material surfaces, usually with air. For this reason, membrane layers and pressure-providing air are the two main elements of the structural characteristics of pneumatic systems. The number of walls, air system, and pressure difference are the main considerations in the selection of pneumatic structures for use in earthquake disasters. Single-walled pneumatic structures are continuous air-assisted and low-pressure (200 kgf/m^2) systems in terms of the air system. Double-walled pneumatic structures are air-assisted and high-pressure (70000 kgf/m^2) structures. In single-walled pneumatic systems, the volume inside the membrane surface is pressurized as a whole, and continuous air support is required. In double-walled pneumatic systems, the two membranes are pressurized between the surfaces. If deflating occurs due to factors such as environmental factors after the first inflation process, intermittent air support can be provided. Single and double-skinned structures have different structural properties from each other. Single-walled ones have features such as especially detailed openings, continuous air support, pressure losses as a result of abrasion on the membrane surface, the occurrence of extinction in the entire volume, and repair by dismantling in case of hole-tear-wear in the membrane material. Since the double-walled systems are more closed systems than the single-walled ones, they can be easily solved with the details developed in terms of these elements.

In addition to classification according to layer, air support, and pressure, pneumatic structures can also be examined in terms of usage area, form, carrier status, and geometric layering. In terms of usage area in architecture, pneumatic structures can be applied as carrier systems, auxiliary carrier systems or building elements, formwork elements, and additionally. They are structures that can take form in linear, superficial, or volumetric spherical and cylindrical forms. Pneumatic structures become carriers only with membrane and air pressure, but can also be built with other carrier systems. In terms of carrier state, pure pneumatics can be used internally or externally with other structural systems, together with frame and space cage systems, with cable supported, tensegrity supported and kinetic structures. Geometric stratification covers cells with one-dimensional and two-dimensional pillows. Thus, pneumatic structures must be planned and built directly according to their structural characteristics for design, use and post-use phases. Because, pneumatic structural systems provide determining factors for all processes after an earthquake disaster, according to their structural features throughout use. A fictional operating scheme was created by proposing the choice of structure with a pneumatic system for the purpose, function and environmental and structural qualities that come with the model gradually.

3.5. Pneumatic System Design in Case of Earthquake Disaster

In many other countries such as Türkiye, tents and containers are generally used after earthquakes. Tents; with a bar system with metal or wooden elements, made of fabric-plastic based material, with insufficient insulation, not resistant to various climatic factors, can be used in various typologies, are not suitable for reuse, do not require expertise for installation, have a shelf life of 5 years. They are structures that can be stored, are lightweight, can be transported quickly and easily, and do not provide auditory privacy. Tents cannot provide sufficient comfort conditions and privacy to users. Containers; a masonry system with metal trapezoidal panel elements, samples that can be insulated but have insufficient insulation are used, resistant to external factors, cannot adapt to different typologies due to its single space, resistant to climatic factors, reusable, assembled, and installed by experts in the production facility and therefore large. They are units that require storage areas, can be transported in large numbers by sea, and offer visual and auditory comfort (Abanoz & Vural, 2023). Transportation and construction of containers to the earthquake disaster area generally take longer time. But tents are faster. Because of that the one or dubbel walled pneumatic systems are recommended and examined in this study for earthquake emergency temporary structures. Pneumatic structures differ from tents and containers to can be light, small volumes, easy to transport, easy to install, and reusable. For this reason, pneumatic systems should be designed and planned for earthquake-related use. The environmental, structural, and design parameters of pneumatic structures in the process were revealed with the model developed within the scope of this study.

Pneumatic systems directly affect the space, the user, and the design in terms of their structural features such as pressure status, number of walls, and material properties. At the same time, the environmental factors mentioned in the previous steps are also effective on the building design. For this reason, a pneumatic structure to be used in earthquake disasters should be designed and produced holistically by the function, purpose of use, user expectations, and requirements. It is suggested to develop a structure in the light of all parameters and inputs in the model. For example, while it is appropriate to use a single-walled pneumatic dome in spaces with large openings for gathering, a double-walled system may be more convenient in a housing module for three or four people. Thus, in case of an emergency, it can provide quick solutions by sending it to the region in small volumes for its purpose.

4. Conclusion and Recommendations

The use of innovative systems such as pneumatic structures, instead of traditional solutions such as tents and containers, which are commonly used in earthquake disasters, can yield more efficient and advantageous results. It has positive features such as fast installation and demolition, no need for reorganization after demolition, no waste, easy transportation in small volumes, lightness, wide openings with less material, and less damage to the environment after use. Its repeated use both reduces environmental damage and provides economic benefits. Its structural features should be designed holistically for user comfort conditions and satisfaction. At the same time, pneumatic structures produced according to the function and purpose of use can be turned into ready-to-use spaces very quickly in case of disaster. Explaining the structural characteristics of pneumatic structures will enable them to be introduced and become more known. Using the model developed within the scope of the study, the use of pneumatic structures for earthquake disasters can be explained and understood and the structure selection can be made. It will be possible to use and select pneumatic structures easily for the user in earthquake disasters and thus find a more widespread application area.

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