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Principle and Applications of Deployable Structure in Aerospace Engineering, Medical Devices and Emergency Facilities

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Abstract:

Deployable structures have become vital in various fields due to their ability to transition between compact and expanded forms. This study focuses on their applications in aerospace engineering, medical devices, and emergency facilities. In aerospace, deployable structures like antennas and solar panels optimize space and functionality. Medical devices, particularly stents and retractable instruments, use deployable designs to enhance minimally invasive procedures. Emergency facilities, such as deployable bridges and shelters, offer rapid, reliable solutions in disaster and military contexts. The research highlights significant advancements, e.g., scissor-like mechanisms in deployable bridges, origami-based solar panels, and NiTi shape-memory alloy stents. Despite progress, challenges remain in improving durability and simplifying deployment processes. Future research should focus on lightweight, durable materials and simplified designs to enhance reliability and expand the range of applications. The significance lies in providing a comprehensive review of deployable structures, analyzing both their benefits and limitations, and offering insights into potential future developments that could influence engineering, healthcare, and emergency response innovations.

Keywords: Deployable structure; aerospace; medical devices; emergency facilities.

1. Introduction

Deployable structures are a type of structure capable of freely changing their geometric configuration on a large scale. These structures can transition from a compact state to a deployed state. Compared to traditional structures, deployable structures offer advantages such as fast construction speed and convenient assembly. They are easy to transport and store, also can be reused multiple times. Deployable structures have gained increasing attention in recent years due to their unique ability to transform between compact and expanded configurations, making them highly versatile across various fields [1]. In aerospace, these structures enable the efficient packaging and deployment of large systems, such as satellite antennas, solar panels, and space habitats, where space and weight constraints are critical. In the medical field, deployable structures are used in medical devices and microstructures, provide equipment support for various medical devices methods. Similarly, in emergency facilities, deployable structures offer quick assembly and transportability, allowing for the rapid establishment of shelters, camps, and other emergency facilities in response to crises. This paper explores the fundamental principles behind deployable structures and examines their applications across aerospace, medical devices, and emergency facilities, highlighting their importance in addressing modern engineering challenges. Throughout the history of deployable structures, many famous inventors and engineers have made significant contributions.

As early as the 15th century, Leonardo da Vinci designed several conceptual deployable structures. Although most of his designs were never realized, his sketches of folding bridges and collapsible devices laid the foundation for later engineering developments. R. Buckminster Fuller was a famous architect and inventor of the 20th century. He first proposed the concept of deployable structure in 1960 and invented the Geodesic Dome, a lightweight yet strong structure that could be quickly assembled and disassembled [2]. His design philosophy focused on achieving maximum strength and stability with minimal materials, influencing future deployable structure designs (NDAFS). In the 1960s, NASA led the development of deployable antennas and solar arrays for satellites. These devices could be compact during launch and expand once in space. NASA's designs, including scissor-like elements and telescopic booms, became classic examples of modern deployable structures, widely used in satellites, space stations, and other spacecraft. Invented by Chuck Hoberman in 1990, the Hoberman Sphere is a classic example of a deployable structure. This spherical structure can expand from a compact form into a large sphere. He also designed the famous Iris dome for the 2000 Hannover World Expo using a folding bar shear unit [3]. Hoberman's design has been widely used in art installations and architecture and has inspired further research into deployable technology applications in fields such as aerospace and medical devices.

These years deployable structures were used in many fields [4]. In spacecraft design, weight and space constraints are extremely strict. Deployable antennas and solar panels are significant technologies for addressing these challenges. These structures remain folded during launch and automatically deploy once in space, providing communication and energy support. For instance, the International Space Station and many satellites use deployable solar panels to maximize surface area, therefore increasing energy conversion efficiency. Small satellites, such as CubeSats, often use deployable structures to extend certain tasks after reaching orbit, such as instrument arms or solar panels. This allows small satellites to stay compact while achieving various functions effectively. Deployable stents are small, expandable devices used to keep blood vessels open, often in the treatment of heart conditions. The stent is inserted through a small cut and expands inside blocked or narrowed blood vessels, helping to restore normal blood flow. This design minimizes surgery impact and shortens recovery time, making it widely used in heart and vascular procedures.

In the event of natural disasters or other emergencies, deployable shelters can quickly provide temporary living spaces. These structures are typically modular in design and can be deployed within minutes through simple operations, accommodating large numbers of people. They are commonly used for emergency housing, command centers, and storage during emergencies. In rescue operations or military applications, mobile bridges and foldable roads can be quickly set up in disaster zones or combat areas to restore transportation and allow supplies to move. These structures are lightweight and easy to transport, but once deployed, they can support heavy vehicles, improving the efficiency of rescue or military operations.

In summary, deployable structures are widely used in various engineering fields and possess significant development potential. This research aims to review and summarize the research on the applications of deployable structures in aerospace, medical devices, and emergency facilities. It compares existing studies, analyzes the similarities and differences, strengths and weaknesses between different research, and identifies the gaps and unresolved issues in the current research. Based on these findings, the paper suggests directions for future research. Sec. 2 introduces the definition of deployable structure and some deployable units, along with the relevant formulas and methods used. Sec. 3 focuses on the applications of deployable structure in aerospace engineering, summarizing and comparing relevant literature, and proposing future research directions. Sec. 4 discusses the applications of deployable structure in the medical field, providing a summary and comparison of related studies, and suggesting future research directions. Sec. 5 explores the applications of deployable structure in emergency facilities, summarizing and comparing related literature, and identifying future research directions.

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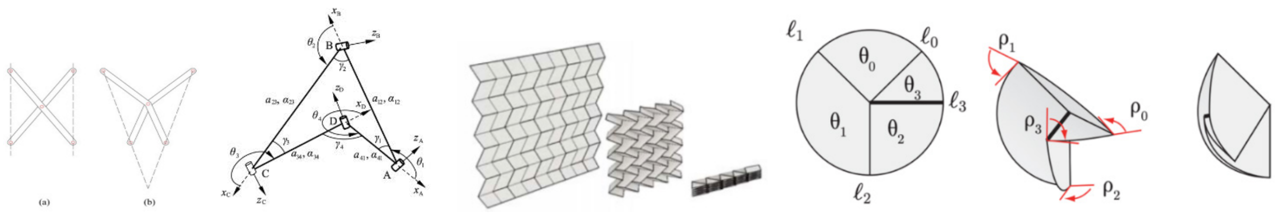

Fig. 1 Concepts of deployable sturcturep [5-7].

2. Concepts for Deployable Structure

Deployable structure has many concepts used in different fields as shown in Fig. 1, such as scissor-like mechanism [5], 4R,5R,6R linkages[6], origami structures [7]. A structure is a combination of resistant bodies made to bear loads. In general, no internal mobility or relative motions among its members are allowed. Deployable Structures are different. Their geometry can be altered to meet certain requirements. In the study of deployable structures, calculating the degrees of freedom (DOF) of mechanisms is essential. This paper introduces a method for calculating DOF using inherent parameters of the mechanism, such as the number of links, the number of joints, and the degrees of freedom of each joint. By substituting these parameters into calculation formulas, the DOF of the mechanism can be quickly determined. This method is widely applicable, efficient in computation, and low in cost. However, it is not suitable for many classical mechanisms and modern parallel mechanisms. This is because these formulas do not account for the effect of overconstraints within the mechanism on its degrees of freedom [8]. In 1869, Chebychev developed the first formula for calculating the degrees of freedom (DOF) of mechanisms:

$$3n-2\left(p_0+p_n\right)=1 \tag{1}$$

Here, 3n represents the number of parameter variables required to describe the position and posture of the nth link in the plane, and $2\left(p_0+p_n\right)$ represents the number of constraint equations. This formula could only be used to calculate the DOF of planar linkage mechanisms and cannot be easily generalized to spatial mechanisms. In 1883, Grübler developed a structural condition for single-degree-of-freedom planar mechanisms like Chebychev's formula (1-1). Considering helical pairs, Grübler introduced a new condition for spatial single-degree-of-freedom mechanisms in 1917:

$$5h-6m+7=0 \tag{2}$$

where h represents the number of helical pairs. Kutzbach later developed a special case of the DOF calculation formula for spatial structures when b = 6-d:

$$M=\left(6-d\right)\left(m-1\right)-\Sigma_{i=1}^{p}(6-d-f_i) \tag{3}$$

Here, d is the parameter for independent loops. Kutzbach considered that for mechanisms with the same d for each independent loop, the formula (1-3) applies universally. This formula, known as the Grübler-Kutzbach formula, or simply the G-K formula, is widely used for calculating degrees of freedom. Most of the formulas from this category of methods were developed in the early stages of the development of mechanism theory. Influenced by the simplicity of early mechanical topologies, most of these formulas could only analyze the DOF of certain specific types of mechanisms, particularly planar mechanisms. Regarding spatial mechanisms, the G-K formula maintains the advantages of fast calculation speed and high efficiency while incorporating the influence of constraint parameters, thus broadening its application scope. However, the G-K formula still does not account for overconstraints within mechanisms, which often leads to failure when calculating the DOF of overconstrained mechanisms.

3. Applications in Aerospace Engineering

The ring deployable antenna structure is a specialized design used in spacecraft to efficiently deploy antennas within limited space. Its design aims to maximize the surface area of the antenna, enhancing communication or signal reception ability, while ensuring that the antenna remains compact during launch to accommodate the size constraints of the spacecraft. In recent years, many scholars have conducted research and analysis on the support structures of deployable antennas [9]. The support structures for deployable antennas are generally composed of deployable ring trusses, as shown in Fig. 2 [9]. In 1997, You Z proposed three topological systems made up of scissor-like mechanisms. The design requires that the top and bottom sections of the units forming the deployable antenna mechanisms are shaped as either isosceles trapezoids or isosceles triangles. In 2021, Cao W A and others proposed a new topological system based on this, as shown in Fig. 3 [9].

The new design requires that the top and bottom of the corresponding units be rectangular. Unlike the isosceles trapezoid or isosceles triangle used in existing designs, a rectangle in this new approach maintains symmetry along both its length and width, and its adjacent sides are perpendicular to each other. These two characteristics simplify the geometric parameters, as well as the kinematic and dynamic analysis of the corresponding units. Regarding the deployment process of the deployable ring truss, Wu X provided a more detailed description in 2020 [10]. She used a double-loop hexahedral ring truss structure, like the concept A proposed by You Z. The double-loop hexahedral truss consists of a ring truss structure formed by polygons in the inner and outer rings. The fully deployed/folded state is shown in Fig. 4 [10]. The outer ring is mainly composed of upper chords, lower chords, vertical rods, and diagonal sleeve rods connected through nodes. The inner ring is connected by upper chords, lower chords, and vertical rods through nodes. The inner and outer rings are connected by link rods and nodes. The deployment process of the structure involves three stages: unlocking, deployment, and positioning. Two adjacent units are shown in Fig. 5 [10].

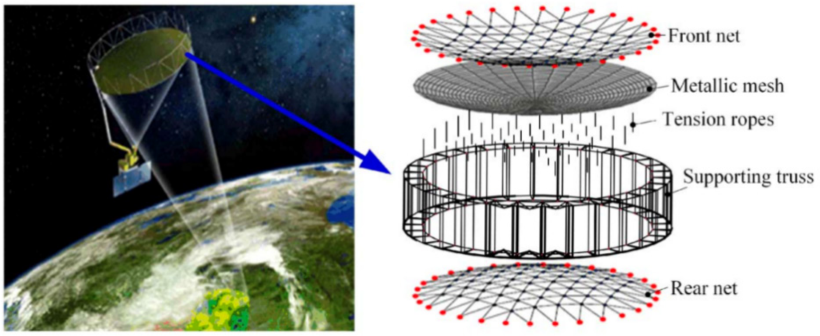

Fig. 2 deployable antenna [9].

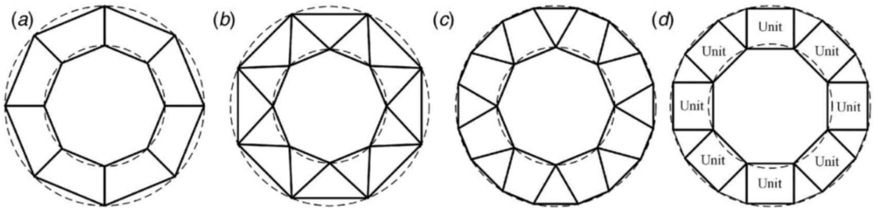

Fig. 3 Concepts of deployable truss [9].

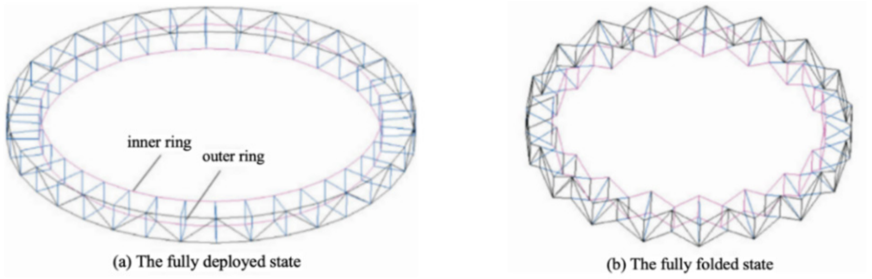

Fig. 4 Deployable truss [10].

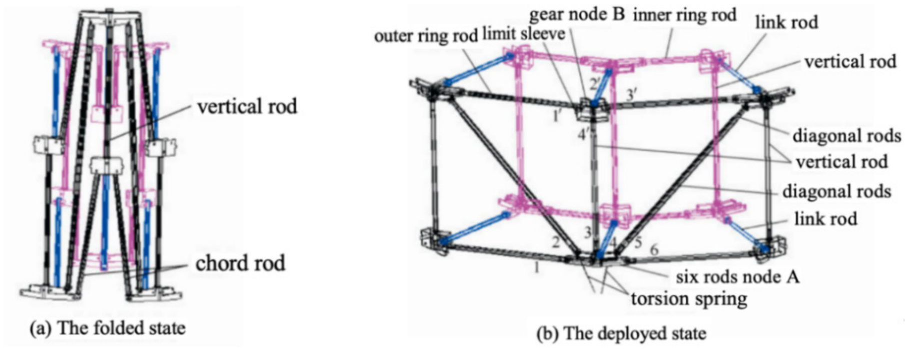

Fig. 5 Adjacent units [10].

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Six rods are connected to node A and rods 1 to 6. Under the driving force of a motor, the inner rods of the diagonal brace sleeves retract into the outer sleeve rods, and gear node 8, under the action of a torsion spring and synchronous gears, achieves the overall deployment of the structure. Wu X continued to conduct a quantitative analysis of the deployment height of the structure. The antenna support structure adopts a double-ring ring-shaped truss with an equal number of sides on the inner and outer rings. Let the circumferential division number of the antenna be 0, the outer ring radius be R, and the inner ring radius be r. According to the formula for the chord length of a regular polygon, the following can be obtained:

$$s_1 = 2r\sin\left(\frac{\pi}{n}\right); s_2 = 2R\sin\left(\frac{\pi}{n}\right) \quad (4)$$

Here, s1 and s2 are the chord lengths of the truss members in the inner and outer rings, respectively. From the analysis of the above folding/deployment process, the main factors affecting the minimum folding height of the antenna are the length of the outer chord rods and the length of the link rods. The maximum folding height is the maximum of the length of the vertical rods and the outer chord rods or the link rods, i.e., the folding height of the antenna structure is:

$$H_1 = max\left(h + s_1, h + L\right) \quad (5)$$

where h is the length of the vertical rod; L is the length of the link rod between the inner and outer rings. The lengths of the outer chord rods and link rods are mainly constrained by the number of sides of the antenna and the antenna aperture. As the aperture of the antenna increases and the number of sides of the antenna polygon increases, the overall folding height of the structure tends to increase at a decreasing rate. This trend becomes more pronounced as the antenna aperture increases. Therefore, using a double-ring hexahedral ring-shaped deployable antenna, the total folding height will not increase proportionally with the increase in the antenna aperture, making it an ideal form of deployable structure.

Origami-based solar panels are a type of deployable solar panel structure designed using origami techniques. Inspired by the art of paper folding, these solar panels can be folded during launch or transportation to reduce their volume and can then be quickly deployed when needed to maximize the surface area for capturing solar energy. This technology has broad application prospects in fields such as aerospace and emergency rescue. In spacecraft design, space and weight are critical constraints. The foldable nature of origami-based solar panels helps to accommodate larger panel surfaces within limited spaces, thus improving energy generation efficiency. At the same time, origami structures are lightweight, easy to operate, and can be deployed rapidly, making them an ideal choice for powering spacecraft and remote equipment. This paper does not analysis deeply into the deployment process of origami-based solar panels but instead summarizes two widely used origami structure deployment methods in aerospace engineering. The aim is to provide a comprehensive overview that can serve as a basis for innovative research.

Yogesh S introduced four deployment methods for origami-based solar panels, which can be classified into two main types: the Miura Folding Pattern and the Folding Fan Pattern [11]. The Miura Folding Pattern(seen from Fig 6) was first proposed by Japanese astrophysicist Koryo Miura. The Miura fold's crease pattern creates a tessellation of the surface using parallelograms. In one direction, the creases are arranged in straight lines, where each parallelogram reflects its adjacent one across the crease. In the other direction, the creases follow a zigzag pattern, with each parallelogram being a shifted version of its neighbor across the fold. The zigzagging creases are either all mountain or all valley folds, and neighboring zigzag paths alternate between mountains and valleys. Meanwhile, the straight paths of creases switch between mountain and valley folds. The Miura fold is an example of rigid origami, meaning the folding process can be performed in a continuous motion where each parallelogram remains flat throughout. This characteristic makes it suitable for folding surfaces composed of rigid materials. Folding fans (right panel of Fig. 6), designed like a section of a circle, are crafted from delicate materials like paper or feathers attached to slats that rotate around a central pivot, allowing the fan to be closed when not in use. In conclusion, deployable antennas can be stored compactly during launch and unfolded in space, making them ideal for tight spaces. Scissor-like mechanisms and double-ring structures help fit various spacecraft designs, improving signal transmission. A key advantage is that as antenna size increases, the folded height doesn't grow significantly, which is crucial for larger missions. However, the mechanical design's complexity increases the risk of issues during deployment. Future research should focus on lightweight, strong materials to withstand space conditions and simplify the design for better reliability. Origami designs for foldable solar panels work well, but material choice is key for flexibility and durability in space. Compared to antennas, these designs may lack strength for certain missions. Future research could explore lighter, stronger materials and new folding patterns beyond Miura and Folding Fan to boost solar panel efficiency and adaptability.

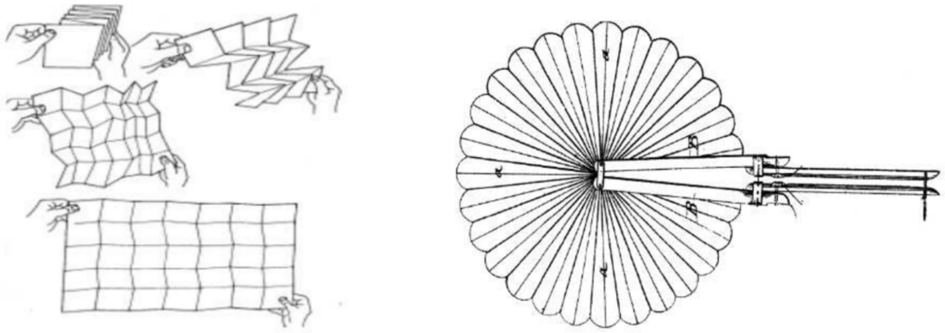

Fig. 6 Folding patterns a and b [11].

4. Applications in Medical Devices

Deployable structures have found significant applications in the medical field, offering solutions that improve both treatment efficiency and patient outcomes. In recent years, deployable stents and retractable surgical instruments are the main applications of deployable structures in the field of medical devices. Deployable stents are widely used in cardiovascular treatments, primarily for addressing artery narrowing or blockage issues. They are typically made of a mesh-like metal structure and are initially introduced into the patient's artery in a folded or compressed state via a catheter. Upon reaching the affected area, the stent expands and anchors itself to the artery walls, helping to keep the artery open and ensuring normal blood flow. Retractable surgical instruments are advanced medical tools used in minimally invasive surgeries, allowing surgeons to access the body through small incisions and perform delicate procedures by expanding or retracting the instruments once inside. These instruments are designed to minimize the size of surgical wounds, reduce surgical risks, and expedite recovery times. This chapter mainly summarizes the literature on deployable stents, compares it and puts forward constructive suggestions.

Medical stents are tubular, mesh-like structures, as shown in Fig. 7(a) [12]. These stents are made from chemically inert materials and are designed with specific mechanical properties to function effectively. When deployed, they exert outward radial forces to support constricted or diseased arteries, thereby helping restore normal blood flow, as illustrated in Fig. 7(b). Stents are characterized by a significant expansion ratio; they have a small diameter before deployment to facilitate easy transport within the body. Once positioned, the stent expands to widen the narrowed blood vessels.

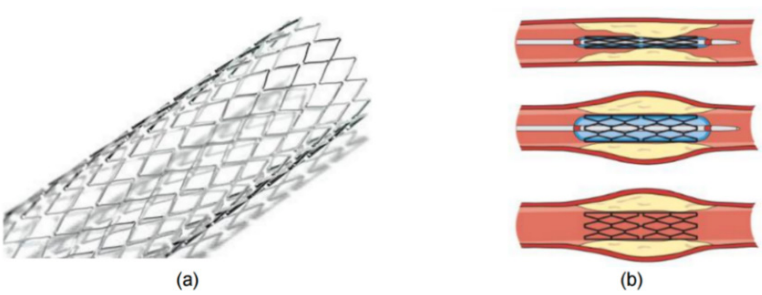

Fig. 7 Deployable stents [12].

As early as 2005, Kuribayashi K and colleagues introduced a stent design based on origami structures (Fig 8), made from folds with alternating mountain and valley patterns [13]. This stent used an innovative material: a Ni-rich titanium/nickel (TiNi) shape memory alloy (SMA) foil. The material exhibits different effects at varying temperatures. Once the fold pattern is applied to the foil, the stent‘s deployment is automatically achieved either through the SMA effect at body temperature or by utilizing the stent‘s superelastic properties. In 2023 Zhang Y investigates the use of a novel NiTi-based deployable stent for Minimally Invasive Glaucoma Surgery (MIGS) (Fig. 9) [14]. The stent aims to reduce intraocular pressure (IOP) by creating a fistula between the anterior chamber and the subconjunctival space. The stent, made of a laser-cut NiTi tube, is designed to be flexible and expandable, and can be inserted into the eye using a minimally invasive surgical approach. The deployable stent holds promise as a stable, adaptable solution to support long-term reduction of IOP, potentially providing an effective, minimally invasive

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treatment for glaucoma.

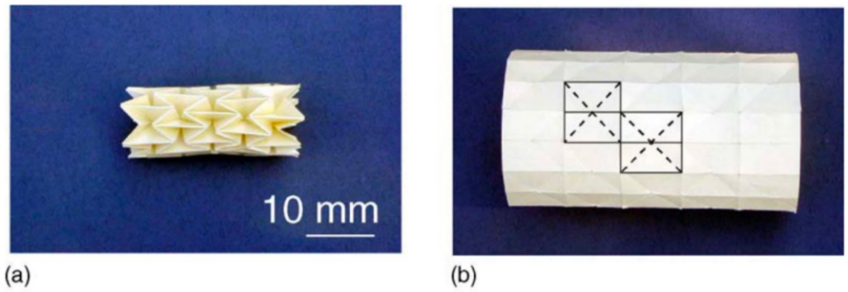

Fig. 8 Origami deployable stents [13].

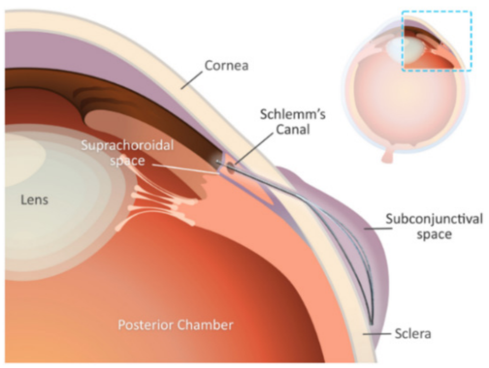

Fig. 9 Deployable stent in the eye [14].

In conclusion, deployable stents are essential in treating artery blockages, helping restore normal blood flow by expanding inside the artery. This reduces surgery time and complexity, greatly improving treatment. NiTi (Nickel-Titanium) shape memory alloys are commonly used in these stents because they can automatically expand at body temperature and are resistant to rejection. However, they can wear out over time, affecting long-term stability. Current designs mainly focus on cardiovascular treatments, with some newer applications in eye surgery, but their use is still limited. Future research should focus on developing lighter, more durable materials that resist wear, such as polymers or composites, to improve stent longevity and lower costs. Additionally, stents could be used in other fields like soft tissue repair, neurosurgery, and orthopedics. Smart materials with sensors to monitor stents in real-time could also enhance their effectiveness in the future.

5. Applications in Emergency Facilities

Deployable structures have found vital applications in emergency facilities due to their portability, ease of deployment, and ability to quickly adapt to urgent needs in critical situations.This paper primarily introduces two applications of deployable structures in emergency facilities: deployable bridges and deployable shelters. It reviews the recent developments in these areas, highlights their shortcomings, and identifies potential opportunities for further improvement and innovation. A deployable bridge is a critical engineering solution primarily used in emergency response, military operations, and disaster recovery. These bridges are designed for quick assembly and easy transportation, ensuring efficient restoration of access to areas that have been cut off due to natural disasters or military conflicts. For emergency deployable bridges, scissor-like mechanism is an excellent choice. Yan C H and Aik T A designed an emergency deployable bridge based on the scissor-like mechanism (depicted in Fig. 10) [15]. The extension and retraction of the emergency deployable bridge are designed using the Nuremberg Scissors theory [15]. This theory involves a planar mechanism made up of several links and pins, forming a scissor-like mechanism capable of expanding and retracting at a specific ratio. Due to its design, the bridge can be easily deployed or collapsed with minimal force. The Nuremberg Scissors mechanism consists of rigid bodies connected through kinematic constraints, and the degree of freedom of the system can be determined using the Kutzbach equation.

$$F = 3(L-1)\ddot{}C2J - H \qquad (6)$$

where F is the degree of freedom, L is the number of links and J is the number of lower pair and H is the number of higher pair. The deployable bridge is specifically designed to fit into the trunk of a 4x4 pick-up truck. When fully retracted, its dimensions are 2.2 meters in width, 2 meters in height, and 14 meters in length. The bridge's design is shown in a model (illustrated in Fig. 11), illustrating its compact nature for transport and deployment during emergencies. In addition, Li Q and others designed a deployable bridge based on scissor-like mechanism.[16] In this design, the structural members primarily experience axial forces, allowing the material to distribute forces uniformly and maximize its performance. Given that an optimized arch structure is subject only to compressive forces without bending, the deployable bridge discussed here is designed as an arch bridge (presented in Fig. 12) [16]. To facilitate ease of production and assembly, a curved shape is selected for the arch axis. This design choice also allows the span of the bridge to be adjusted by increasing or decreasing the number of shear hinge structures. To enhance the structural stability of the deployable arch bridge, diagonal support bars and tie bars aligned with the direction of travel are introduced. These elements, along with the main structural components, form a triangular configuration, which improves the overall stability. The horizontal thrust at the ends of the arch is managed by the tie bars, reducing the geological requirements for the foundation of the arch bridge.

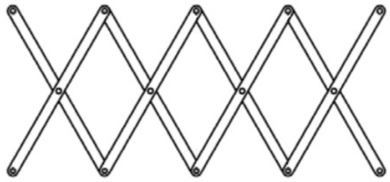

Fig. 10 Scissor-like mechanism [15].

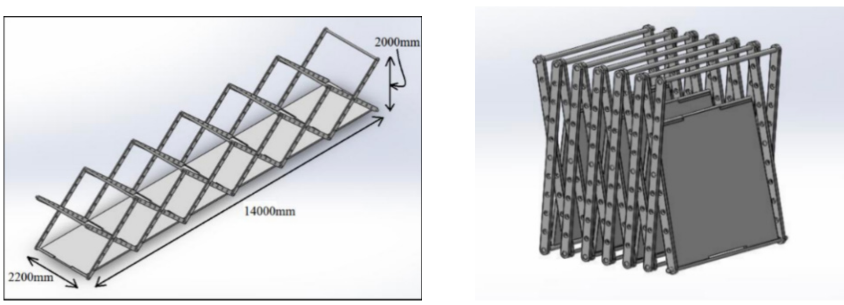

Fig. 11 Deployable bridge model [15].

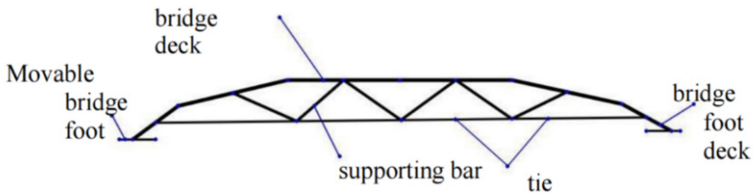

Fig. 12 Deployable arch bridge [16].

Deployable shelter is a portable, temporary structure designed to be quickly assembled and used in emergency situations, such as natural disasters, military operations, or humanitarian relief efforts. These shelters are designed for rapid deployment, easy transportation, and compact storage. They provide essential protection from the elements and a temporary space for medical treatment, accommodation, or command centers. Verzoni A and others proposed a deployable shelter based on origami structures and analyzed how to transition from a thin-walled shelter (seen from Fig. 13) to a thick-walled shelter in practice [17]. The transition from thin-walled shelters to thick-walled structures involves several key adjustments to accommodate the thickness of the panels while maintaining their flat-foldability and functionality. Traditional thin-walled origami structures rely on zero-thickness panels, where fold lines are located along straight edges. To convert these into thick-walled structures, the location of the hinges must be adjusted, either by using offset crease techniques or by shifting hinge lines to the edges of the panels (depicted in Fig. 14). These adjustments allow for thick panels to fold without interference between adjacent panels.

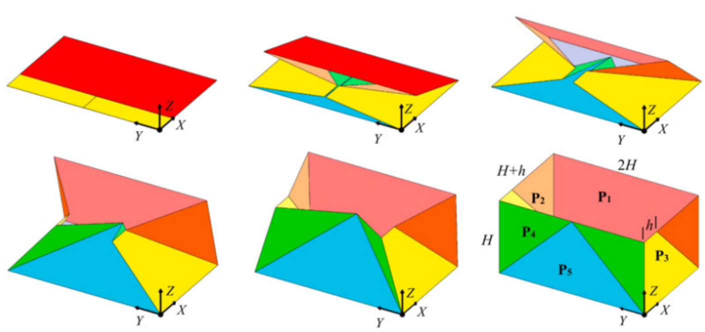

Fig. 13 Thin-walled shelter [17].

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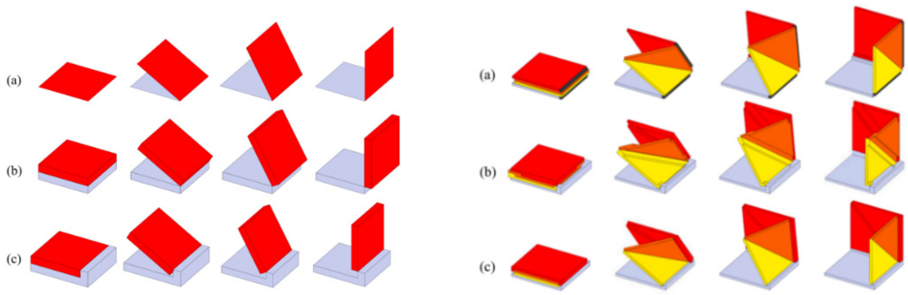

Fig. 14 Thin-walled structure to thick-walled structure [17].

Another method used is the nesting of panels, where some panels are designed with varying thicknesses at specific points to ensure they can fold into each other neatly, preserving the foldability of the flat. This technique involves modifying panel thickness locally to allow them to fold together. Their paper discusses different techniques, such as the offset panel technique and hinge shift technique, which help maintain kinematic compatibility when transitioning to thick-walled designs (shown in Fig. 15). These methods prevent panel intrusion and ensure that the thick-walled structure can still be folded flat for transport and rapidly unfolded into a stable shelter.

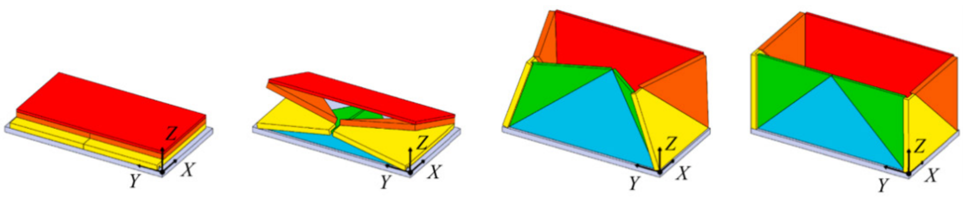

Fig. 15 Thick-walled structure [17].

Scissor-like structures are also widely used in the design of deployable shelters. Arslan A and others analyzed a type of post-disaster emergency shelters in Turkey, which are prefabricated houses known as Kızılay Tents and Mevlana Houses [18]. The house is engineered to accommodate a family of four, with cross-sectional stresses and deformations modeled during its transformation from fully closed to fully open. The moving section of the house opens by sliding along wheels, aided by a mechanical arm. As the arm rotates, it generates a force that causes the scissors-like mechanism to extend outward, unfolding the movable section in a way like an accordion. In its fully closed state (as shown in Fig. 16), the deployable earthquake house incorporates a pantograph mechanism. As it opens, the system moves outward on wheels, and a central belt is incorporated to both reinforce the structure and provide a platform for the lower panels. When the system is completely unfolded, the roof panels are secured by fastening screws through the slots located along the central belt. The connection details are depicted. This ensures the roof remains in the fully open position.

In conclusion, deployable arch bridges are designed so that the main structural parts mostly handle axial forces, which optimizes material use and boosts performance. Adding diagonal support and tie bars strengthens the bridge by creating triangular shapes, allowing for flexibility in the bridge span by adjusting the number of shear hinge structures to fit different lengths and terrains. However, some bridges still depend on specific ground conditions for stability, which could limit their use in challenging environments. Future designs should focus on using lighter, stronger materials that keep the bridge sturdy while reducing its weight for better portability. Implementing automated systems could also speed up the assembly process, making deployment quicker and requiring less specialized help. The shift from thin-walled to thick-walled designs has been achieved using techniques like offset panels and hinge shifts, ensuring they stay strong without losing the ability to fold. However, thick-walled designs can be tricky due to panel interference during folding, and while methods like panel nesting help, construction remains complex. The materials used for these shelters, especially those meant for temporary use, may not be durable enough for long-term conditions. Future research should aim to develop lightweight yet durable materials that enhance the shelter's resilience without sacrificing portability or ease of assembly. Simplifying the folding process and reducing moving parts could further improve reliability and decrease the chances of mechanical failure.

Fig. 16 Post-disaster emergency shelters [18].

6. Conclusion

Overall, deployable structures are a major improvement in many areas like aerospace engineering, medical devices, and emergency facilities. Their ability to easily change from a compact state to an expanded state helps save space, makes them easy to transport, and allows for quick setup in critical situations. In aerospace, deployable antennas and solar panels help maximize space while boosting performance during missions. In the medical field, devices like stents and surgical instruments are designed to be deployable, which improves treatment accuracy and shortens recovery times. In emergencies, deployable shelters and bridges enable fast responses during crises. Despite these advancements, there are still challenges to overcome, such as improving their mechanical strength, durability, and deployment processes. Future research should focus on tackling these challenges to make deployable structures more reliable, efficient, and versatile for a wider range of uses. This research summarizes the application of deployable structures in these three fields contemporarily, analyze the advantages and disadvantages, and give suggestions for future development, which plays a constructive role in future research.

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