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Review Article

A REVIEW PAPER ON OPTIMIZATION OF SCISSOR HINGE DEPLOYABLE SPACE ROOF UNDER SELF-WEIGHT AND DEFLECTION

TabishIzhar[1]., Mohd Hamza*[2] and Neha Mumtaz[1]

[1]Department of Civil Engineering, Faculty of Engineering and Technology, Integral University, Lucknow (U.P.), India
[2]Department of Civil Engineering, Masters in Technology, Integral University, Lucknow (U.P.), India

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ABSTRACT

One area in which space grids are set to advance in the future is the field of deployable and foldable structures. The property of deploy ability in a space grid structure may be used just once or many times. These space grids can be assembled in compact form, transported into outer space and then deployed in a 'one-off' operation. Alternatively, temporary transportable buildings can benefit from the use of rapidly deployable structures. There is need to conduct analysis of newly introduced deployable space structure for large spans so that they could be used in stadiums or large open spaces or grounds where the entertainment is hindered sometimes due to unfavorable weather conditions. A deployable scissor grid can be considered as a kinematic linkage of scissor units, also known as pantographs or scissor-like elements. Scissor grids are created by interconnecting multiple scissor units at their end points. Translational units allow constructing spatial double-layer scissor grids with a myriad of shapes and a foldable deployment behavior, of which the design can be simplified to a set of two-dimensional problems, as all its upper and lower layer nodes are located on parallel line. Analysis and design issues of a new concept of deployable structures featuring stable and stress-free states in both deployed and collapsed configurations and behavior of these structures during their deployment[1] procedure, which is associated with geometric compatibility requirements have to be studied thoroughly.

INTRODUCTION

In architecture and structural engineering, a space frame or space structure is a truss-like, lightweight rigid structure constructed from interlocking struts in a geometric pattern. Space Frames can be used to span large areas with few interior supports. Like the truss, a space frame is strong because of the inherent rigidity of the triangle; flexing loads (bending moments) are transmitted as tension and compression loads along the length of each strut. Steel space frames provide great freedom of expression and composition as well as the possibility to evenly distribute loads along each rod and external constraints. With these features, steel space frames can be used to achieve also complex geometries with a structural weight lower than any other solution. The inner highly hyper-static system provides an increased resistance to damages caused by fire, explosions, shocks and earthquakes. Space frames are modular and made of highly industrialized elements designed with a remarkable dimensional accuracy and precise surface finish.

Types

Within the meaning of space frame, we can find three systems clearly different between them:

Curvature classification

Space plane covers. These spatial structures are composed of planar substructures. Their behaviour is similar to that of a plate in which the deflections in the plane are channelled through the horizontal bars and the shear forces are supported by the diagonals.

Barrel vaults. This type of vault has a cross section of a simple arch. Usually this type of space frame does not need to use tetrahedral modules or pyramids as a part of its backing.

Corresponding author: **Mohd Hamza**
Department of Civil Engineering, Masters in Technology, Integral University, Lucknow (U.P.), India

Spherical domes and other compound curves usually require the use of tetrahedral modules or pyramids and additional support from a skin.

Classification by the arrangement of its elements

- **Single layer grid-** All elements are located on the surface to be approximated.
- **Double layer grid-** The elements are organized in two layers parallel to each other at a certain distance apart. Each of the layers form a lattice of triangles, squares or hexagons in which the projection of the nodes in a layer may overlap or be displaced relative to each other. Diagonal bars connect the nodes of both layers in different directions in space. In this type of meshes, the elements are associated into three groups: upper cordon, cordon and cordon lower diagonal.
- **Triple layer grid-** Elements are placed in three parallel layers, linked by the diagonals. They are almost always flat.
- Other examples we could attach with the definition of space frame are these:
- **Pleated metallic structures-**Emerged to try to solve the problems that formwork and pouring concrete had their counterparts. Typically run with welded joint, but may raise prefabricated joints, a fact which makes them space meshes.
- **Hanging covers-** Designs on the cable taut, spine, and the catenary arch anti funicular show their ability to channel forces theoretically better than any other alternative, have an infinite range of possibilities for composition and adaptability to any type of plant cover or ensure vain. However, imprecisions in shape having the loaded strand (ideally adapts dynamically to the state of charge) and the risk of bending the arc to unexpected stresses are problems that require pre-compression and prestressing elements. Although in most cases tend to be the cheapest and the technical solution that best fits the acoustics and ventilation of the covered enclosure, are vulnerable to vibration.
- **Pneumatic structures-**Wherein the closure membrane is subjected to a pressurized state, may be considered within this group. Figure 1 shows an example of a pneumatic structures.

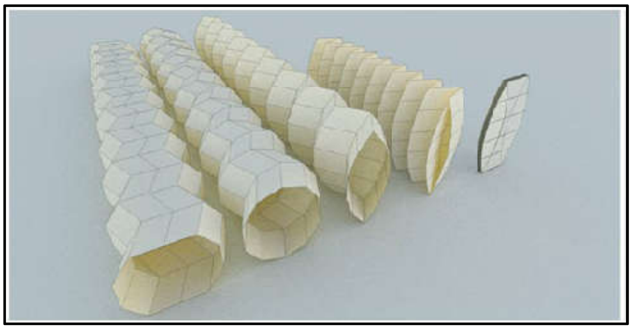

Figure 1 Pneumatic structures

LITERATURE REVIEW

One area in which space grids are set to advance in the future is the field of deployable and foldable structures. The property of deployability in a space grid structure may be used just once or many times. These space grids can be assembled in compact form, transported into outer space and then deployed in a 'one-off' operation. Alternatively, temporary transportable buildings can benefit from the use of rapidly deployable structures.[1]

Figure 2 and Figure 3 shows the classification of space structure by Stevenson and Rivas Adrover respectively.

There is need to conduct an analysis of newly introduced deployable space structure for large spans so that they could be used in stadiums or large open spaces or grounds where the entertainment is hindered sometimes due to unfavourable weather conditions.

In reticulated foldable space grids structures, the basic folding unit is made of two members connected together at or near their mid-length to produce a 'scissor' mechanism. The ends of the members of several scissor mechanisms may then be connected together in a predefined way, in order to form an expanding truss-like arrangement. A series of these planar assemblies may be connected by similar scissor mechanisms running transversely, so forming a folding three-dimensional grid. Space grids are frequently used for long-span roof structures for sports stadiums or aircraft hangars, for example, and in these situations, the method of erection may significantly affect the cost of construction.

A deployable scissor grid can be considered as a kinematic linkage of scissor units, also known as pantographs or scissor-like elements. Scissor grids are created by interconnecting multiple scissor units at their end points. Translational units allow constructing spatial double-layer scissor grids with a myriad of shapes and a foldable deployment behaviour, of which the design can be simplified to a set of two-dimensional problems, as all its upper and lower layer nodes are located on parallel line. Analysis and design issues of a new concept of deployable structures featuring stable and stress-free states in both deployed and collapsed configurations will be considered. The behaviour of these structures during their deployment[1] procedure, which is associated with geometric compatibility requirements will also be covered.

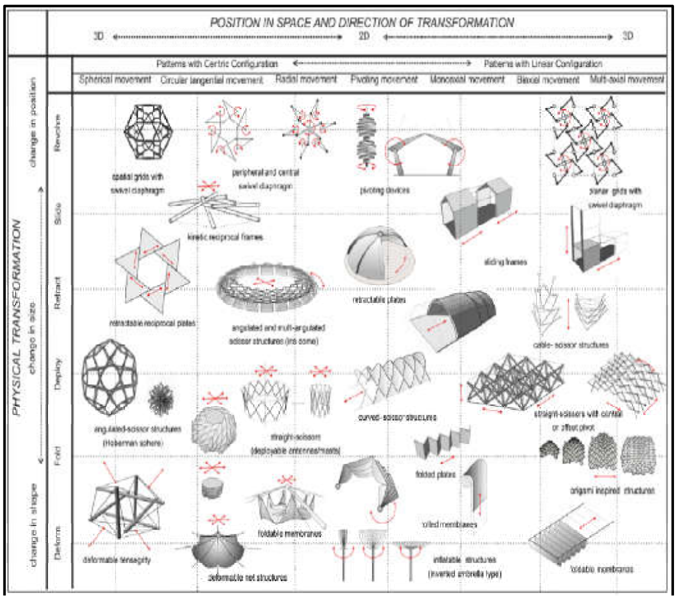

Figure 2 Classification by Stevenson

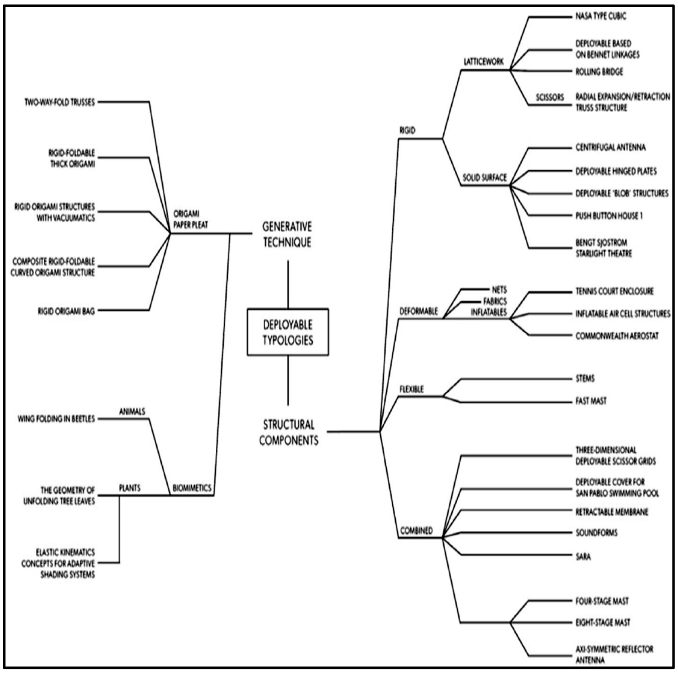

Figure 3 Classification by Rivas Adrover

Deployable- collapsable structures have many potential applications ranging from emergency shelters and facilities. Through relocatable, semi-permanent structures, to the space-station component. Their main advantages are the small volume they occupy during storage and insulation, and their fast and easy erection procedure. A new concept of self-stabilizing deployable structures featuring stable, stress-free states in both deployed and collapsed configuration shows even higher promise. During the deployment phase, these structures exhibit a highly nonlinear behaviour. A large displacement/ small strains finite element formulation was used to trace the nonlinear load-displacement curve, and to obtain the maximum internal forces that occur in the members of the structure during deployment. The influence of various parameters that affect the behaviour of the structures, such as geometric shape, dimensions of the members, cross-sectional properties and kinematic assumptions are already investigated.[2]

Deployable structures are prefabricated space frames that can be stored and transported in a compact folded configuration and then deployed rapidly into a load bearing configuration. The structures are stable and stress-free in the folded and the deployed configuration, but exhibit a highly nonlinear behaviour during deployment. Therefore, their design process should include simulation of their response in two phases: in the deployed configuration under service loads, and during deployment. The first phase involves linear analysis while the second one requires a geometrically nonlinear finite element formulation. Both simulations can be very demanding in terms of computer storage requirements as the number of degrees of freedom increases. In addition, the nonlinear analysis is quite expensive because of a large number of load steps that are necessary in order to trace the complete load-displacement path. Some papers first described a set of numerical models that were used to simulate the exact structural behaviour using the finite element program ADINA. Then, some simplified analytical and numerical models were proposed that can be applied in the preliminary design stage, or even for final design, in order to obtain approximate but satisfactory results at a much lower cost.[3]

The indispensable dialogue between theoretical and experimental methods was underlined. Some characteristics related to the so-called “parametric method” used to understand and design space structures were described. Original pedagogical experiences were presented: bi-cable model, graph theory, form finding procedure, and construction of prototypes. They emphasized on the building of physical models, study of construction details, and even, necessary exercises requiring a physical involvement from the students.[4]

A two-phase genetic algorithm (GA) for minimum weight design of free-form steel space-frame roof structures consisting of discrete commercially available rectangular hollow structural sections (HSS).Subsequently, the algorithm was extended to topology optimization of structures. This article presents a new methodology for simultaneous sizing, topology, and shape optimization of free-form steel space-frame roof structures with complex geometries using evolutionary computing. Two methods so faltering the geometry of the structure a represented, one a simple method to be used for roof structures with relatively regular geometries, and the other for more complicated geometries. The goal is to achieve additional structural efficiencies by altering the geometry of the roof structure while simultaneously optimizing the roof member and column cross-sectional dimensions and the roof topology. Esthetics is a significant consideration in the structures of the type considered in this research. As such, preserving the general form created by the architect is considered in the proposed shape optimization algorithm. To achieve this, heuristic limits are imposed to avoid drastic or undesirable changes in their architectural form. The methodology is applied to two real-life free-form steel space-frame roof structures. They are two of the thirteen train stations making up the Ottawa Light Rail Transit (OLRT) system to be completed in Ottawa, Canada, in 2018. Efficiencies in the range of 10–16% are reported for the two examples.[5]

Deployable scissor grids can quickly transform between different configurations, making them particularly fit for mobile and temporary applications. Their ability to deploy typically comes along with a high design complexity and a limited freedom of shape. However, we've found that by using so-called translational scissor units it is possible to generate a myriad of curved spatial grids through a design process that can be simplified into a set of two-dimensional problems. The resulting scissor grids are mechanisms with a smooth and stress-free deployment behaviour. Due to their qualities, they have formed the topic of previous research, but nevertheless, we've noticed that a large part of their design potential has remained unexplored. By for the first time unravelling the general principles that govern the motion and shape of this scissor grid type, we've managed to reveal various new and interesting design possibilities. This paper presents these new proposals together with the existing ones in order to form a comprehensive overview of the geometric potential and kinematic behaviour of deployable scissor grids consisting of translational scissor units. It covers the mathematical concepts needed to analyse and generate this scissor grid type, ranging from a single scissor unit to large assemblies. In addition, the paper introduces multiple methods to include joints in the line models without modifying their deployment behaviour. This work, therefore, broadens the design space and compiles the main characteristics of this scissor grid type in order to improve their accessibility and applicability in design.[6]

Compliant mechanisms such as tape springs are often used on satellites to deploy appendices, e.g. solar panels, antennas, telescopes and solar sails. Their main advantage comes from the fact that their motion results from the elastic deformation of structural components and the absence of actuators or external energy sources. The mechanical behavior of a tape spring is intrinsically complex and nonlinear involving buckling, hysteresis and self-locking phenomena. In the majority of the previous works, dynamic simulations were performed without any physical representation of the structural damping. These simulations could be successfully achieved because of the presence of numerical damping in the transient solver. However, in this case, the dynamic response turns out to be quite sensitive to the amount of numerical dissipation, so that the predictive capabilities of the model are questionable. In this work based on numerical case studies, we show that the dynamic simulation of a tape spring can be made less sensitive to numerical parameters when the structural dissipation is taken into account.[7]

A two-phase genetic algorithm was presented by Maggie Kociecki, HojjatAdelifor simultaneous sizing and topology optimization of free- form steel space frame roof structures consisting of discrete commercially available rectangular hollow structural sections. The algorithm is applied to two real-life space roof structures intended for Ottawa Light Rail Transit (OLRT). It is shown that the algorithm is effective for topology optimization of real-life roof structures with complex curvatures in multiple planes.[8]

Recently a two phase genetic algorithm (GA) for minimum weight design of free form steel space frame roof structures consisting of discrete commercially available rectangular hollow structural sections (HSS). Subsequently, the algorithm was extended to topology optimization of structures. The article by him presented a new methodology for simultaneous sizing, topology, and shape optimization of free form steel space frame roof structures with complex geometries using evolutionary computing. Two methods of altering the geometry of the structure are presented, one a simple method to be used for roof structures with relatively regular geometries, and the other form or e complicated geometries. The goal is to achieve additional structural efficiencies by altering the geometry of the roof structure while simultaneously optimizing the roof member and column cross- sectional dimension sand the roof topology. Esthetics is a significant consideration in the structures of the type considered in this research. As such, preserving the general form created by the architect is considered in the proposed shape optimization algorithm. To achieve this, heuristic limits are imposed to avoid drastic or undesirable changes in their architectural form. The methodology is applied to two real-life free- form steel space-frame roof structures. They are two of the thirteen train stations making up the Ottawa Light Rail Transit (OLRT) system to be completed in Ottawa, Canada, in 2018. Efficiencies in therangeof10–16% are reported for the two examples.[8]

A two-phase GA approach was presented for minimum weight design of free-form steel space-frame roof structures consisting of discrete commercially available rectangular hollow structural sections (HSS). The new methodology was applied to two roof structures subjected to the AISC LRFD code and ASCE-10 snow, wind, and seismic loadings. They are two of the thirteen train stations making up the Ottawa Light Rail Transit (OLRT) system to be completed in Ottawa, Canada, in 2018. Both examples have a diamond grid pattern and their members are subjected to torsion in addition to bending and axial forces. The initial design in both cases is an actual design performed in a design office by the first author iteratively using general-purpose structural analysis software over a period of days. The optimum solutions obtained using the new methodology resulted in savings of 12% and 7% for the two examples. The advantages of the two-phase GA optimization algorithm presented in this paper are threefold: a) automation of the design process of a complicated and one-of-a-kind structure; b) relieving the designer of days of the iterative design process, and c) achieving a lighter and therefore more economical design.[10]

A space frame structure assembled by pultruded circular hollow section (CHS) GFRP members. This large-scale structure was built with the span length of 8 m, the width of 1.6 m and depth of 1.13 m, but weighing only 773 kgf. The structural details and design considerations are developed for potential pedestrian bridge applications and may be further extended for roof structures with pedestrian activity. Experiments were conducted under three-point bending to understand the structural stiffness, load-carrying capacity, and failure modes. The structure showed satisfactory overall stiffness and load-carrying capacity in terms of potential pedestrian bridge applications. It was further found that the second order bending of critical compressive members might cause large nonlinear deformation of the overall structure. This is because bending of the critical compressive members resulted in a decrease in structural stiffness, with the maintenance of the load applied and an increase of deformation until the ultimate material failure. The structural behaviour can be well described by FE modelling considering realistic initial imperfections such as out-of straightness, the eccentricity of members, and additional eccentric compressive forces. [11]

The dynamic and fatigue performances of a large-scale space frame assembled using pultruded glass fibre reinforced polymer (GFRP) composites, with reference to pedestrian bridge application. The experimental structure was assembled by circular hollow section (CHS) GFRP members with the assistance of a novel steel connection system. The results from free vibration tests were analyzed using peak-picking (PP) and stochastic subspace identification (SSI) methods to extract modal parameters, i.e. natural frequencies, damping ratios, and mode shapes. From both experimental and validated FE analysis results, the proposed space frame structure satisfied the standard requirements for pedestrian bridge application in terms of natural frequency. The torsion mode as the first order mode shape can be avoided when the contribution of a bridge deck is considered. Furthermore, the structure was examined with 2.1 million fatigue load cycles and then statically loaded up to failure. The failure load showed no decrease when compared with that of a space frame without fatigue. The structural stiffness and strain of critical compressive members measured at 0.3 million fatigue loading intervals showed no significant variations, indicating that the applied fatigue did not degrade structural components and connections.[12]

Discrete flow mapping to three-dimensional domains by propagating wave energy densities through tetrahedral meshes. The geometric simplicity of the tetrahedral mesh elements is utilised to efficiently compute the ray transfer operator using a mix-ture of analytic and spectrally accurate numerical integration. The important issue of how to choose a suitable basis approximation in phase space whilst maintaining a reasonable computational cost is addressed via low order local approximations on tetrahedral faces in the position coordinate and high order orthogonal polynomial expansions in momentum space.[13]

Mobile Bridgeis a deployable bridge that uses a scissors mechanism to achieve its useful structural form. The bridge has a compact size in its undeployed state and can be transported easily to where it is needed. Its rapid deployment makes this type of bridge very useful in areas struck by natural disasters by enabling vehicles to cross terrain that has been made impassable. In previous research, experiments and analyses were conducted on a small-scale bridge designed for pedestrians. In order to consider a bridge of increased size, it is necessary to assess whether design and analysis techniques of the small scale bridge are applicable to the full-scale one.

In this paper, we consider a full-scale deployable bridge with a lower deck and two scissor units that allows for a light vehicle to pass across. We have carried out a light vehicle loading test in order to investigate its basic structural characteristics. Furthermore, the paper presents the theoretical design method and numerical models based on the experimental work followed by validation and comparison with the obtained experimental values.[14]

Deployable structures can exhibit remarkable and continuous geometric transformations, however, they are likely to be rigid under certain external loads. This study adopts group theory to evaluate the mobility of symmetric deployable structures under external loads. Mobility analysis is expressed as determining the orthogonality of internal mechanism modes and external loads. Based on the symmetry groups, both the mechanism modes and external loads are associated with specific symmetry subspaces. Thus, it can be evaluated whether the external loads stiffen all the internal mechanism modes.[15]Illustrative examples of pin-jointed structures and over-constrained mechanisms are given to verify the proposed method. It turns out that the product of the internal mechanisms and external loads is equivalent to that of the mechanisms and loads in the symmetry subspaces associated with different irreducible representations. A deployable structure will be immobile under external loads if symmetry order of the loads is higher than that of the mechanisms. In addition, the structure will be immobile, if the internal mechanisms and the external loads are equi symmetric and orthogonal to each other. The conclusions agree with published results and need much fewer computations. The proposed method is efficient and applicable to most symmetric deployable structures.[16]

Deployable structures have the capacity to transform and predictably adopt multiple predetermined configurations, moving through known paths, while deploying in a controlled and safe way. These characteristics introduce benefits when considering issues such as ease of transportation, erection and the overall sustainability of the structure by means of high material efficiency, modularisation and maximum use of natural energy resources. The aim of this article is to provide a critical review of existing attempts at classifying deployable structures identifying connections between different families through their mechanical and structural behaviours. The classifications selected consider theoretical and applied deployable structures, not focusing on a single application of deployable structures but including those ranging from spatial applications, to temporary and disaster relief structure, through to medical applications, providing coherence where terminology varies between applications. In order to gain a consistent understanding, tree diagrams were created for the review/classification to allow drawing commonalities and establishing differences between authors.

A chronological approach was adopted, using key review work as focal points for the timeline, complemented by smaller more specific pieces of work. This enabled the identification of common features and divergences between the different authors, bringing to the conclusion that a clear, comprehensive, consistent and unified classification of deployable structures is currently missing within the field.[17]

In a dynamic and evolving society, there is a need for temporary and mobile structures. For this, deployable scissor structures – structural mechanisms that can transform from a compact state to a fully deployed configuration – are suitable. However, this transformational capacity complicates the design process since there is a strong interaction between geometry, kinematic properties and structural response. In the conceptual design phase, there is a need for more structural insight related to geometric aspects of deployable scissor structures. Toward this end, this research evaluates the influence of design parameters (height, span, structural thickness, number of units, and scissor type) on the structural behaviour (stress, deflection and mass) of scissor arches. A sensitivity analysis is first performed which determines the relative influence of each of these parameters. Then a comprehensive parametric structural study is performed to determine the best values for efficient (low mass) scissor systems. The result of this research is a set of guidelines to facilitate the design of competitive scissor structures and enhance further analysis and realisation.[18]

Metal membrane suspended roofs are used considerably less than other types of suspended roofs. Russia possesses an undoubted priority in this type of structures. At present time, all theoretical and practical problems are solved, but in spite of this, few design offices and project organizations would undertake the design and supervision of construction of large-spanned membrane metal suspension roofs. In the paper, brief information on the history of the emergence of metal suspended roofs is presented, and general information on structural features of membrane roofs is given. As illustrations, the most outstanding membrane roofs erected in Russia are shown and description of some existing tension fabric membrane structures built in Austria, Canada, Japan, China, and other countries is presented.[18]

Several types of tubular, origami-inspired plate mechanisms for use as metamaterials and deployable structures. However, research into mechanical properties of these mechanisms is limited to rectilinear forms. This paper investigates the structural feasibility of non-rectilinear rigid foldable cellular materials for application as deployable arch structures. An experimental and numerical investigation is first conducted on a new type of folded tubular arch, with failure contributions identified from hinge rotation and plate buckling failure mechanisms. A common geometric description is then developed between three different types of origami-inspired tubular arches, which are numerically investigated under three-point loading. The double-kite arch developed in this paper is seen to have the highest failure load.[19]

Some cases of kinematic behaviour of deployable scissor-hinge structures, which consist of link members and pivot and hinge joints, have been investigated. However, few have concerned the inherent symmetry and potential interference of these structures. Here we present a new mode of an integral mechanism for symmetric structures. Adopting this integral mechanism mode, the algorithm of kinematic analysis is improved and is capable of following the motion path of a scissor-hinge structure efficiently. During deployment, the geometric configurations and kinematic indeterminacy of the structure are studied.

Further, we concern the interferences among nonadjacent members and potential kinematic singularity for these deployable structures. The numerical analysis points out that kinematic singularity could be induced when a scissor-hinge structure is fully deployed or folded. Geometric transformations of these deployable structures are continuous and significant when moving along the motion path.

Nevertheless, the inherent symmetry keeps unchanged, and the integral mechanism mode preserves full symmetry. The proposed integral mechanism mode is unique to a specific deployable structure, and it is therefore helpful for further studies on deployable structures.[20]

Architecture is mostly perceived as a static, unchanging and rigid element without an ability to react to the changing environment around it and the specific conditions of its location. The digital approach to architectural design has already shown that it is possible to create architectural prototypes that react to the external inputs by changes in their material properties or even in the shape. The conventional, stationary architecture is not able to react to the environmental factors, nor to the changing needs of building occupants, which brings architects, designers, and engineers to the issue of movement in architecture. This paper describes selected adaptive materials and structures used in architecture. An adaptive shape is designed and analyzed using a combination of 3D modelling tool Rhinoceros and the visual algorithmic plug-in Grasshopper, together with the extension for Grasshopper, Kangaroo. The wind simulation is made in the Flow Design. [21]

A new adaptive deployable spatial scissor-hinge structural mechanism (SSM) is introduced, which can be converted by means of actuators between a multitude of arch-like, dome-like and double curved shapes, where it can be stabilized and carry loads. This novel SSM is a spatial extension of a planar SSM introduced recently that can achieve a wide range of planar geometries. Main differences of the proposed structural mechanism from current deployable structures are the new connection type of the primary units and the proposed modified spatial scissor-like element (MS-SLE). With the development of this new connection detail and the modified element, it becomes possible to change the geometry of the whole system without changing the dimensions of the struts or the span. After presenting some disadvantages of current deployable structures and outlining the main differences of the proposed spatial SSM with existing examples, the dimensional properties of the primary elements are introduced. Then, geometric principles and shape limitations of the whole structure are explained. Finally, structural analyses of a typical structure in two different geometric configurations are performed, in order to discuss stiffness limitations associated with the advantage of increased mobility.[22]

A long-span retractable roof structure based on the beam string structure (BSS) and scissor mechanisms were placed parallel to each other and they were connected with the linear scissor mechanism. During the folding or unfolding, the structure just had one degree of freedom. The geometry of the retractable roof structure was firstly given. Then structural^2 analysis of an integrated model of the unfolded configuration was conducted. Furthermore, the structural behaviour of the structure in the semi-open configuration was also investigated. Finally, using the translational and rotational springs to model the elastic support of the strut, an analytical model for the lateral buckling of the BSS during the motion was developed. Based on the virtual work principle, the formulation of the critical load was obtained. Then a detailed parameter analysis of the BSS with a straight beam was undertaken.[23]

A new adaptive scissor-hinge structure, which can be converted by means of actuators between a multitude of curvilinear arch-like shapes, where it can be stabilized and carry loads.

The key point of this new structure is the proposed Modified Scissor-Like Element (M-SLE). With the development of this element, it becomes possible to change the geometry of the whole system without changing the dimensions of the struts or the span. The proposed scissor-hinge structure discussed here is planar, but it is also possible to combine structures in groups to create spatial systems. After outlining the differences of the proposed structure with existing designs, the dimensional properties of the M-SLE were introduced. Then, geometric principles and shape limitations of the whole structure were explained.

Finally, structural analysis of the structure in different geometric configurations was performed, in order to discuss stiffness limitations associated with the advantage of increased mobility.[24]

The geometric design of deployable scissor structures. These structures were classified as foldable or deployable. A foldable structure guarantees a stress free condition during deployment. A new equation, the foldability equation was derived. The foldability equation was formulated using a purely geometric approach. The foldability vector used in the foldability equation was formulated for some basic units in deployable structures. The foldability equation was then used to analyse the kinematics and determine the foldability/ deployability of translational, cylindrical, and spherical configurations.[25]

A hierarchy of scissor hingedmechanism (pantographs). Expandable Structures were a special kind of mechanism that can be used in several different geometries. The geometry of structures based on scissors was introduced to explain concepts necessary to design a wide range of forms like masts, arches, plane spatial structures, cylindrical and spherical bar structures.

Expandable Structures are a special kind of mechanism that can be used in several different geometries. The geometry of structures based on scissors was introduced to explain concepts necessary to design a wide range of forms like masts, archs, plane spatial structures, cylindrical and spherical bar structures.[27]

Langbecker proposed a systematic method for analysing such structures from a kinematic perspective.Transformable structures possess the ability to change morphology and readjust in response to varying conditions and needs that can include changing the environment and climatic conditions, different functional requirements and emergency situations. Depending on how the transformation is carried out, transformable structures can be deployable or demountable.

A. Kavehtand A. Davaranlstated an efficient method which was developed for the analysis of scissor-link foldable structures. The stiffness matrix of a unit of such a structure, called a duplet, was derived and incorporated into a standard stiffness method. A computer program was developed and many examples were studied. The results were compared to the analysis using uniplet elements. Substantial improvement was obtained through the introduction of duplets in place of the use of uniplets.[28]

CONCLUSION

The popularity of deployable structures has increased since the latter half of the 20th century as they introduce a novel and unique type of engineering, which allows structures to be packaged into a small configuration, for example, for transportation, and to be expanded and opened when needed. Retaining the functionality of traditional structures, they are able to undergo large configuration variations in a controlled and autonomous manner. Applications are close to limitless and vary considerably in scale if one compares an expandable stent-graft used to perform minimally invasive surgery on the human body to the retractable roofs of big stadium arenas.

Analysis and design issues of a new concept of deployable structures featuring stable and stress-free states in both deployed and collapsed configurations will be considered. The behaviour of these structures during their deployment procedure, which is associated with geometric compatibility requirements will be covered. Research in this field relating to issues such as assessment of the sensitivity to initial member and node imperfections and to other deployment procedures, as well as a comparison of stresses during deployment and under service loads in the deployed configuration will be addressed. The ultimate goal is to formulate specific design recommendations for this type of structure. Important contributions can be made by following the approach not only in the field of deployable structures but also in many other engineering problems.

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