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Exploring Rigid Plates Integration in Barrel Vault Deployable Scissor Systems

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Abstract

Scissor systems, characterized by their inherent elegance, unmatched deployability, and rapid construction, are a notable class of kinetic structures. These systems offer advantageous temporary solutions for deployable architectural applications, fostering circularity in both structural elements and materials. While scissor systems utilize bars and beams to form functional scissors units, the effective covering of these units remains a challenging task. The aspiration of such systems is to achieve optimal covering that controls the environmental conditions within the created space while maintaining the ease of deployment and optimal system performance.

A large number of research studies have focused on coupling the scissor systems with soft covers to enclose spaces. Soft materials provide a convenient and flexible form that effortlessly follows the mechanism of scissors units with ease and lightness. However, the resulting temporary space is susceptible to security concerns and renders it vulnerable to vandalism, theft, or material and weather damage. As an alternative to soft covers, this paper explores the feasibility of a real-scale system that combines rigid covers with scissor units, employing a singly curved geometry. In the proposed system, the plates provide a covering for the space but also offer a structural function within the system. The design aims to merge the fundamental deployability mechanisms of scissor structures with the stiffness of rigid plates, thereby creating an enclosed hybrid system that is structurally competitive, more secure, and durable compared to widely used textile structures, yet maintains the ease and flexibility of deployable scissor grids. This study utilized parametric simulation and physical models to explore the geometrical design of the integrated system of a vault-like scissor system.

Keywords: Form finding, Scissor grids, Rigid plates, Temporary structures, Deployability.

1. Scissor grids (challenges and opportunities)

Scissor grids are a notable class of kinetic structures that is widely studied for their unmatched deployability and potential applications. Their use is extended to cover applications as small as Hoberman Sphere toys, to spatial applications of movable pavilions (J. Sanchezf [2]).

Within all of that wide range of applications, This paper looks into the use of scissor grid systems for spatial enclosed temporary structures of vaulted geometry. The resulting structures should offer several functions from temporary event spaces (Konligo [1]) to humanitarian crises(Koumar, et al. [3, Alegria Mira, et al. [4]) or temporary hospitalization pods.

Scissor grids excel in providing deployable solutions that efficiently utilize materials and geometries. They offer rapid retractability of grid members, saving space and eliminating time wasted in assembling members into the final shape compared to other systems. However, for spatial applications of scissor grids, these qualities face more sophisticated challenges that can hinder the theoretical potential of the system. One such challenge is the scaling up of systems, which increases the forces required for deployability, often necessitating mechanical actuation to achieve the final shape. Another challenge is the inversely proportional relationship between the weight of the structure and its resistance to typical lateral forces during outdoor use. While this is a fundamental drawback common to lightweight structure systems, it is amplified in lightweight scissor structures. Overcoming this challenge typically involves adding more layers of deployment procedures during the construction process.

In practical applications, lightweight scissor systems for temporary use are marketed as easily deployable alternatives with a rapid one-step construction process involving pulling or pushing two points. However, in reality, construction often requires an additional step of adding weight foundation blocks or anchoring the structure to the ground. This not only directly opposes the theoretical elegance of system deployability but also increases the weight of transporting all structural elements.

The third challenge is to provide covering for the spaces created with scissor grids. The scissor grids consist mainly of beam or bar members. The resulting structure typically requires an additional element to cover or enclose the space for architectural functionality, regardless of the materials or technical proportions of its members. Soft covering is usually used as an adequate tool to provide the flexible envelope that follows the mechanism of the grid (J. Sanchezf [2]) (Koumar, et al. [3]). Using the nature of textiles, this very practical solution offers both a covering of spaces and the capability to deploy both the grid and the covering simultaneously. In addition, textiles represent a minimal possible weight of covering for the whole system.

On the other hand, a subtle drawback emerges from this integration of soft covers and scissor grids. The dominant presence of scissor units dilutes into a subordinate element in the whole resulted system. In other words, the structure depends primarily on the textile/soft covering to enclose and highlight the space for any application, while leaving the scissor grids to only mount the textiles into the final geometry. The quality of the space then depends on the quality of textiles used. Like most textile-based spaces, it is vulnerable to vandalism and theft, and the membrane materials are sensitive to weather damage, in addition to having an overall lower lifetime span than other rigid alternatives.

When promoting this system in the market as an alternative to conventional textile systems, it may be contended that the final result of integrated systems of scissor grids and soft covers could be achieved by replacing the scissor grids with normal beams and pulling cables, as done in conventional tents. Scissor grids could be described as a complex system that supports a normal tent space—an imprecise statement, but a reflection of the dominant role of textiles felt by users in integrated systems with scissor grids.

While those challenges are possible to overcome with some design adjustments and measurements, They still add a layer of complexity that decelerates the spread of the system's use on the market. Solving those challenges presents the scissor grids as an alternative rapid deployable spatial solution. That offers competitive qualities in comparison to equivalent systems such as temporary textile structures or aluminum trusses of assembled parts. This paper explores replacing the soft covers with rigid cover to be coupled with scissor grids. Using hardcovers will tackle two challenges out of the three presented challenges. It will enhance the quality of coverage for spaces created by the scissor grids. In comparison to soft covers, hard covers could provide indoor environmental control, security, and better insulation. In addition, hard cover will increase the total weight of the system which would provide more stability to the whole system against lateral forces in the scale of small pavilion spaces.

2. Scope of paper

Geometrical forms of scissor grids have been intensively investigated. (Roovers and Temmerman [5]) & (Maden, et al. [6]) explored the singly curved scissor grids geometrically. This paper explores the integration of hardcovers with scissor grids employing a singly curved vault geometry (Gaussian curvature of zero) for real-scale space application.

3. Two-directional deployability scissor unit (Concept of design)

Within a basic scissor unit with transitional elements, connecting a plate to the unit with any 3 or more different points on the same plane will disable the unit's mechanism. The plate must be foldable within one or more foldable line joints to allow the mechanism. While this solution will solve the geometrical integration, foldable plates will complicate the manufacturing and fabrication process. Consequently, the conceptual design of this integrated system explores adding a 'rigid plate' within a basic unit of two directional scissor grids with all transactional members (Roovers and Temmerman [5]). The plates, in that case, will be installed post-deploying the unit. The plates can be inserted into two directions of the grid to correspond to the directions of the deployability mechanism of the unit "Figure 1 - b, c". The resulting system can be deployed in two phases: the first phase is to deploy the scissor grid, and the second phase is to add the rigid plates connected to the I-bar beams or joints. In this case, the rigid plates not only provide a coverage solution for units but also brace the unit to halt the mechanism. All elements work simultaneously to stabilize the final unit in the desired shape.

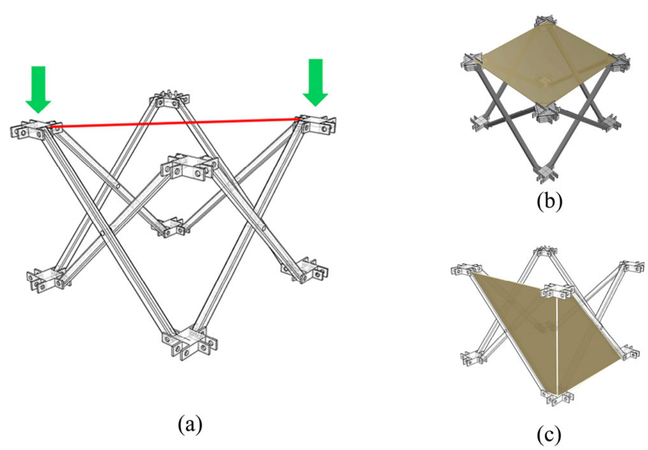
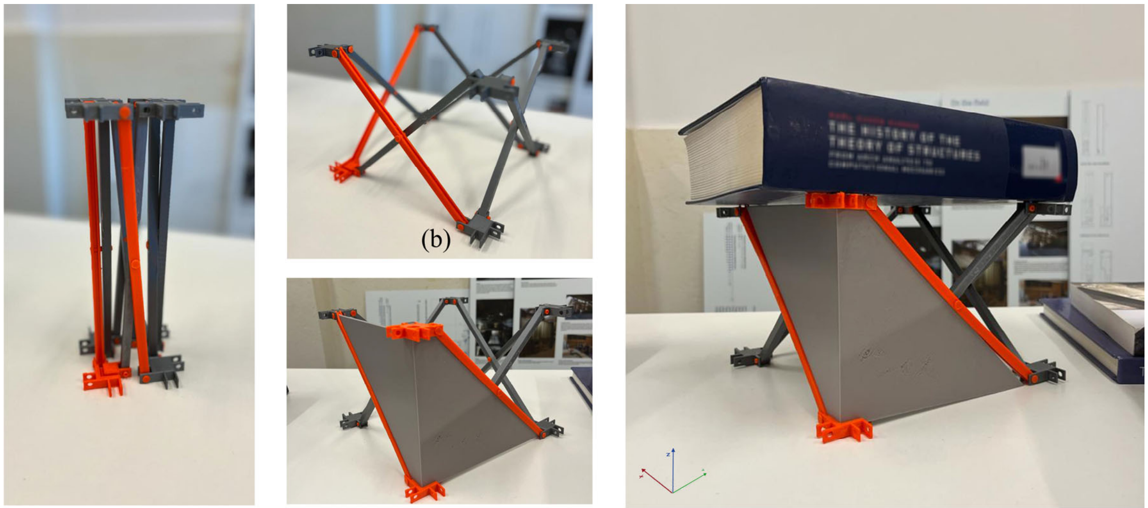


Figure 1: (a) Base two-direction scissor unit with transitional beams. (b) integrated scissors with rigid plates in XY plan. (c) integrated scissors with rigid plates in ZY plan.

"Figure 2" shows a 3D printed model of the basic scissor unit tested with plates in the ZY and ZX planes and experimented under a simple load for proof of concept. The plates are inserted into I-section beams (in orange) and the corner joints to create a sealed connection, while the scissor grids have fully unrestricted movement under both normal and lateral forces. The addition of plates has proven adequate for bracing the unit.



(a) (b) (c) (d)

Figure 2 : (a) Scissor unit in compacted state. (b) scissor unit in deployed state. (c) integration of plates with the base units. (d) rigid plates integrated within scissor grid under load (proof of concept).

4. One-directional deployability scissor unit

To explore the concept further, adding plates to the basic scissor unit was investigated with a reduced degree of deployability. The two-directional deployability freedom of the basic unit was tuned down to one-directional deployability. “Figure 3” shows the simplified version of the scissor units with the integration of the plate. This resulted unit will only deploy in one direction while maintaining the same length in the other orthogonal direction.

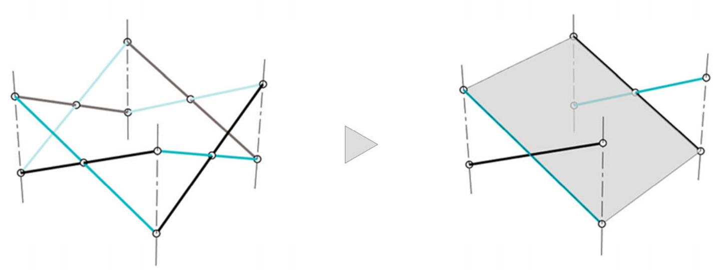


Figure 3 : Integration of plates within one-directional deployable unit.

The integration between rigid plates and scissor grids can be scaled up to form a full single curved geometrical grid, constructing a vaulted space. The base unit is duplicated to create several geometrical configurations in a double-layered scissor grid (DLS) or multi-layered scissor grid (MLS). “Figure 4 – c” shows the 3D printed model of a vaulted geometrical grid. The grid is retracted in one direction to reach the compacted state in “Figure 4 – d”. The same concept can be further explored in different configurations as shown in “Figure 4 – a”. Changing the order and sizes of members and plates within the system results in various alternatives of closed and open surfaces.

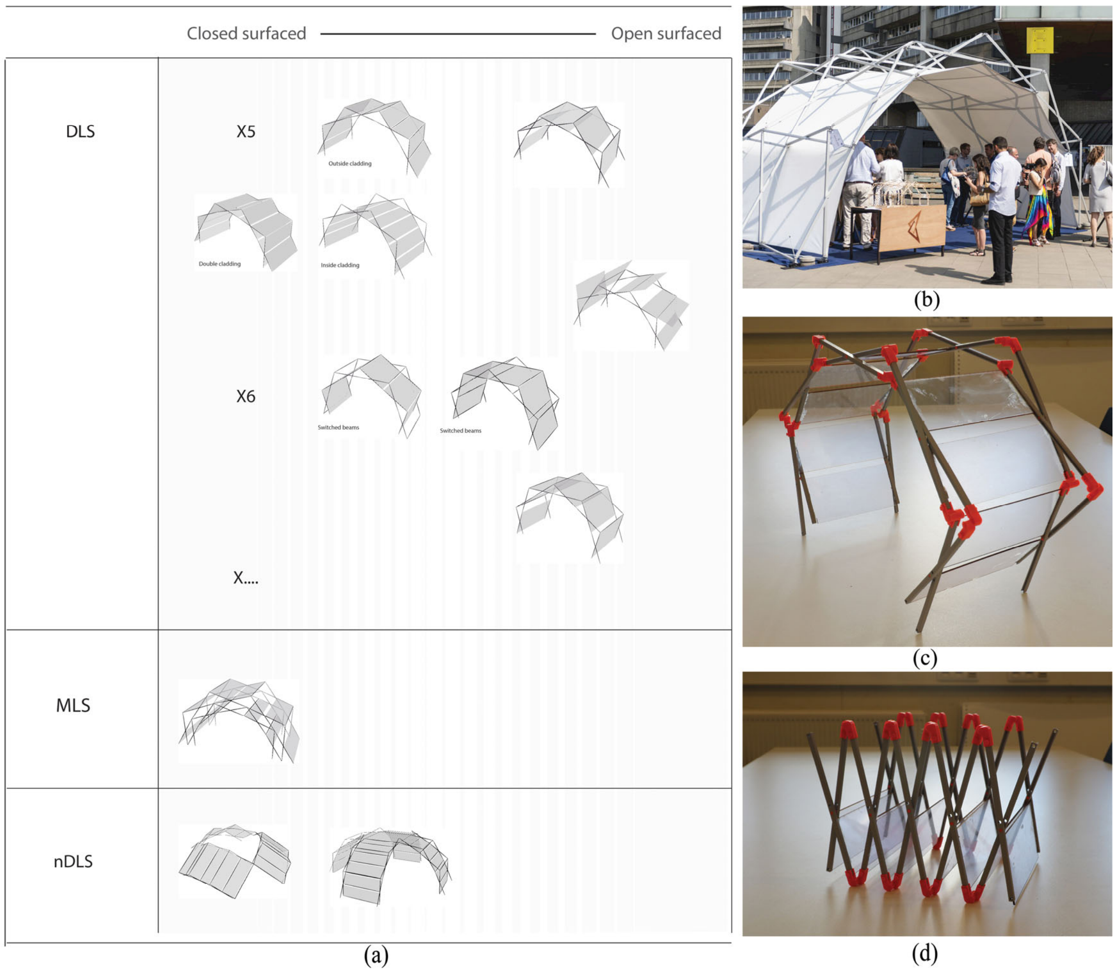


Figure 4: (a) An exploration map of rigid plates integrated with scissor grids. (b) Fastival structure product produced by (Konligo [1]). (c) 1/10 model of 3d printed model of vaulted space of plates integrated with scissor units. (d) Compacted state of the model.

Discussion:

Using rigid plates as an alternative to soft covers for single-curved scissor grids is a promising theoretical solution that can offer other qualities to the spaces created. In comparison to similar vaulted scissor grids with soft coverings in the market “Figure 4 – b”, using rigid grids offers an alternative solution and opens the door to using different materials while obtaining the deployability and geometry of the same space.

However, the combination of plates and scissor grids comes with one of two major drawbacks. In the case of two-directional scissor units, the plates are added after deploying the unit. To combine the plates within the process of deploying the units, the plates will need to be folded like an origami structure. (Bahremandi-Tolou, et al. [7]) explored a similar concept for the spherical geometry of the scissor grid. This approach will drastically complicate the design and manufacturing process; therefore, the plates for the proposed design are added separately after deployment as a locking/bracing element.

In the other case, the one-directional scissor unit allows the plates to be deployed simultaneously with the system; however, the whole system then only deploys in one direction, leaving the final compacted state relatively larger than the two-direction deployable scissor grid.

The paper looked into the most simplified version of scissor units with transitional elements. However, further investigation of different geometrical solutions will produce more alternatives. The covering of the sides of vaults/singly curved geometry remains a challenge whether the space is covered with soft or rigid covers. In addition, the one-directional integrated system resulted in a promising structure that should be further analyzed numerically.

Acknowledgement

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