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New proposal for a retractable roof over a courtyard in Tabriz Islamic Art University

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Abstract

This paper by reviewing the main examples of small to medium-scale retractable roof structures covering building courtyards is to present an innovative rigid retractable roof system employing spatial frames for a courtyard of an existing building in Tabriz Islamic Art University. The courtyard is currently used for temporary exhibitions and gatherings whenever permitted by environmental conditions. The proposed retractable roof will extend the application of the building throughout whole year period and also adds to its beauty and functionality. One of the main advantages of this design that makes it as a good alternative for this building is the way that the roof is retracted in different segments separately in a regulated deployment process and its potential in being used in different stages of the deployment process. The proposed roof consists of four retractable zones all covered with transparent rigid material and a fixed central part being inspired by the patterns of Iranian historic architecture. The retractable parts are placed at four corners and composed of rigid panels sliding across each other. An actuating force is applied to the first panel of each module and consequently makes the other panels move throughout the associated fixed track.

Keywords: *Retractable roof, Transformable mechanism, Sliding rigid panels, Iranian traditional architecture, Spatial frame systems.*

1. Introduction

A retractable roof is considered as a kinetic system protecting architectural spaces against extreme weather condition and at the same time can add to aesthetic and functional value of the building, which is covered. Therefore, it is not just a covering system that is to be closed and opened on the basis of the proposed requirements but it can also be considered as a piece of art by means of mechanisms it employs for its movement and transformation [1].

The Roman 'vellum' which covered the Roman Coliseum in antiquity was one of the first examples of the application of a retractable roof over permanent structure of 20,000 sqm [2]. It was presumably the most prominent transformable structure in ancient times [3]. In the 20th century, following new developments in deployable structures by Buckminster Fuller, Frei Otto and Emilio Perez Pinero, these structures were employed in building with various scales and with different types of structural systems including membrane, tensegrity and, pantographic structures etc. [4].

This paper proposes a retractable roof over a courtyard of a newly constructed building in the main campus of Tabriz Islamic Art University that includes historic buildings. Some design limitations such as being in compliance with the historic buildings' regulations, supplying an appropriate lighting and ventilation condition for adjacent buildings are among several design requirements that this proposal is to meet them. The proposed roof should also provide enough lighting for the courtyard while it is in fully closed configuration.

2. A Review of Existing Retractable Roofs of Building Courtyards

The study of the existing retractable roofs covering building courtyards shows that they have employed different types of retractable mechanism with different materials in order to fulfill the proposed requirements. In general two types of retractable system including retractable membrane and moveable spatial plate systems are used specifically for covering building courtyards [4]. For example in the retractable roof above the courtyard of Alden Biesen in Belgium, the requirements of creating an adaptable roof over the courtyard is fulfilled by employing

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funnel-shaped foldable umbrellas. In this courtyard due to the scale and application of the space, it has been possible to locate carrying columns and by dividing the covered surface into four segments, four overlapping functionally independent umbrellas were used. This system also provides proper protection considering the required functions and local weather condition. Moreover, Translucent white PVC coated polyester, which is applied in this roof, fulfills required natural light and illumination (Fig. 01) [5].

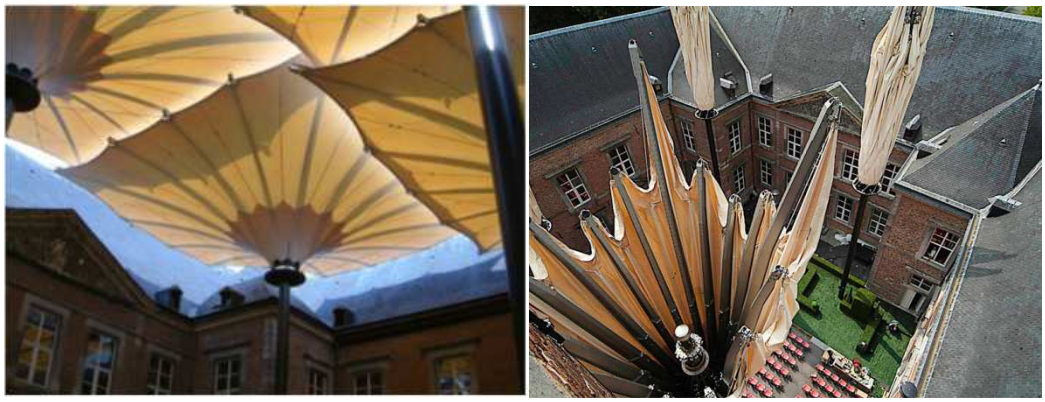

Fig. 1. Retractable umbrellas over Alden Biesen courtyard in Belgium [5]

The retractable roof of the City Creek Centre that has earned national recognition award of Innovative Design in Architecture and Engineering in 2013 is among those structures that benefit from retractable spatial plate systems that move along linear tracks [6]. A six-panel retractable skylight on each row of arches above the central walkway creates an indoor shopping environment during Utah's snowy season. The panels open to admit sunlight and fresh air, and reduce the demand for air conditioning in warmer months. Being located between two buildings enables the skylight′s segments to move above the adjacent buildings′ roof. In this roof, a rigid retractable structure provides a precise movement and securely filled the seams in between the panels while the roof in its fully closed position [7] (Fig. 02).

Fig. 2. Retractable sliding roof over the City Creek Centre (Photos Courtesy of Uni-Systems)

The foldable roof over the courtyard of City Hall in Vienna built in 2000 is one of the examples of retractable membrane structure. The wave-like shape of this membrane is determined by upper and lower cables, which hang from four multi-chord truss girders. On two sides of the courtyard, longitudinal girders are fixed to the building and serve as tracks that allow the cables and trusses to move by means of radial and axial rollers. During the folding process, the bays of the membrane are folded between these girders that form the line of support. The roof is activated by means of gear racks and is moved by four electric motors that are installed on three of the four trusses. The cables that carry the membrane are pushed or pull according to the direction of the movement. The roof can be fully opened in approximately four minutes. In order to protect the membrane from soiling and to prevent the valleys from being affected in severe weather condition (specially uncontrolled filling of the valley with snow) the folded roof (4m thick) is covered under a glass canopy [8].

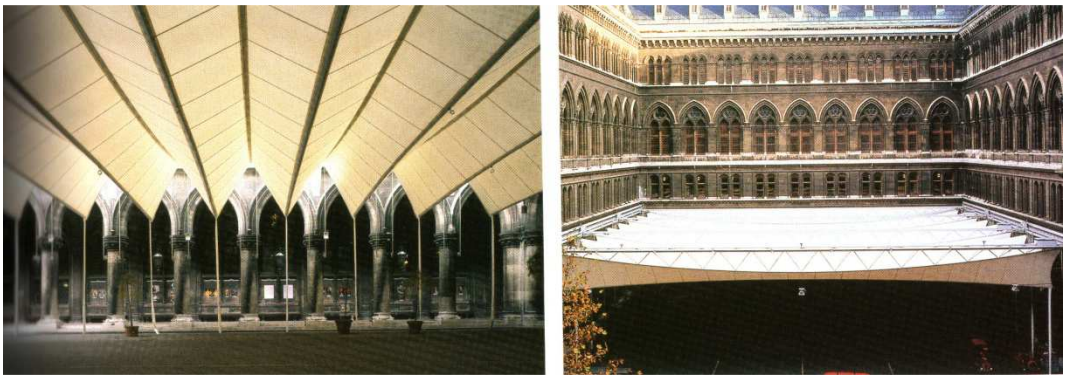

Fig. 3. Roof over the courtyard of Vienna in closed and open positions [8].

In Fortress Kufstein courtyard, a translucent white membrane, which gracefully unfolds like a flower is used. The roof can be opened or closed within four minutes and protect the area from unpredictable weather conditions. The retractable roof extends the use of the outdoor space and avoids costly event cancellations [9]. This roof includes a continuous membrane operated by a number of guiding cables and motors and allows the natural light to penetrate inside the courtyard while the roof is in its fully closed configuration. However, due to the large size of the membrane used and its vulnerability, the roof requires a high level of maintenance and an active monitoring system in order to keep the roof in its fully functional order.

Fig. 4. The retractable membrane roof over the Fortress Kufstein Courtyard in Austria [9]

Summary of Evaluation

The examination of the existing retractable roofs that cover the courtyards of the existing buildings reveals that the application of spatial plate structures with rigid covering is more reliable when a repeated deployment is required. These retractable systems can also create a completely sealed closed envelope and also offer a high degree of safety for their residents. They also satisfy many desirable aesthetic aspects required and have an ability to be integrated with fixed roof. The inherent characteristic of this type of systems is the integration of structural and architectural components, which enhances a building's interaction with its environment and at the same time helps it to have increased adaptability and flexibility that responds to the users' requirements.

The other advantages of retractable spatial plate systems as explained in the example of the city Creek Centre is that the moveable sections remain intact during transformation and each portion of the roof can be operated independently from the other portions and this in turn offer more flexibility in comparison to other types of retractable roof systems such as the roof over the Fortress Kufstein Courtyard. However, this evaluation suggests the moveable sections should be light enough in order to make effective use of the power supply and driving system and ensure the smoothness of the retraction. Moreover, in the design of deployment patterns it is necessary to pay special attention to the effect of the movable panels on the space occupied by them, in terms of changes of the environmental conditions and the impact of transformation patterns on the quality of architectural spaces.

Considering the main design requirements for the retractable roof of the courtyard of the mentioned building in Tabriz Islamic Art University that suggests repeated retraction and the ability to be used during a course of a year even in severe weather condition, the authors decided to use a retractable spatial plate system with segments that can function and move independently. The proposed structure also offers a high degree of flexibility in the deployment sequences. The following parts of this paper will explain the proposed structures and will illustrate the required drawings and document of the deployment mechanisms and architectural configurations.

3. Proposed Structure

The proposed retractable roof covers the courtyard of an existing building with an area of 14x8 sqm. This courtyard plays an important role in lighting and ventilation of adjacent spaces and also it is a place for holding different ceremonies and exhibitions during the course of a year. Therefore, the choice of the covering material and the movement mechanism of the retractable roof plays an important role in the functionality and aesthetic of the courtyard (Fig. 05).

Fig. 5. Courtyard of the Art Building in Tabriz Islamic Art University

3.1. Main concept

In summary, the important factors that affect the main design concept include climatic condition, respect to the historic site, response to various functions and its consistency with the existing buildings in terms of their identity and history. Considering the mentioned factors, as the courtyard is a part of a newly constructed building in a historic site of Tabriz; paying attention to the historic characteristics of the existing buildings is one of the main challenges that should be responded carefully in the proposed design. Due to variable climatic conditions of the city of Tabriz and a need for adequate lighting and ventilation, erecting duration and frequency and covering material should be considered properly in the design of the deployment mechanism. The panels should also be sloped in order to direct rainwater toward the edges of the roof and prevent interruption in the functionality of the courtyard even in severe weather condition (Fig. 06, 07).

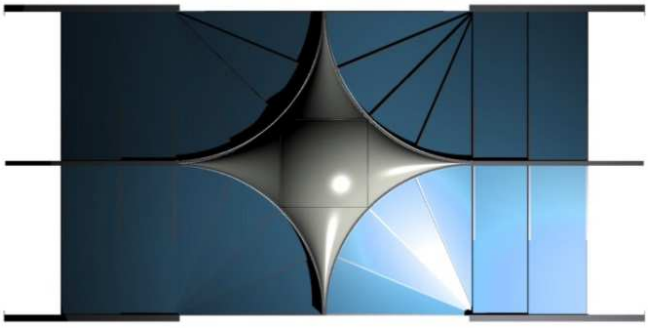

Fig. 6. An aerial view of the proposed retractable roof

Fig. 7. Slope of 25% in each panel toward edges

3.2 Structural system

The roof is divided into four moveable parts and a fixed central section. Each retractable part consists of six rigid sliding panels moving independently of other sections (Fig. 08). The fixed part of the roof includes four structural members supporting fixed and movable panels and at the same time are used as guiding profiles for the moveable segments (Fig. 09). The profiles have separate tracks for each moveable panel and this in turn increases the profiles' depth and consequently enhances bending strength (Fig 10).

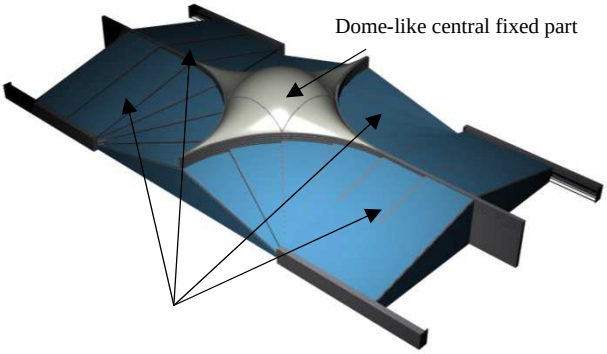

Fig. 8. Four deployable parts and the fixed central section in the proposed roof

Fig. 9. Fixed structural elements of the roof

Fig. 10. separate tracks for each panel

3.3. Deployment mechanism

The moving path of each section of the retractable roof consists of a profile in a shape of a quarter of a circle and a linear track. Each retractable section includes four triangular parts moving through a curved path and two rectangular sections with linear movement (Fig. 11). An actuating motor makes the first panel slide toward the next one and consequently allows all triangular sections to come to their final open configuration. The second motor located in the inner side of the rectangular panels operates simultaneously with the first one to make the panels slide (Fig 12). A total of eight actuating motors are used in the retractable system that allows independent movement of the different sections. Fig. 13 illustrates the retraction process including various configurations of the roof in fully closed, open and semi-closed stages.

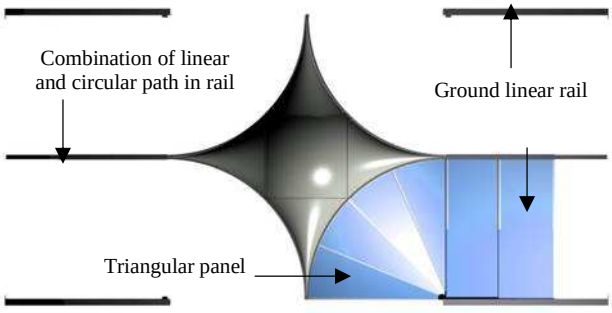

Fig. 11. Four triangular and two rectangular panels of each deployable section with two different rails

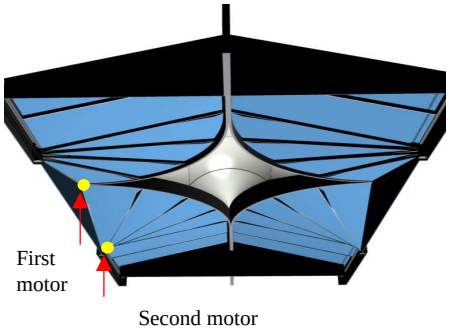

Fig. 12. Location of the two actuating engines in each deployable part of the roof

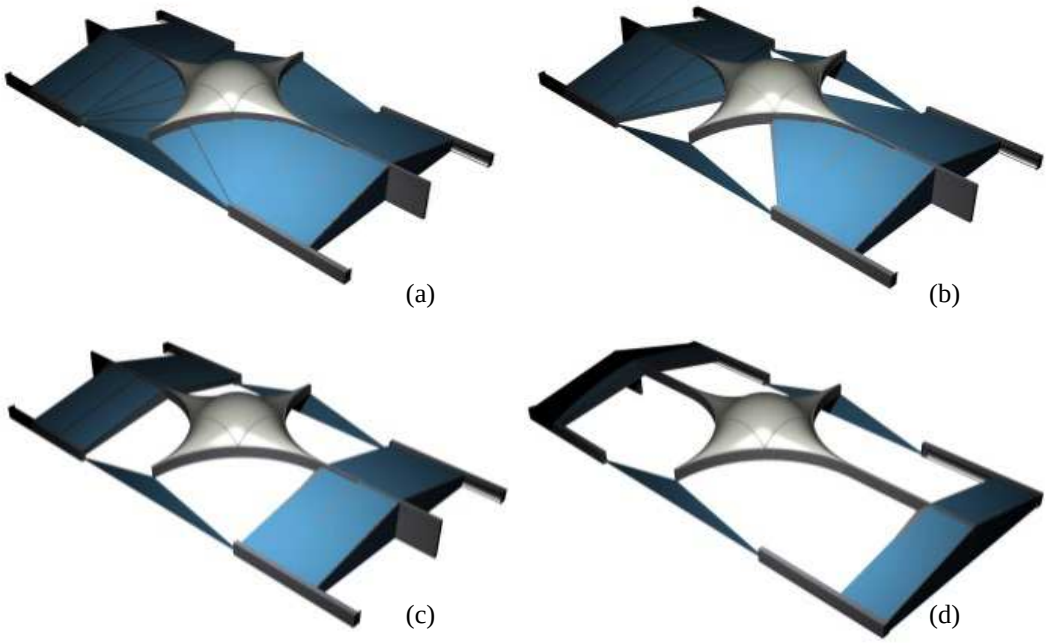

Fig. 13. Process of contracting the proposed roof

3.4. Details and materials

In the proposed retractable roof each panel (either the triangular or rectangular parts) are placed in a separate track and are moved by means of wheels attached to the end of each panel. Therefore, each panel can move and slide completely and independently without any limitations (Fig 14).

As shown in Fig.15 and 16, each rail located in the four corners of the roof consists of two main parts including a fixed part holding the wheels of each rectangular panel and a shaft consisting of four rotary hinges carrying triangular panels. Other rails located at other side of the panels and in the middle of the roof, hold the wheels of each panel in their specified position and allow smooth movement of the panels possible (Fig 16, 17). The panels with a slope of 25% could direct the rainwater to the edges and finally to the gutter located under the ground linear rail at the corners. Furthermore, the gap between two neighbouring panels is sealed by means of a rubber strip in order to prevent water penetration. This rubber strip also plays the role of a damper between two panels (Fig. 18).

Fig. 19 shows two adjacent parts of a portion of the retractable roof and the way they are overlapped. While a panel slides, the profiles interlock and the moving panel makes the adjacent one slide. This movement continues sliding all panels by means of two actuating motors as explained earlier. After all triangular sections come to their final stages; the wheels carrying the curved side of the panels are directed toward the linear tracks by means of telescopic bars and consequently it allows the movement of the triangular parts in the linear tracks until they come to their final parking positions (Fig. 20). In this retractable roof to ease the movement process of the panels and to make the structure as light as possible, a resistant lightweight aluminium material such as is used in the fixed structural rails and the profiles. All frames are also covered by polycarbonate sheets, which are made in a very thin thickness from 1mm to 18mm and have the ability to adapt with different climatic conditions. This material could also be cold bent in order to come to the required shapes (Fig. 21).

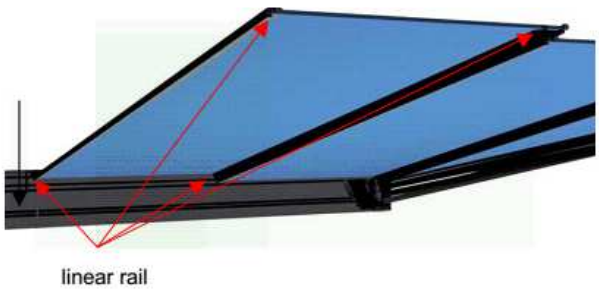

Fig. 14. Operating wheels placed in each corner of each panel

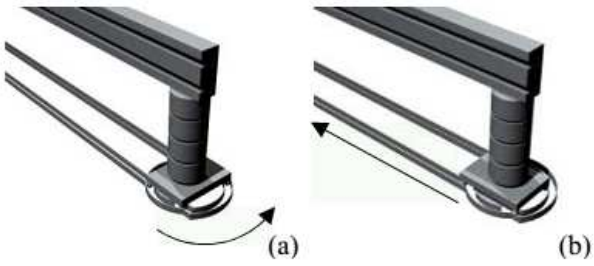

Fig. 15. Rotating part carrying triangular panels and directions of its movement in the linear rail

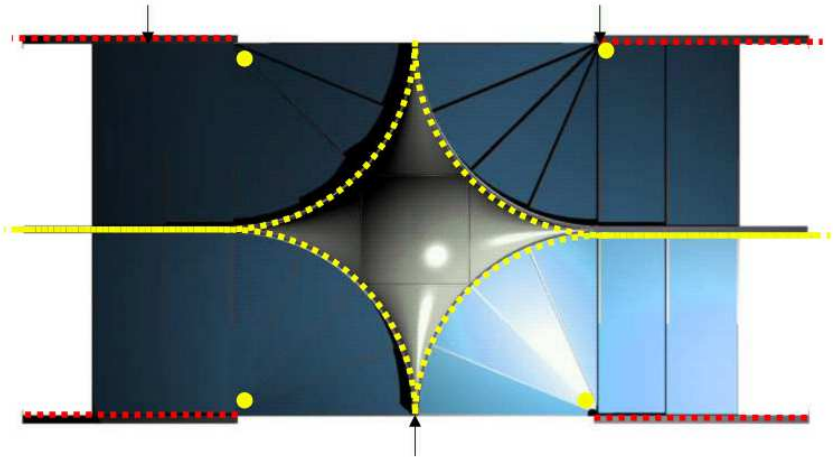

Fig. 16. Location of different parts of rails in the proposed roof

Fig. 17. The section of a fixed rail in the middle of the roof

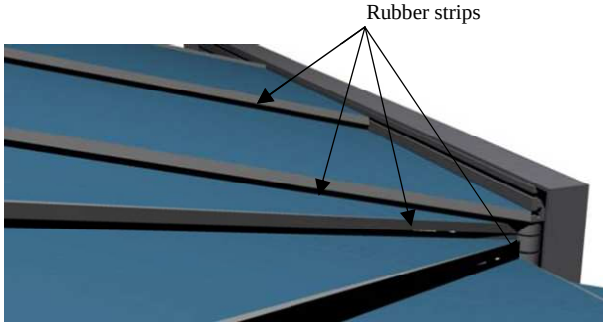

Fig. 18. Rubber strips between the edges of panels

Fig. 19. A view of two adjacent parts of a retractable section

Fig. 20. Telescopic bars attached to triangular parts for making a connection to linear tracks

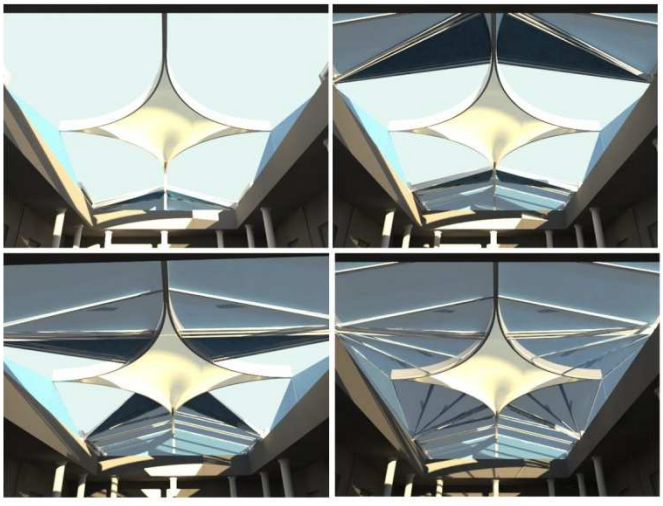

Fig. 21. Views of the roof in various deployment configurations

3.5. Alternative scales and expansions

This proposal is also compatible with various shape configurations in different scales with slight alteration. In larger scales, it is possible to divide panels into smaller ones for maintaining the stability. The proposed roof is also able to cover areas with various length to width proportions. In this circumstance, a square is used in the middle of the roof encompassing the moveable triangular panels plus the fixed portion of the roof and retractable rectangular panels are devised for the rest of the roof benefiting from linear movement (Fig 22).

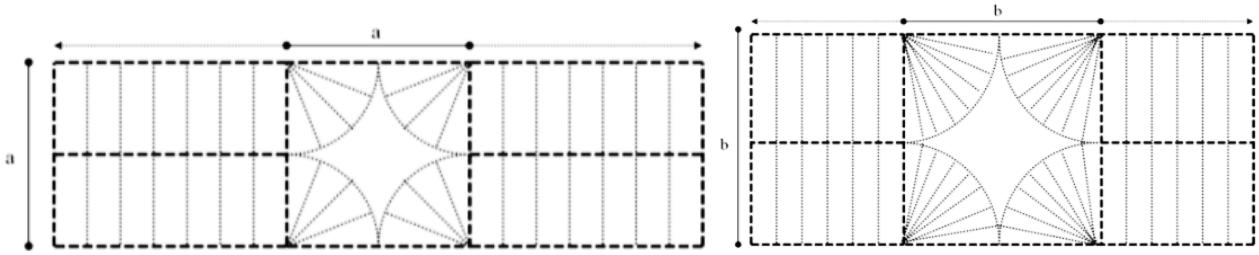

Fig. 22. Alternative configurations for the retractable roof

4. Conclusion

In this paper, a creative proposal has been put forward for a retractable roof, which could be employed for small to medium scale multifunctional spaces and courtyards. The proposed roof benefits from a stable yet flexible structures allowing various configurations from fully open to closed states. The functional independency of different portion of the retractable roof also make it possible for the users to change the degree of openness of the roof as required and according to weather conditions. The use of aluminium frame and polycarbonate material not only make the structure as lightweight as possible but it also allows the penetration of natural light when the roof is in fully closed configuration and consequently reduce energy and maintenance costs and expenses. The use of traditional Iranian architectural features especially in the design of the central fixed portion of the roof is also another stunning characteristics of this design that suggests how innovative technology can simultaneously respond to emerging functional and aesthetic requirements and respects to the historic identity of its context and surrounding environment. This proposal is also compatible with various shape configurations in different scales with slight alteration. In larger scales, it is possible to divide panels into smaller ones for maintaining the stability. The proposed roof is able to cover areas with various length to width proportions. This deployable system can also be stabilized in different configuration during deployment stages so that it can meet different functional and aesthetic requirements.

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