

A Novel Design for a Retractable Roof with Rigid Panels for Small-Scale Spaces

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Abstract: Retractable roof is a kinetic architectural system protecting architectural spaces against extreme weather condition and at the same time can add to aesthetic and functional value of architectural spaces. Therefore, it is not just a covering system that is to be closed and opened on the basis of our requirements but it can also be considered as a piece of art by means of mechanisms it employs in its movement and transformation.

Retractable roof systems could be roughly classified into two types of rigid and flexible coverings. Rigid retractable Roofs are mostly used to cover large-scale spaces, while flexible ones are commonly applied in smaller spans. This paper by reviewing relevant examples of small to medium-scale retractable roof structures is to present an innovative rigid retractable roof proposal for a courtyard of an existing building in Tabriz Islamic Art University. One of the main advantages of this design that makes it a good alternative for this building is the way that the roof is retracted in different segments separately in a regulated deployment process.

The proposed retractable roof consists of four retractable zones all covered with transparent rigid material and a fixed central part being inspired by the historic 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.*

1. Introduction

The early history of using retractable roof goes back to convertible textile roof of Roman Coliseum in the first century. In the 20th century, following new developments in deployable structures by Buckminster Fuller, Frei Otto and Emilio Perez Pinero, these structures were applied in various scale retractable roofs with different types of structural systems such as membrane structures, sliding panels, pantographic structures etc. [1].

This paper proposes a retractable roof above a courtyard of a newly constructed building in a historic site with several design limitations such as in compliance with the existing buildings, supplying an appropriate lighting and ventilation condition for adjacent buildings to provide a multifunctional covered space in unpleasant weather condition during the year.

2. A review of existing retractable roofs for building courtyards

The study of the existing retractable roof covering building courtyard shows that they have employed different types of retractable mechanism with different materials in order to fulfill the program requirements.

For example in the retractable roof above Alden Biesen in Belgium, the objective of creating an adaptable cover in courtyard is fully obtained by employing an umbrella mechanism. In this courtyard due to the scale and application of the space, it has been possible to locate carrying columns. By dividing the covered surface in to four segments, the scale has been feasible to apply umbrella system. In addition, each of these segments is independent in erecting. While this system could not provide complete sealing, it is proper for this design due to the weather condition. Translucent white PVC coated polyester which is applied in this roof fulfills required illumination. The redness of the brick façades is reflected and creates a warm colored ceiling (Fig. 01) [2].



Fig. 01 Alden Biesen retractable roof in Belgium.

In City Creek Center project a six-panel retractable skylight on each block arches above the central walkway, creating 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. As the segments, move to the open position, five of the panels in each skylight bow down,

moving their cantilevered arches out of the view of the public areas below. In this roof, a rigid retractable structure has provided precise movement and sealing of the segments (Fig. 02)[3],[4].



Fig. 02 City Creek Center retractable roof in Utah.

Bunching roof of Town Hall in Vienna with parallel movements cover a space in order to protect from dazzling sunlight while also allows having natural ventilation. Lightweight membrane cover of this roof enables the sliding mechanism move easily (Fig. 03) [5].



Fig. 03 Town Hale retractable roof in Vienna.

In Fortress Kufstein courtyard, a translucent white membrane, which gracefully unfolds like a flower, can be opened or closed within four minutes to protect the area from unpredictable weather conditions. This extends the use of the outdoor space and avoids costly event cancellations (Fig. 04) [6].



Fig. 04 Fortress Kufstein retractable roof in Austria.

According to the mentioned retractable roofs for building courtyards several significant factors including concept, material and mechanism are involved in designing a retractable roof. Considering the application of the courtyard, frequency of retracting, weather conditions, aesthetic features, cost and available technics, the final deployment system is determined.

3. proposed structure

The proposed retractable roof covers an area of 14*8 meter in a cold and dry weather. This area plays an important role in lighting and ventilation of adjacent spaces and also it is a place to hold different ceremonies and exhibitions during the year (Fig. 05).



Fig. 05 Courtyard of TIA University in Tabriz.

3.1 Main concept

Generally, several important factors which affect the main concept in this design include climate condition, respect to the historic site, response to various functions and different features of Iranian

traditional architecture -such as central geometry, symmetry, human scale- appealing form and innovative design.

Among all mentioned factors, as the courtyard is part of a newly constructed building in a historic site in Tabriz; consequently historical features and Iranian architecture are the most significant factors in the proposed design (Fig. 06, 07).

Due to variable climate of Tabriz and need for adequate lighting and ventilation, erecting duration and frequentation should be adapted to numerous deployment and contraction. The panels are located with a slope of 25% while constituting form of the roof; it could direct the rain-water to the edges (Fig. 08).



Fig.06 Samples of roof in Iranian traditional architecture:

- (a) Dome of Sheikh Lotfollah Mosque, Isfahan [7].
- (b) Ceiling of Bazaar, Yazd [8].
- (c) Tabriz historic bazaar complex. Tabriz [9].

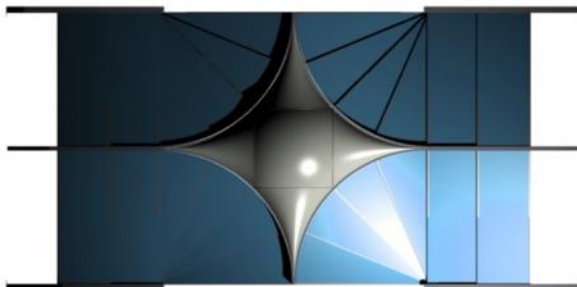


Fig.07 The proposed retractable roof according to features in Iranian traditional architecture.

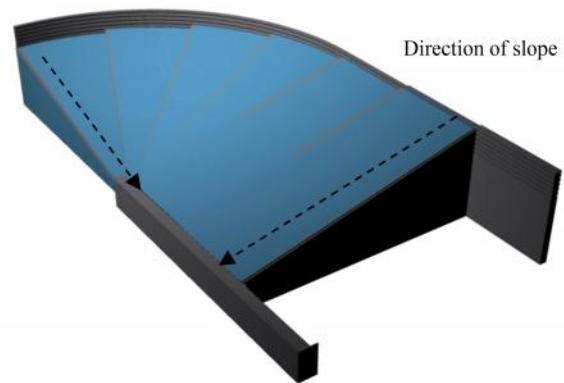


Fig. 08 Slope of 25% in each panel toward edges.

3.2 Structural system

The roof is divided into four deployable parts and one fixed central section. Each of the retractable parts is consisted of rigid sliding panels moving independently of other sections (Fig. 09). The fixed structural roof system is four profiles carrying panels while it is also the moving rail of the panels. These rails are sited on triangular frames at the roof edges (Fig. 10).The profile has separated rails for each panel and it causes an increasing in the profile height and consequently enhances bending strength (Fig 11).

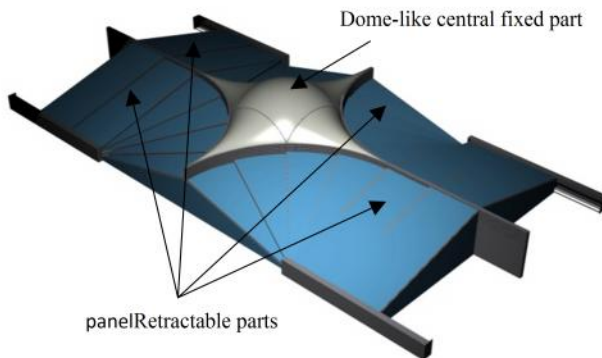


Fig. 09 Four deployable parts and one fixed central section in the retractable roof.

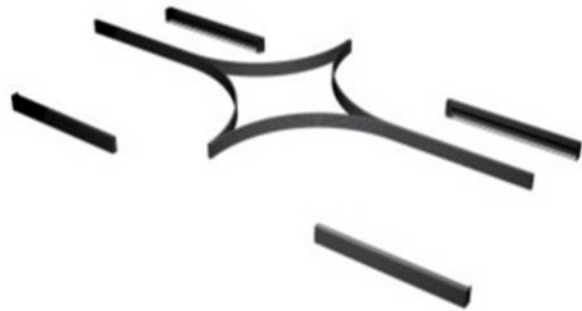


Fig. 10 Fixed structural elements of roof.

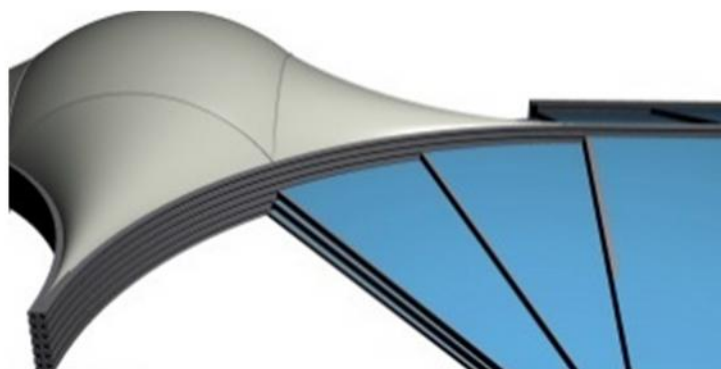


Fig. 11 separated rails for each panel.

3.3 Deployment mechanism

The moving rail of each part consists of a quarter of a circle and a linear path. Each of the first four triangular panels is one fourth of the curved path and two last rectangular panels are located in the linear part of the rail (Fig. 12).

An actuating engine is attached to the beginning of the first panel and slides the first panel toward the next one and continues contracting the curved part of the roof. In the linear path of the rail a second engine -which is located in the other side of the panels- operates simultaneously with the first one to slide the entire panels (Fig 13).

Finally by eight actuating engines the whole roof could be deployed completely. Fig 14 illustrates the process of retracting the proposed roof.

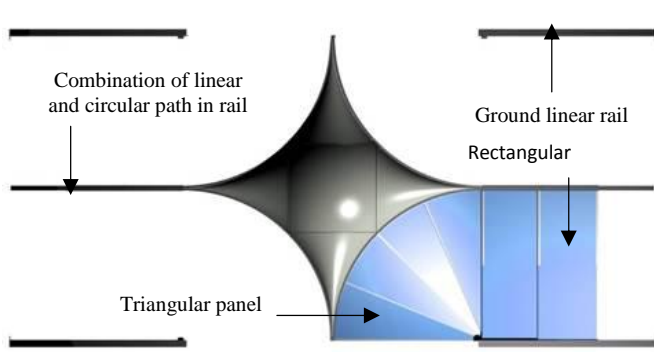


Fig. 12 Four triangular and two rectangular panels of each deployable section with two different rails.

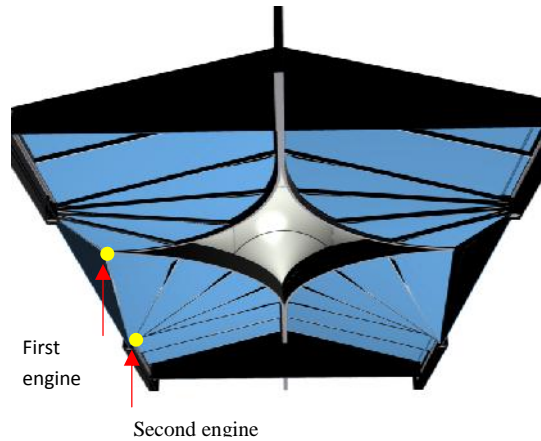


Fig 13 Location of the two actuating engines in each deployable part of the roof.

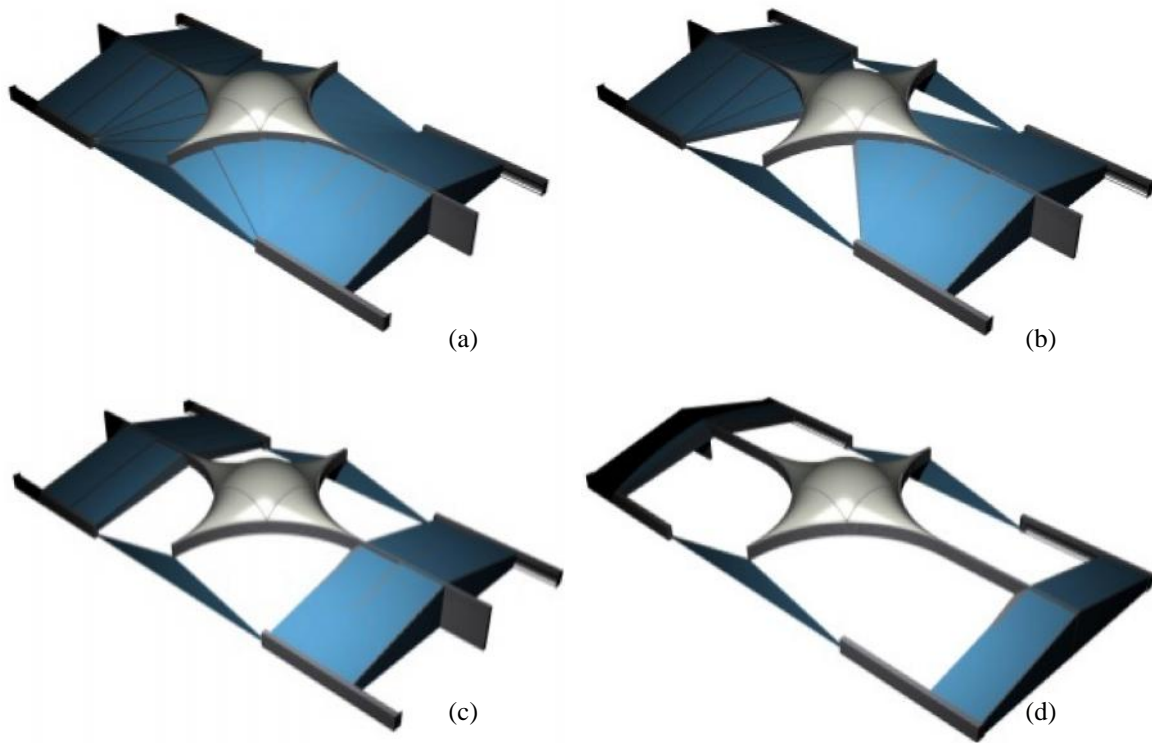


Fig. 14 Process of contracting the proposed roof.

3.4 Detailing and materials

In this retractable roof each panel should be placed in a specific rail and also should be carried in each rail by means of wheels fixed at the end of each panel profile. Thus each panel can move and slide completely without any obstruction (Fig 15).

As it is shown in Fig.16, 17 the ground rails—which are located in the 4 corner of the roof— consists of two main parts: the fixed part holding the wheels of each rectangular panel and the rotating section carrying triangular panels, while the second rail, which is located at other side of panels and in the middle of the roof, just holding the wheels of each panel in a fixed profile (Fig 17, 18).

The panels with a slope of 25% could direct the rain-water to the edges and finally to the gutter located under the ground linear rail at the corners. Furthermore, the gap between two panels is covered by a rubber strip in order to have adequate sealing. This rubber strip also plays the role of a damper between two panels (Fig. 19).

Fig. 20 shows the details of each panel's profile. While a panel is sliding, the profiles are interlocking and the moving panel makes the adjacent one slide. These movements continue to slide the whole panels completely just by two actuating engines. The mentioned rubber strip is glued to this profile in order to avoid any damage.

While an actuating force rotates the first triangular panel, it makes others revolving. After the rotating movements the whole triangular panels should slide along rectangular ones. As a result the telescopic axis of the wheels starts increasing in length one by one in order to slide correctly (Fig. 21).

In this retractable roof to facilitate the process of transforming structural elements should be made of a resistant lightweight material therefore, Aluminium is proposed to be used in structural fixed rails and panel profiles due to its various range of forms, variety of surface finishing, lightness, wide range of alloys, and so on. In addition, covering elements of central part especially can be composed of polycarbonate sheet which are made in very thin thickness from 1mm to 18mm and have the ability to accommodate with different climate conditions. This material also could be cold bent in order to get to its appropriate form [10]. Covering could be made of compact layers of GRP sheets [11].

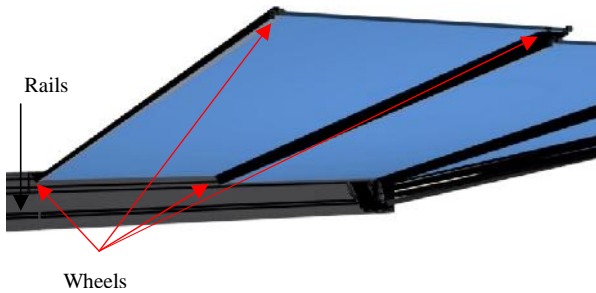


Fig. 15 Wheels in each corner of panel holding by rails.

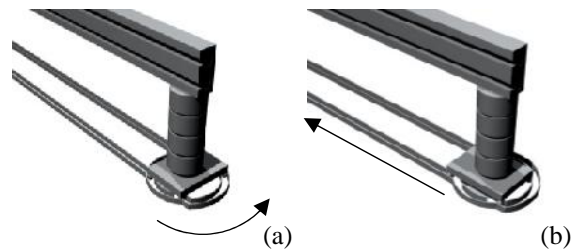


Fig. 16 Rotating part carrying triangular panels and directions of its movement in the linear rail.

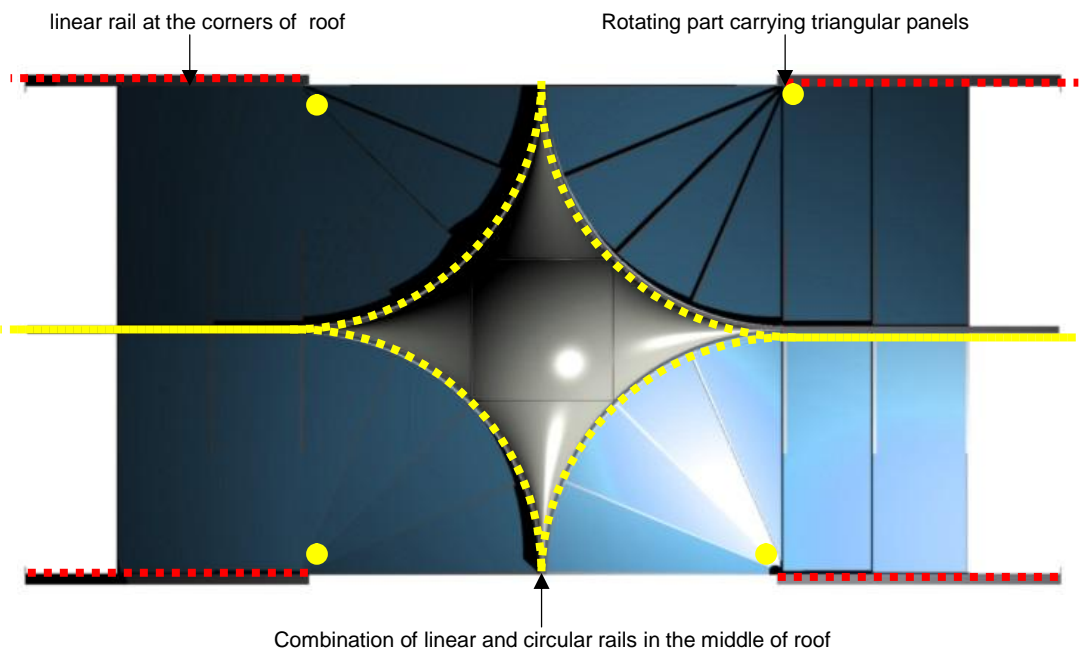


Fig. 17 Location of different parts of rails in the proposed roof.



Fig. 18 Section of fixed rails in the middle of the roof.

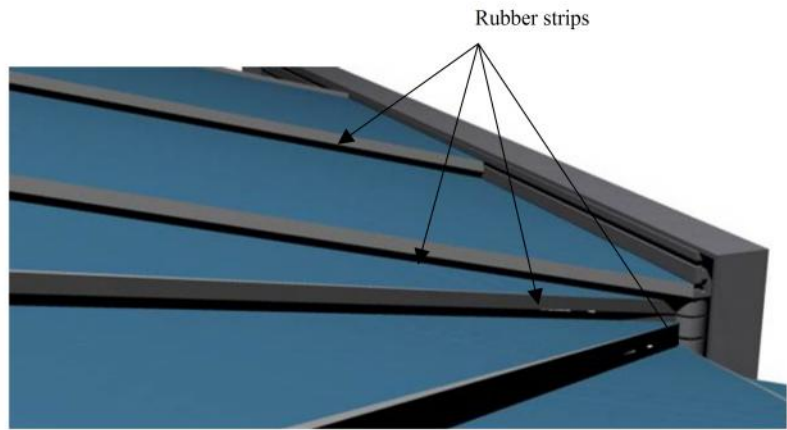


Fig.19 Rubber strip between edges of panels.



Fig.20 Section of panels' profile in adjacent panels.



Fig.21 Increasing in length of the wheel axis in each triangular panel.

3.5 Alternative scales and expansions

This retractable roof could be adaptable to different dimension of space. In larger scales it is possible to divide panels in to smaller ones for maintaining the stability. The design is also practicable to cover areas with various proportions of length and width. In this circumstance, a square is chosen in the middle of the roof for the curved part of it and adjacent areas are executed by adequate numbers of rectangular panels (Fig 22).

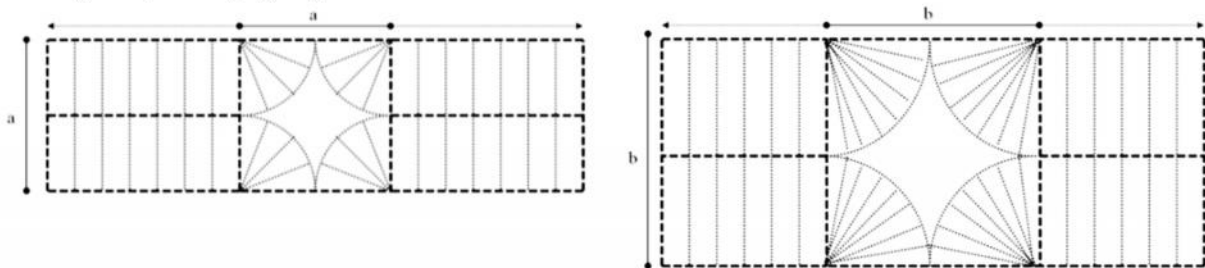


Fig.22 Proposed retractable roof is suitable for different proportions.

4. Conclusion

In this paper, a creative idea has been put forward for a retractable roof which could be applied in small-scale multifunctional open-space applications. Reviewing existing deployable roofs in small to medium-scale covering building courtyards, illustrates general criteria of designing a retractable roof such as concept, material and mechanism. Furthermore using Iranian's features in architecture makes this roof an appropriate design for the courtyard with its specific applications. The proposed roof is

consisted of rigid panels sliding along rails and opening towards the edges. The main advantages of this design are its adaption to different scales and space proportion by changing panels dimensions and also rapid and easy deployment. The proposed retractable roof is able to be stabilized in different configuration during deployment so that with contracting the same number of panels different state of opening is possible.

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