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Adaption of Tensile Architecture in Tropical Monsoon Climate

Latifa Sultana *
Architecture Department,
Southeast University, Dhaka, Bangladesh

Nazmun Nahar
Monad Architects, Dhaka, Bangladesh

Abstract: This paper will thoroughly investigate the use and opportunities of tensile architecture, which can be applied in rain, wind, heat, daylight issues in the architecture of Bangladesh. As Bangladesh laid on Intertropical Convergence Zone (ITCZ), the built form of this region prefers an open-type structure. Humidity and temperature always become an issue in this region due to the tropical monsoon climate of Bangladesh. These issues of environment follow the traditional Bengal architecture pattern. Furthermore, the contemporary architecture of Bangladesh respectively follows these significant characteristics of tropical monsoon climate. On the other side, Tensile Membrane Structure (TMS) has qualities to hold large spans, lightweight, translucency, aesthetic value, and flexibility. TMS and the traditional hut system of Bengal can be said as complementary to each other in this tropical monsoon climate of Bangladesh. Tensile membrane structure can be that element of contemporary architecture that can be adopted in this climate by satisfying all the primary issues of the tropical monsoon climate of Bangladesh. Tensile structure can be designed as lightweight roof shade, which is more similar with "Bengal hut" pattern of Bangladesh.

Keywords: *Climate, hut pattern, tensile structure, fabric*

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I. INTRODUCTION

A. Background

Tensile membrane structures are naturally lightweight and easily movable thus approve them to enable a large range of unique dynamic desige form [1]. TMS are relatively new structural system and it is different from other roofing structural system which are generally used in Bangladesh. Tensile membrane structure are usually designed for lightweight dynamic roofing system. In rural Bengal, traditional built form are made of mud wall and traditional roofs are made of bamboopanel and thatch which are aligned in angle. This special roofing system are called 'Bengal Hut' which are similar with tensile roofing system by functionally and aesthetically. 'Bengal Hut' pattern is the most preferable pattern for the climate of Bangladesh. But by the passage of time this civilization has misplaced this structural system due to lacking of strong and stable available material and structural system. Moreover, Bangladesh is the deltaic pavilion of Southeast Asia. It has an intense tropical monsoon climate. The characteristics of tropical monsoon zone is hot humid and blow mild winds overall in the weather. In Bangladesh, the summer season is associated with heavy rainfall. The summer monsoon brings a hot humid climate and torrential rainfall to this area. At the end of winter, warm and moist air from the southwest Indian Ocean blows toward this region. A low wind always blow over this region as a result, humidity and temperature become an issue for this climate. The traditional Bengal architecture pattern is followed by these issues of climate. Furthermore, the contemporary architecture of Bangladesh respectively follows these significant characteristics of tropical monsoon climate. Tensile membrane structure is such a structure which can emerge with all these climatic issues of Bangladesh [2, 3].

*Correspondence concerning this article should be addressed to Latifa Sultana, Architecture Department, Southeast University, Dhaka, Bangladesh. E-mail: dsafe93@gmail.com

B. *Significance*

It is the pinnacle time to introduce Bangladesh with tensile architecture. This light weight structure can be a perfect solution to face most of the climatic complexities and natural calamities of Bangladesh. Fabric structures (sub part of tensile structure) can be designed as light weight roof shade which is more similar with Bengal hut pattern of Bangladesh. This kind of structure greatly allow the mild wind and protect the instance heat. And most importantly it provides shades and cross ventilation of air and serve a purpose of semi-outdoor space. As well as, tensile architecture can be a temporary solution for disaster-prone areas of this region.

In Urban area of Bangladesh, park, circulation spaces, waiting platform, Railway station and many other public spaces are appropriate for tensile roofing as because the climate of Bangladesh required all many of these features of TMS.

II. TRADITIONAL BUILDING FEATURE OF BANGLADESH

A. *Bengal Hut*

In rural Bangladesh, Arcadian heritage forms are acknowledged through generation to generations and influenced the evolution of the traditional house form of Bengal. The traditional Bengali house form is known as, 'Bengal Hut'. The basic form of 'Bengal Hut' is a single storied dwelling unit which is surrounded by a courtyard. This cluster form unit including courtyard is called 'uthan' in local language.

Fig. 1. Bengal hut pattern with 'uthan' activities

Bengali Hut is also arranged by cultural norms and codes. There are two basic parts of 'Bengal Hut', which are 'the female domain' and 'the maledomain'. 'The female domain' is considered by 'Inner house' and 'The male domain' is considerd by 'Outter house'.

Climatic factors directly affect the rural house pattern of Bengalas the introvert layout of the hut around the courtyard, the roof of the hut is low heighted with projected overhangs and vegetation around to restrain the landscape. The thatch roof, mud wall or bamboo panel all contribute significant insulation capacity to the excellent thermal performance of the Bengali Hut [4, 5, 6]

Fig. 2. (a), (b), (c) Variations of Bengali hut

B. Deltaic Pavilion

The most significant architectural characteristics in the south-east delta is 'pavilion' structure. Its singular presence in dwelling patern directly illuminate the culture of Bengal Delta. It is the most primitive structure of Bengal. The rustic 'Bengali hut' basically constituted with a roof (known as the Bangla roof) which is a canopy defined by the uniquely bent roof. This roof primarily repulse the intense sun and torrential rain and directional wind and secondarily the less use of walls, permit to the movement of the air and placed well within the perimeter of the roof. All the characteristics of a pavilion is also present in 'Deltaic pavilion'. The hut is free standing from without wall. It basically stand on a free structure.

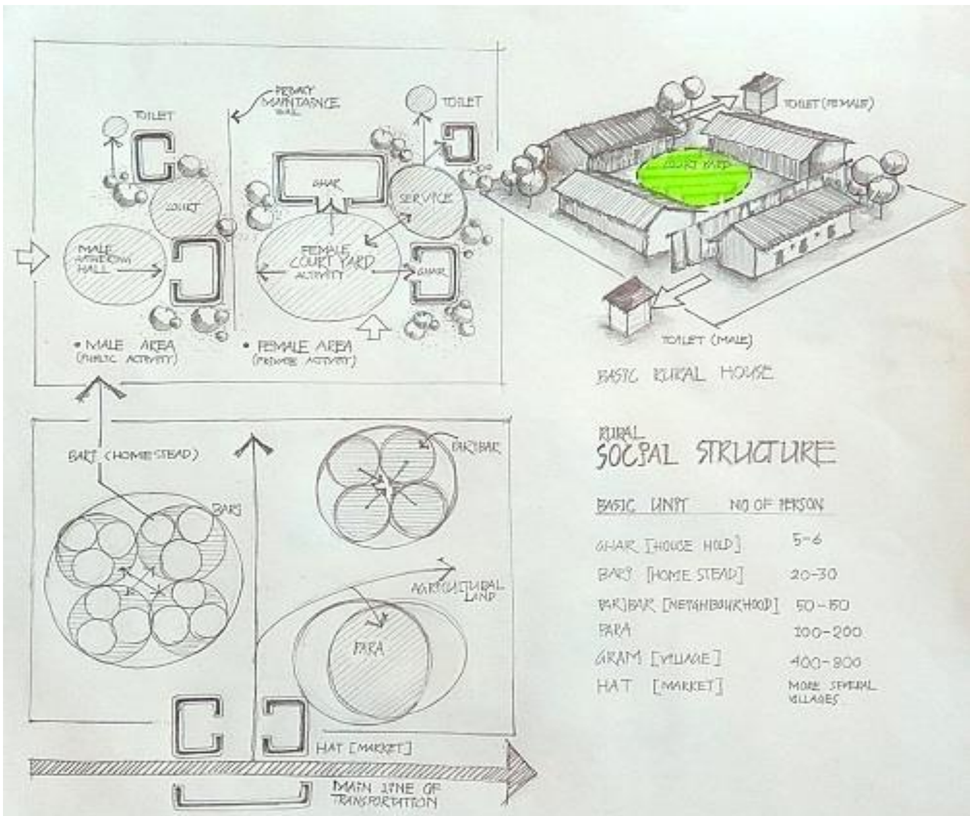


Fig. 3. The basic space arrangement of Bengal hut

Fig. 4. Basic shapes of deltaic pavilion

Demonstrated by the parasol roof and emphasized verandahs. Terrace and semi enclosures create an ambiguity between indoors and outdoors. And the cluster huts creates a social norms of being together and central space (courtyards) of these cluster huts work as a space of performance. Sometimes this courtyard is a breathing space, a space of relaxation; sometimes it is a meeting place of important decisions.

Other architectural forms of Bengal are also influenced from this hut. All informal activity zone were also derived from Bengal hut and achieve the characteristics of deltaic pavilion. As example, ‘Macha’, ‘GowalGhor’, ‘pathshala’, ‘boithok Khana’, ‘Shamiana’ etc. [4]

(a) ‘GowalGhor’ of Bengal

(b) ‘Macha’of Bengal

Fig. 5. (a) & (b) Deltaic pavilion shade pattern

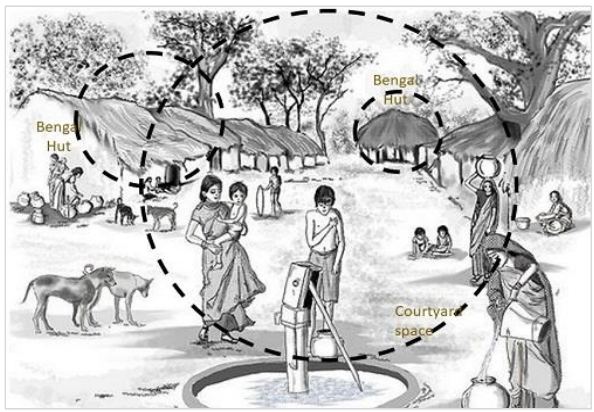


Fig. 6. Enclosed courtyard space in Bengal cluster house

III. TENSILE ARCHITECTURE AND METHODOLOGY

A. *What is Tensile Architecture?*

A TMS is a construction of such structural elements which carry only tension and no compression or bending. TMS is mostly used as a roof of light weight structure. This structures are economical and attractive. So this light weight structure can span large distances easily [Wikipedia]. Fabric membrane structures are a form of lightweight structural systems. The structural components of fabric membrane such as masts, cables, connecting joints or roofs are exhibited to make them visible from the inside or outside or from both sides. Tensile structures are being used throughout the history. They were originally used to provide temporary shelter where materials were lack of availability or mobility was required [7].

Tensile architecture is a structural system that basically uses tension instead of compression. Tensile and tension are used conversely [8]. Tensile architecture involves structures of small mass relative to their span that utilize elements acting in tension to carry loads to the support.

Tensile architecture is the synthesis of nomadic tents and permanent settlement [9]. Back to the history, first man-made structures were outside to the cave, Laugier’s Primitive Hut is considered as first man-made structure as a theory and that was mainly a compression structure. These tent-like fabric structures pulled tight around a timber or bone frame. Tensile design was similar with this kind of nomadic tents and small teepees [8].

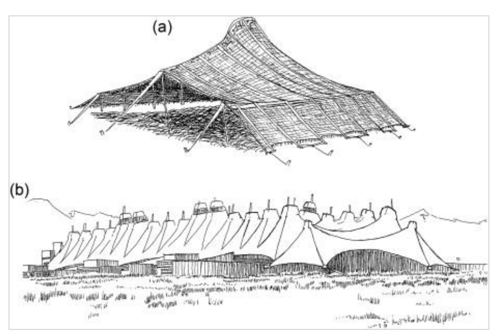


Fig. 7. (a) & (b) Transformation into tensile roof from simple tent tensile roofing system

Throughout the centuries, tension architecture was downgraded to circus tents, suspension bridges (e.g., Brooklyn Bridge), and small-scale temporary pavilions. Flexibility and lightness of materials allow tensile fabric structures to be erected again and again in different places [8].

There are some significant shapes considered for tensile architecture.

Three Basic Shapes of Tensile Architecture:

All tension designs are narrated from three basic forms-

"Hypar - A twisted free form shape"

"Conical - A cone shape, characterized by a central peak"

"Barrel Vault - An arched shape, usually characterized by a curved arch design" [10].

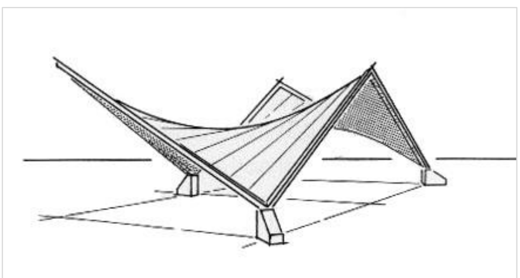


Fig. 8. One basic form of tensile structure

The art of light weight structures or tensile structures started from 1950's especially in Germany. 'Minimal surface' concept of tensile membrane structures are based on German Architect and Engineer Frei Otto's soap film experiments [9].

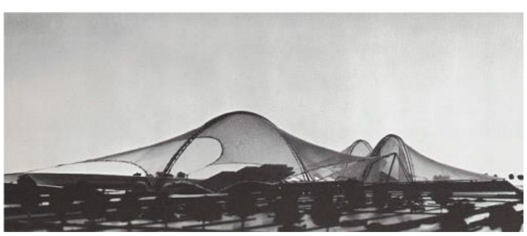


Fig. 9. Sports center roofs, sports-film presentation model, 1969

Fig. 10. Fountain tent starwave, Cologne, Germany, rebuilt 2000 ArchitekturbüroRasch + Bradatsch with Frei Otto.

The works of legendary German architect and engineer Frei Otto have greatly influenced on the development of TMS. One of the most famous of his works is Munich Olympic stadium, Germany in 1972. This is one of the finest examples how TMS can span large spaces.

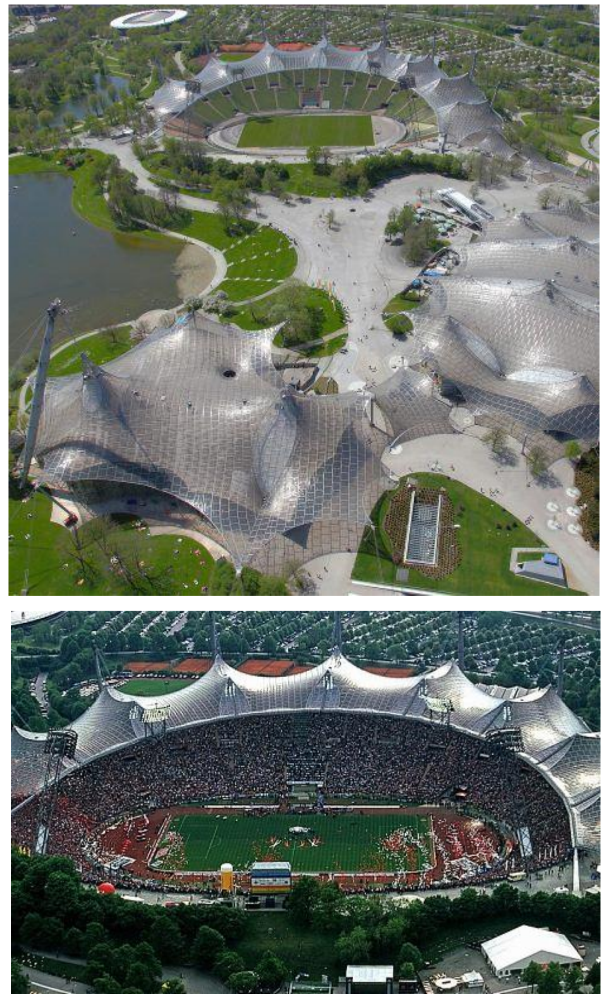


Fig. 11. Olympiastadion, Munich Olympic stadium, Germany, 1972, Frei Otto

IV. METHODOLOGY

The Membrane Structures are divided in two materialgroups-

(1) Tensioned surface material, and

(2) The elements of support structure.

The tensioned surface materials are the ones that have shapes formed by the forces in tension applied by the elements of support structure and the ones that will receive most of the load, membrane structure is always in equilibrium conditions. The elements of the support structure will assist the surface material by applying all the forces in tension and at the same time the surface material assisted the support structures. This equilibrium can be obtained by applying the right values of forces and can be accomplished by making the right analysis for each material.

Let's take the example of an anticlastic form using a textile, where with only a very thin material we can have a very efficient design that will mostly carry load on tension.

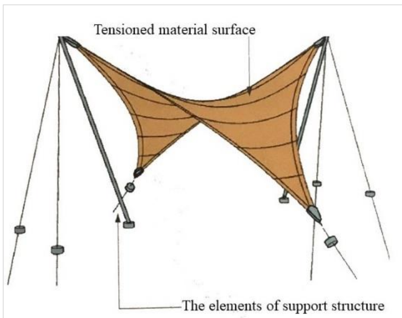


Fig. 12. Membrane structure identification

A. Steps to Develop a Membrane Structure

To introduce an idea of the steps used in developing a Membrane Structure, below is a list divided into processes and time frames.

1. Form Finding
2. Analysis for tensioned surface material
3. Analysis for the elements of support structure
4. Detailing for the elements of support structure
5. Patterning and detailing for tensioned surface material
6. Installation of the tensile structure.

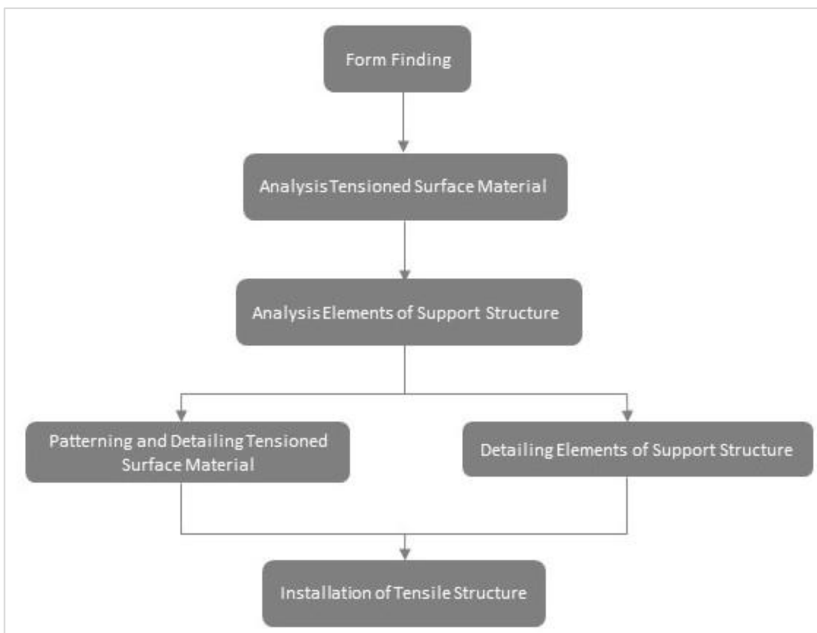


Fig. 13. Developing a membrane structure

B. Principles of Tensile Structures

The success of designing Membrane Structures will be accomplished by applying the following principles to the Form Finding:

1. Double curvature to the shape of the surface: performed by applying Anticlastic and Synclastic forms.

2. Pre-stress levels: applied by tensioning the anchor points or the perimeter of the Surface. Shapes with smaller radius curves smaller forces, and Shapes with larger radius curve larger forces.

3. Uniform load distribution of the Surface: to obtain a stabilized membrane structure.

4. Avoid flat surfaces: when designing the shape, think about the slope for the evacuation of water and snow.

5. Always design the shape with more than 3 points: In order to be an anticlastic shape, the form will need to have 4 points or more [11, 12, 13, 14].

C. Thermal Environment of Tensile Membrane Skin

Tensile membranes are constituted with little thermal mass and as react very quickly to the changes of temperature in the environment around them. They speculum the prevailing ambient radiant temperature and heat during periods of bright direct sunshine and cool quickly to reflect the external radiant temperature at night which is necessarily needed in tropical monsoon climate.

1) The Thermal Environment Inside Textile Enclosures: Tensile membrane structures tend to create internal thermal environments that differ strongly from those encountered in more conventional buildings and, as such, strongly influence the environmental design strategy. These peculiarities arise both from the properties of the textile skin as well as from the topology of the space they enclose.

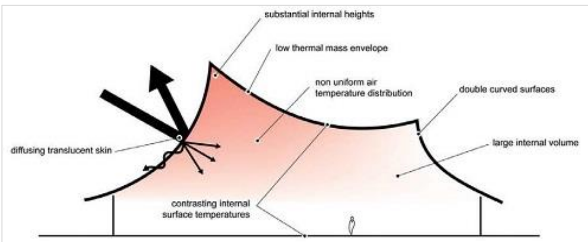


Fig. 14. Developing a membrane structure

2) Highly responsive building envelope: In conventional buildings the thermal capacity of roof and wall reduces the effect of rapid changes in outdoor temperature and radiation since a large amount of energy and a significant delay is required for changes in external surface temperatures to influence the internal conditions.

A tensile membrane skin is extremely thin and lightweight. It therefore provides little or no thermal buffering to the interior. Temperature difference between the two opposite surfaces of a single membrane skin is always less than 0.5°C.

3) Translucent skin: Translucency is one of the great qualities of TMS. It offers artistic opportunity to design with natural and artificial light. Translucency depends on the type, coating, thickness and color. Structures are reinforced by the translucency of membrane or fabric material. Translucency can vary from 10% to 40% [9].

Fig. 15. Kagawa prefecture Sanuki City Shido elementary school, Kagawa, Japan

4) Non uniform internal conditions: The spanning of large spaces, as well as the presence of high points to achieve the desired double-curvature of the membrane skin, almost inevitably leads to very large undivided volumes of air. Substantial internal ceiling heights favor the accumulation of buoyant warm air at the high points of the structure resulting in the formation of cooler layers of air in the lower/occupied zones. This phenomenon is amplified during daytime when the lightweight membrane roof is heated up by solar radiation.

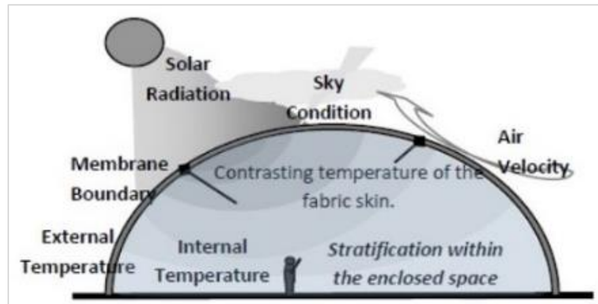


Fig. 16. The stratification of air in tensile membrane enclosures

The stability of this thermal layering depends both on the membrane roof temperature and on large-scale internal air movements triggered by buoyancy forces and ventilation. These complex internal air flows result in non-uniform temperature distribution within the space and make it difficult to predict the thermal conditions experienced at human height.

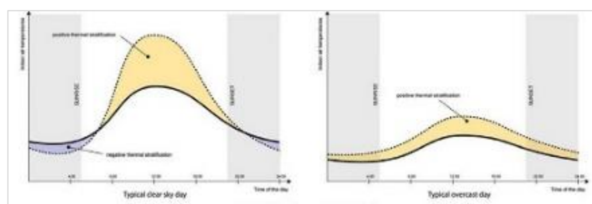
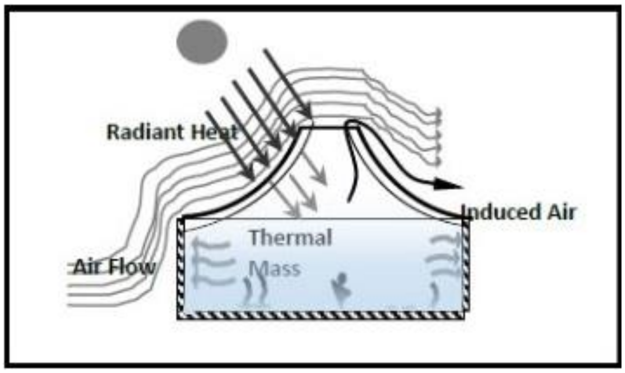


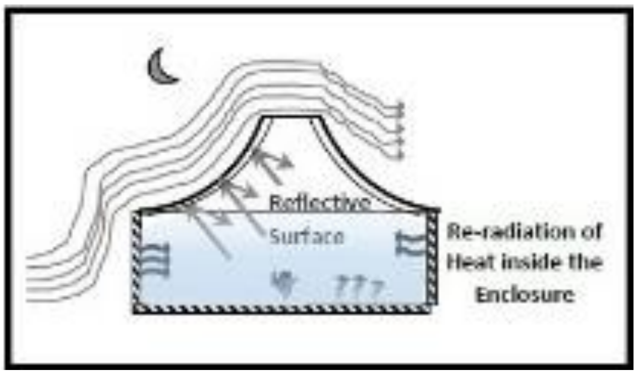
Fig. 17. Diurnal evolution of the temperature stratification in a typical unheated membrane enclosure, under clear sky condition (left) and under cloudy condition (right)

D. Environmental Properties of Membrane Skin

Thermal behavior of TMS is very changeable. Because of the thinness of the fabric, temperature of the fabric may rise quickly in daytime by solar radiation on the surface. Indoor environment becomes thermally stratified. Convective cooling takes place among different layers which allow cool outdoor air at low levels to get in. Due to thermal optical properties TMS acts as filter rather than barrier to external conditions. The selection of appropriate optical properties TMS can be used for shading and natural ventilation purposes.



(a) Thermal behavior of TMS at day



(b) Thermal behavior of TMS at

Fig. 18. Thermal behavior of TMS

E. *Ventilation Strategy*

The enclosure of TMS can play an important role in the cooling strategy and the mixing of buoyant warm air accumulating in the upper part of the enclosure. The configuration of the ventilation openings should therefore be of a displacement type, where cool outdoor air is introduced at low levels and exhausted at high level, so as to follow the natural flow of the internal buoyant air.

Conversely, outdoor air intakes should be minimized during the heating season to reduce heat losses and internal mixing should be promoted to avoid the accumulation of warm air above the occupied zone.

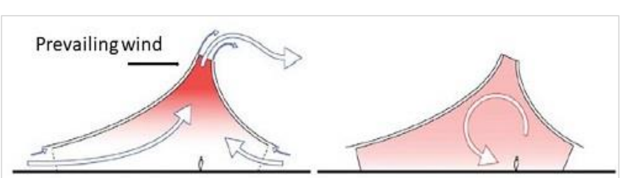


Fig. 19. Ventilation strategies (a) during heating season (b) during cooling season

Air flows into the internal space can be controlled by adjustable openings in the building envelope, designed and positioned to make maximum use of both wind pressure distribution around the enclosure and temperature differences to enhance natural ventilation.

Fig. 20. Operable windows on perimeter glazed walls, Inland Revenue Amenity building, Nottingham, UK (Michael Hopkins Partners,1995)

F. *Stack Effect*

Temperature driven airflow is commonly referred to as the "stack effect". The driving force results from the temperature difference and therefore density difference between indoor and outdoor air. As the outdoor air entering the enclosure picks up heat from internal and solar gains, it becomes buoyant and rises in the space. If the warmed air is discharged through openings at high level, the generated depression draws colder outdoor air into the space through openings situated lower down. This phenomenon is commonly known as the "Thermo-syphon effect".

V. ACCESSIBILITY OF TENSILE ARCHITECTURE IN BANGLADESH

A. *Resemblance of TMS & Traditional Bengal Hut Pattern*

Climate is an important issue while designing a space in the context of our country. Our climate is tropical monsoon in general. Humidity level is very high almost throughout the year. Airy open type structure is preferable because of flow of fresh air [9].

With the concern of rural and urban settlement of our country, more sustainable and functionally flexible solution need to be investigated in this field [9].

Traditional Bengal hut and TMS are compared to observe the strength and weakness of them.

- Structural system of Bengal hut is very simple where roof generally is tied to bamboo or wooden poles with horizontal bamboo or wooden members. No load or tension force is applied to the thatch or sheet roof. Thatch or sheet roof is just cladded on bamboo or wooden frame. This Thatch or sheet type of roof system is called Lean-to-roof system. Lean-to-roof is constructed against an existing wall or other supportive roof structure.

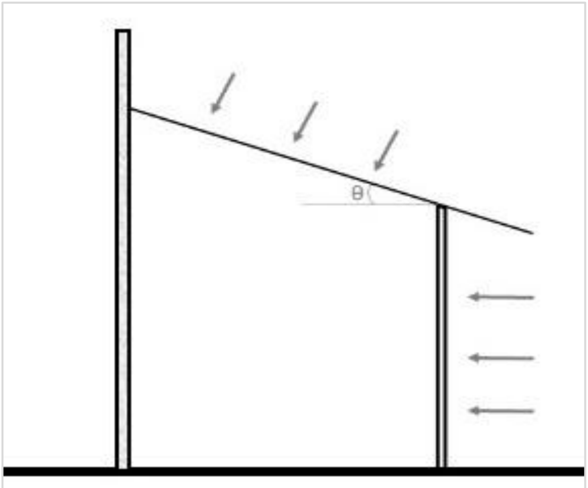


Fig. 21. Structural load flow in lean to roof

On the other hand in case of TMS, fabric is part of the structural system. It acts as skin and structural system as bone. Fabric is tensioned with adequate force calculated for stability and to withstand wind uplift force. The edge of the fabric is tied with wire rope which takes tension force from the fabric and transfers it to corner plates. Corner plates transfer load to supporting structure [9].

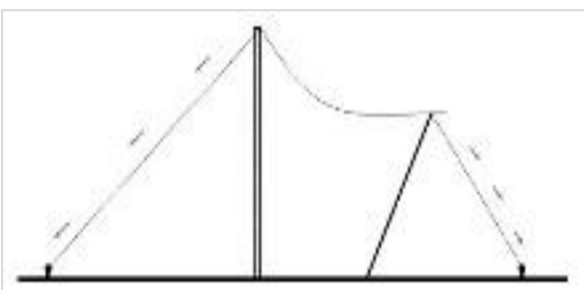


Fig. 22. Structural load flow in lightweight tensile fabric structure

- The lightweight nature of TMS membrane is an effective solution because it requires less structural steel to support the roof compared to conventional building materials. It enables long spans of column-free space which is comparatively economical with conventional structures. They require minimal maintenance when compared to an equivalent-sized conventional building. It is a permissive structural system and climatic responsive solution for tropical monsoon climate.
- In daylight, fabric membrane translucency offers soft diffused, naturally lit spaces reducing the interior lighting costs and thus the same with traditional Bengal hut (lean-to-roof). During the night time, artificial lighting creates an ambient exterior luminescence.
- Most of the tensile membrane structures have high sun reflectivity and low absorption of sunlight, resulting in less energy used within a building and ultimately reduce electrical energy costs. As Bengal hut usually made of thatch, sheet or bamboo, they also absorb low sunlight and keep the semi-outdoor temperature cool.
- Sheading device is another component of Bengal hut. These device control direct sunlight to go through the semi-outdoor part of hut. And TMS is very flexible to make any kind of sheading angle.

Large public gathering occasion such as marriage ceremony, religious congregation, fairs, festivals, platforms, waiting zone, and many other circular zone which mandatorily demand semi-outdoor space in Bangladesh, are recommended to use TMS system as this structural system has equivalence with traditional building pattern and climate of Bangladesh.

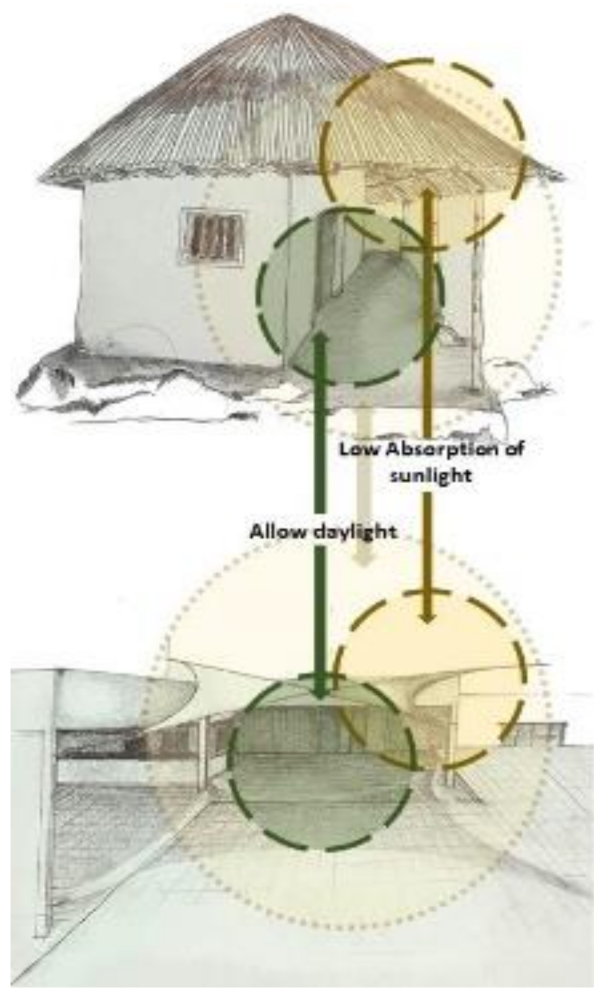


Fig. 23. Similarities between Bengal hut and contemporary semi-outdoor

B. Case Studies

There are some significant architectural projects in Bangladesh which has proved the essentiality of tensile architecture in tropical monsoon climate. And surely tensile architecture will create a new era of Bengal hut in contemporary architecture practice of rising Bangladesh.

BAY'S EDGEWATER, GULSHAN 2, DHAKA

Bay's Edgewater is an exhibition hall of renowned capital of Bangladesh. At the semi-outdoor space of this exhibition hall, TMS has constructed. TMS significant features of 'Bay's Edgewater' are describing bellow:

1) Lightweight: The major advantage of TMS is its lightweightiness which is achieved in these projects. Prestressed shapes of the membrane,low mass and wide span provide opportunity to express lightness and stability.

2) Translucency: Translucency is one of the great qualities of tensile membrane structures. It offers anesthetic opportunity to design with natural and artificial light. Translucency depends on the type, coating and color of membrane material.

3) Flexibility: Tensile membrane structures are not rigid. Membrane shapede forms in response to rain and wind load. It finds efficient shape for different loading conditions which offers better flexibility. Unique sculptural shapes can be achieved through membrane structures. It offers a floating quality defying gravity. With the help of artificial lighting it offers an opportunity to design a tensile membrane structure in to a sculpture of light.

4) Naturalventilation: Membrane material with open structure can be used for shading and stimulate natural ventilation. The open air feeling and impression no flightiness of tensile membrane structures are reinforced by the translucency of membrane material.

Fig. 24. Bays's edge water, North Avenue, Gulshan 2, Dhaka, Bangladesh

There are many other projects which have achieved their complete goal by constructing TMS. Here are some images of tremendously suitable project 'BISTRO FANTASTICO' of Dhaka, Bangladesh.

"BISTRO FANTASTICO", DHAKA

Fig. 25. Bistro fantastico, Dhaka

C. *Opportunities of TMS*

Tensile membrane structures are a good solution for shading roofs due to its environmental compatible characteristics as flexibility, lightweight, and natural lighting and ventilation [10]. This research intends to explore how designers can emphasize the impact of utilizing tensile structures, which significantly increase the possibilities of both the geometric and physical properties of their design in respect of tropical monsoon climate of Bangladesh.

D. *Limitations of TMS in the Context of Bangladesh*

Every great possibility comes with some limitations. Applying tensile architecture in the field of Bangladesh will defiantly start a new era of light-weight structure if this structure get enough support of technology and design guidance, because this material is new compared with commonly used materials as steel or concrete. Materials of tensile membranes are expensive but construction can be easy. As this projects are unique, they need to vary expertized professionals, both engineers and architects. The form of this membranes needs to be calculated for each project by engineers, and specially in more complicated projects it can increase the time and cost.

VI. CONCLUSION

For ease of mobility and deploy-ability, tensile membrane structures can be used in case of emergency situations and can also be served as soft urban spaces in various open public events with minimum Intervention. And be dismantled for future use, thus urban open spaces can be preserved. Tensile membrane structures provide the advantage of traditional Bengal hut in many ways. Enclosing large spaces without intermediate supports, using a minimal amount of material and rapid erection are the common feature of tensile membrane, Bengal hut and the climate of Bangladesh. Recently, the need for such wide span enclosures has greatly increased in both developed and developing countries, to accommodate and facilitate the multi functional, collective activities of society [7].

The paper has indicated how the unique nature of the tensile membrane structures topology can be effectively harnessed to achieve better environmental performance in tropical monsoon climate such as Bangladesh. Features like topography, local climate, sun and site orientation and wind should all have a significant role in the form finding of a tensile structure. The possibility of using the fabric's topology to enhance the ventilation rates and the climatic performance of the interiors along with the employment of a number of architectural strategies commonly applied to conventional buildings were introduced [7].

REFERENCES

[1] S. K. Chiu and E. S.-H. Lin, "Transformable tensile façade: Performance assessment on energy, solar and daylighting," in *Advanced Building Skins*, Graz University of Technology, Graz, Austria, 2015.

[2] National Geographics. (n.d.) Monsoon climate. [Online]. Available: https://bit.ly/2Rgc0vK

[3] M. Pankow, B. Justusson, M. Riosbaas, A. Waas, and C. Yen, "Effect of fiber architecture on tensile fracture of 3D woven textile composites," *Composite Structures*, vol. 225, pp. 1–14, 2019. doi: https://doi.org/10.1016/j.compstruct.2019.111139

[4] A. V. Mannan and S. Barua. (2011) Anecdote of Bengal vernacular space. [Online]. Available: https://bit.ly/2UIrVVq

[5] C. M. Chien and J. H. Hou, "An approach to open source model on the collaborative construction in human civilization," *Journal of Advances in Technology and Engineering Studies ,*, vol. 4, no. 1, pp. 17–26, 2018. doi: https://doi.org/10.20474/jater-4.1.3

[6] J. C. V. Sim and W. Y. Jung, "Fragility assessment of the connection used in small-scale residential steel house subjected to lateral wind loads," *Journal of Advances in Technology and Engineering Research*, vol. 3, no. 3, pp. 101–107, 2017. doi: https://doi.org/10.20474/jater-3.3.5

[7] A. Elnokaly, J. Chilton, and R. Wilson, "Environmental aspects of tensile membrane enclosed spaces," in *Lightweight Structures in Civil Engineering, (LCSE)*, Warsaw, Poland, June 24-28, 2002.

[8] J. Craven. (2018) Exploring the architecture of tension. [Online]. Available: https://bit.ly/2UHHexQ

[9] G. M. C. Rana, "Comparative study of tensile membrane structures in the context of Bangladesh," *SEU Journal of Science & Engineering*, vol. 7, no. 1, 2013.

[10] Anonymous. (n.d.) Urban space regeneration design using architectural minimal structure (old market place regeneration using tensile structure). [Online]. Available: https://bit.ly/2W6iYXG

[11] Carpentry & Construction Hornsby. (2016) Construct pitched roofs trade notes. [Online]. Available: https://bit.ly/2UW0i09

[12] R. Rivera, R. Zarfam, C. Talavera, T. V. Dessel, and C. Ozturk, *Membrane Structure, First Step Towards Finding*. San Juan, Puerto Rico: Membranas Estructurales, Inc., 2014.

[13] A. Sabmeethavorn, *Introduction to Membrane Structures*, 2016. [Online]. Available: https://bit.ly/2VunX7w

[14] B. Forster and M. Mollaert, *European Design Guide for Tensile Surface Structures*. Belgium: TensiNet, 2004.