International Journal of Research (IJR) Vol-1, Issue-5, June 2014 **ISSN 2348-6848**

ADAPTIVE ENVIRONMENTS: *SPATIAL ADAPTATION BY RECONFIGURATION*

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Abstract

Space Crunch" is a daily struggle in the life of majority of Urban Dwellers, more so for growing families to which they either respond with unique design solutions or compromise. Internal non load bearing walls occupying valuable floor space is one of the reasons contributing to this "Space Crunch". Thereby necessitating a study to explore transformations on the

Wall plane. This paper is a study of reconfigurable systems both on the wall as well as roof plane leading to an apt design solution for Reconfigurable, Internal Modular space dividers in Tensile Fabric. The paper would finally conclude with a conceptual design solution answering the "space crunch " issue enhancing functional efficiency of residential dwelling units with changing occupants.

Keywords:

Adaptive Environments, Spatial Adaptation, Reconfiguration

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Space Crunch : A by product of rising urbanisation

Migrating population is on the rise as cities offer lucrative employment opprtunities. But work places go hand in hand with corresponding dwelling units, to house this growing populace. Land is limited and families still has the pottential to grow. Predictably needs also grow and households need more space. This has been going on right from the time of Industrial Revolution and humans have always found a solution because they possess this incredible power to "Adapt"to changing situations, one of which is through "Spatial Transformation".

Concept of Spatial Transformation

"Spatial Transformation" in this context is defined as any

- ALTERATION
- ADDITION
- EXTENSION
- MODIFICATION

Of Residential Interior Space Usage

It has been identified as an integral part of Inhabitation. In the context of self built houses in developing countries [1], as well as homes all over the world occupied by the Urban populace ,studies show that there is an abundance of transformation incidents. [2].

Transformation in Interior walls is defined as Partition Level [PL] transformation, by the author T.H. Khan in his book Living with Transformation. Permanent construction works is involved as the Internal non load bearing walls are made of Bricks which is a rigid material.

Categories of Partition level Transformation

1. **EXPANSION**:The size of one unit is increased by devouring some space from adjacent units on the same floor. For eg : as families grow, a larger bedroom is required and a smaller dining space is acceptable as a compensation[Fig 1]

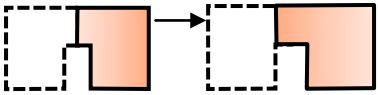


Fig 1 : Transformation by expansion

2. **REDUCTION** : The size of one unit is reduced usually due to change of usage of part of any area into non residential

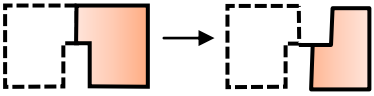


Fig 2 : Transformation by reduction

activities.[2] For eg : the reduced part becoming office or storage space.(Fig 2)

3. **SUBDIVISION** :It involves constructing or demolishing partition walls , or simply closing a door or two so that parallel

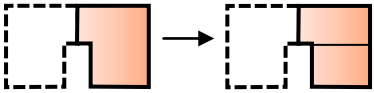
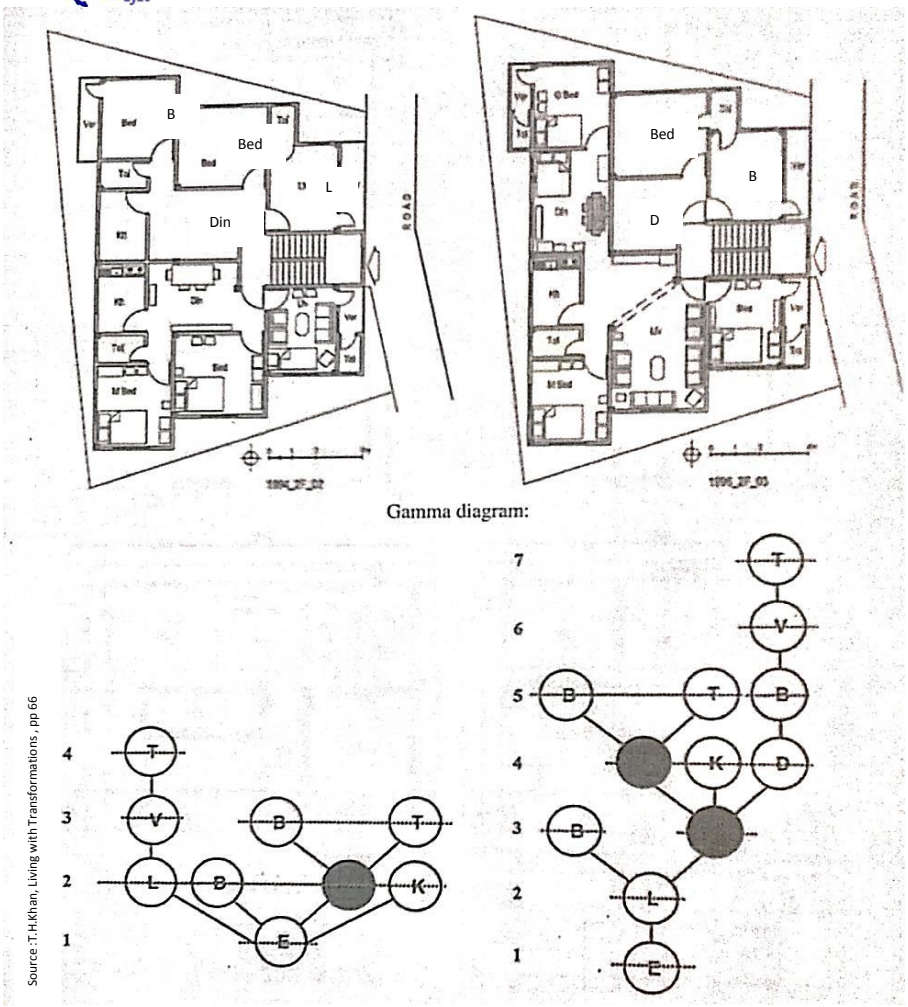


Fig 3 : Transformation by subdivision

private functions can be carried out in these subdivided areas. [2] (Fig 3)

These categories of transformation incidents are a common occurrence in small dwellings in urban areas causing " Space Crunch" due to rigid internal non load bearing walls occupying valuable floor space .



Source :T.H.Khan, Living with Transformations , pp 66

Fig 3(I): Transformation by subdivision
With circulation analysis = Gamma Diagram

*Analysis : Increase in depth after transformation. Previously no space had more than four levels. Now the toilet at NW has entry at the seventh level: **L**iving-**P**antry-**D**ining-**B**ed-**V**erandah-**T**oilet. **Black dots** indicate circulation spaces.*

Internal subdivisions causes increase in circulation space, thereby resulting in more wastage of space. (Fig 3)As families grow, sometimes adjacent flats are purchased and merged into one and the internal circulation is reconfigured by shifting the position of few non load bearing walls resulting in transformation by subdivision.

However not all the transformations follow basic architectural norms of space hierarchy. Examples of such transformations include

entry to toilet through verandah, entry to a bedroom through another bedroom , multiple entry of a room to solve circulation, evolution of complicated circulation spaces etc. Using Gamma diagram it is found that the levels of depth increase after transformation.[2] causing wastage of valuable floor space. [Fig 3(I)]

Thereby it is seen that there is scope for further research in the field of Lightweight Modular Walls Defining Flexible Internal Spaces Enhancing Functional Efficiency of Residential Dwelling Units with Changing Occupants.

Optimum space utilization

Considering the Housing scenario in India, The real estate prices in metro cities are as follows.
The following table shows that residential spaces are becoming more & more unaffordable for the middle income sector.[Table 1]

Table 1 :2013 Residential property prices, Average for each metro city.

Source :www.magicbricks.com. Last accessed on 12/9/13

City	***Rate per Square feet***
Mumbai	12,000 Rs.
Bangalore	8,000 Rs.
Delhi	15,000 Rs.
Kolkata	7,500 Rs.

A general trend in India, shows that home buyers pay more for considerably lesser space that they effectively occupy .Home buyers pay for a total built up area whereas they occupy only the carpet area.

For Example:

Carpet area = 900 sq. ft*[Area occupied]*

Loading factor =25% [125]

Built up area = Carpet area + Loading factor

= 1125 sq.ft.

Therefore, **Carpet Area = 80 % of Built up Area**

Balance 20% is profit for the builders.

Out of the above mentioned 80%,rigid space divisions in the form of internal walls, further reduces maximum space utilization.

Actual space utilized = 70% of Built up Area

In such a scenario, Reconfigurable Modules of Tensile fabrics can greatly reduce space wastage by an astonishing **20%, as there is reduction in area coved by fixed walls,& the reconfigurable nature of tensile modules makes multiple internal wall configurations easy, thereby achieving optimum space utilization.**

Reconfigurability on the wall and roof plane : Built examples

This study was undertaken to understand the design characteristics of reconfigurable modules. Even though majority of the featured projects show reconfigurability on the roof plane, their analysis led to the kinematic development of the conceptual design of Lightweight modular walls.

1Project :ROOF OVER SWIMMING POOL in Unterluss, Germany.

Fig 4 : Internal View of Swimming pool showing double layered membrane roof[barrel form].(3)

Architectural Firm : L. Stromeyer& Co.
Year : 1972
Reconfigurability Analysis :Double Layered membrane = ***good design for reconfigurable modules***

From the point of view of reconfiguration, if a module consists of 2 layers of fabric with an intermediate air space in between of minimum 3 cm. The internal pressure in the double layered skin can be used to control the foldable structure, which gives it stability in a reconfigured position. This concept is in function, but in the form of an external envelope for the swimming pool at Unterluss, Germany

(4) Commonly umbrella based folding designs offer two functional and structurally sound states of deployment : fully collapsed and fully expanded.

During the process of deployment the cantilevering arms of an umbrella like structure shift from a vertical to a horizontal position. In large scale structures like the prophet's holy mosque in medina, this process is time consuming and occupies a considerable volume of unobstructed space near the central mast. However as this concept is proposed to be applicable in home interiors , the process would have neither of the above disadvantages.

Source :http://www.sl-rasch.de/p_048.html [for all 4 images]

Fig 5 :Closed to open position showing folding action of the umbrellas[clockwise from top

2Project: CANOPIES FOR SHADING COURTYARD OF PROPHET'S MOSQUEin Medina.
Architectural Firm :BuroHappold.
Year : 1972
ReconfigurabilityAnalysis :Modules with an inherent flexible geometry ***Utilizing folding action***

The project described above [Fig 5] is of 17 X 18 M upturned umbrella form of canopies used for shading the courtyard of the prophet's mosque in medina, Saudi Arabia.

Kinematically Utilizing folding action as described in Project 2**is more advantageous to be applicable in the context of this reconfigurable module design** as described below

Complete reconfiguration of roof canopy module allows barrier free zone on floor level. [Fig 5 & 6]

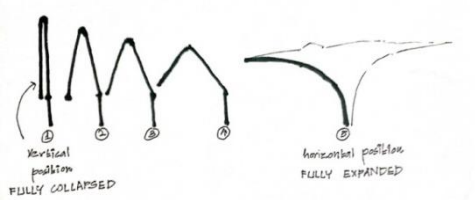


Fig 6 :Process of reconfiguration[1-5] allowing barrier free zone on floor level.

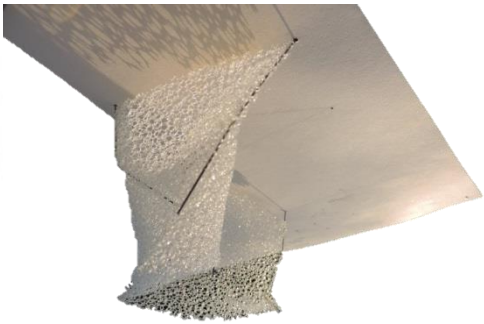


Fig 7 :Conceptual model of a reconfigurable wall module fixed at the roof level

Similarly In the context of this research, the mechanism implies a 100 % reconfiguration, thereby allowing a complete barrier free zone on the floor level, if the module is attached at the roof level.[Fig 7& 8]

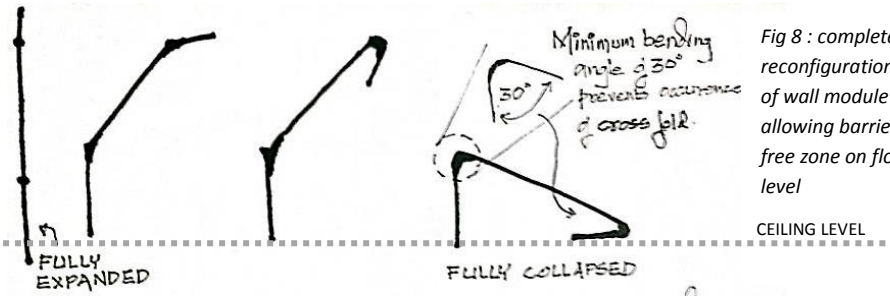


Fig 8 : complete reconfiguration of wall module allowing barrier free zone on floor level

3Project :SOUTH FACADE OF THE INSTITUTE OF THE ARAB WORLDin Paris, France.
Architect : Jean Nouvel.
Year : 1988
ReconfigurabilityAnalysis :Transformation on the wall plane using an IRIS type diaphragm.

Transformable facades have been used in the past as part of environmental strategies for day-lighting control within buildings. An example of a transforrnable facade that uses a retractable ring structure can be found in the south facade of the Institute of the Arab World in Paris, France.

It comprises 27,000 motor-operated aluminium retractable rings divided into 113 panels .Each ring operates individually and is equipped with a photosensitive mechanism, similar to the iris-type diaphragm of a camera (Fig 9).

Working in conjunction,the retractable rings allows control of the amount of light entering that side of the building, according to the weather and seasonal conditions. This is a very high-tech and beautifully engineered solution for a transforrnable facade. Unfortunately, due to high maintenance and operational costs the rings no longer work. Commonly, the iris-type diaphragm used within photographic cameras consists of number of very thin

Source :http://www.thenational.ae/stor

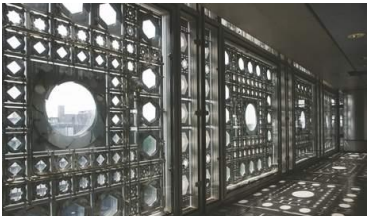


Fig 9 :Retractable ring panel detail of the South Façade of the Arab World.

metal blades mounted on a base plate and covered with a blade actuating ring that has a series of welded pieces(Fig 10). By rotating this ring the welded pieces push or pull the blades and the size of the lens opening can be varied.(3)

With this system the blades overlap each other during the deployment; as a result they are forced to operate on a sloped angle. The slope of the blades increases as they approach the closed position. This is more evident when the width of the blade is greater. Such condition restricts the range of designs possible with this system.

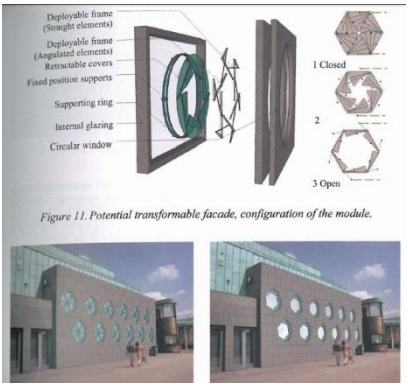


Figure 11. Potential transformable facade, configuration of the module.

Fig 11: Potential transformable façade utilizing a simpler swivel diaphragm CONCEPTUALDESIGN (5)

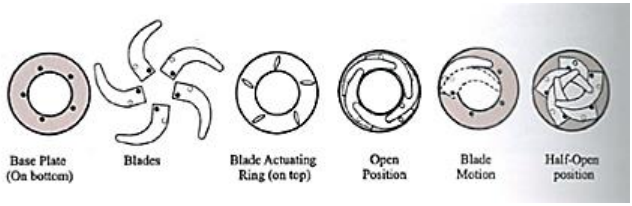


Fig 10: Parts of the Iris Diaphragm (3)

Reconfigurability on the wall and roof plane : Coneceptual Designs

Resarchers have always looked for a simpler and cost effective solution with regards to fullfiling this gap and have come up with innovative designs, some of which are described below

4 Project :THE SWIVEL DIAPHRAGM

The swivel Diaphragm is a retractable ring structure and is at a conceptual design stage. It is developed by C.Rodriguez and J.Chilton.

ReconfigurabilityAnalysis :Modules with an inherent flexible geometry ***Utilizing Swivelling action for Polygonal configurations***

It is constituted by a concentric series of angulated and straight elements linked together through elementary pivot joints.(5)

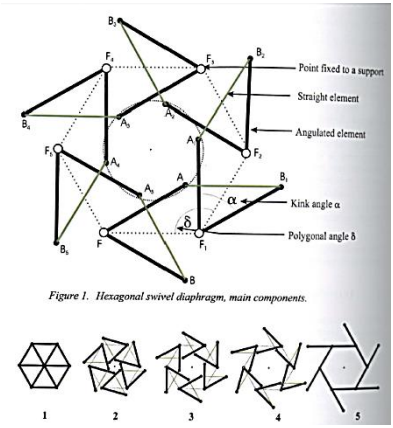


Figure 1. Hexagonal swivel diaphragm, main components.

Fig 12: Hexagonal swivel diaphragm and it's process of deployment (5)

Such an assembly forms a closed circuit where all the elements expand and contract simultaneously from or towards the centre of the structure. Therefore any force applied to a single component spreads through the rest of the structure. [Fig 12].

Advantage 1 : The ingenuity of this design is the link and the flexibility of it's individual components.This allows it to be **operable in one plane**, therefore space/**activities** on either side of the plane is **not disrupted** [Fig 13].

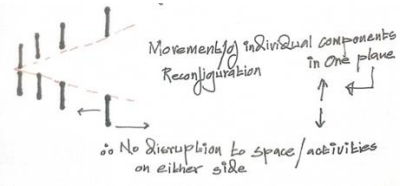


*Fig 13: Design **Advantage :** Movement in one plane.*

Advantage 2 : Simple design

Structures operable on the retractable ring mechanism due to the swiveling action have been studied by various researchers, amongst others are C.Hoberman, J.Pellegrino, and Z.You (6). Their research suggests that compared to other retractable ring mechanism, the swivel diaphragm is a simpler mechanism that allows interconnection between elements and uses only pivoting joints with a single degree of freedom. As these joints pivot fixed in position to a support, there is no need for specialized systems like rails for it's operation.

This is advantageous when the design is to be applied in areas where specialized technology is not available. From the point of view of this area of research, this design concept has a pottential to be applicable as reconfigurable space dividers in homes of low income families.

Disadvantage

However it does have a disadvantage from the point of being applicable to a home environment as vertical space dividers. The geometry of the module being that of a polygon, it has a tendency to expand in all directions in order to achieve a reconfigured position. A flat / apartment house has a fixed vertical boundary, that of the floor and the ceiling , as shown in the diagram below. This would not allow for full polygonal reconfiguration.[Fig 14]

Polygonal configuration expands in all directions, therefore disadvantageous within restricted boundaries.

The designer J.Chilton in his research paper suggests that *"many shapes regular or irregular are achievable by changing the polygonal shape described by the fixed joints and/or the internal angle **α** in the angulated*

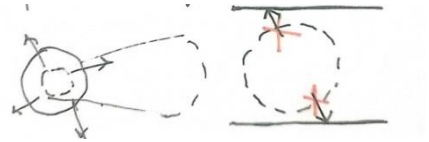


*Fig 14: Design **Disadvantage:**Polygonal geometry.*

element " [Fig 12 & 15].

This creates a pathway for further research and experimentations which might give possible solutions to it's current disadvantageous geometry.

Conclusion of Project 4: Swiveling action can

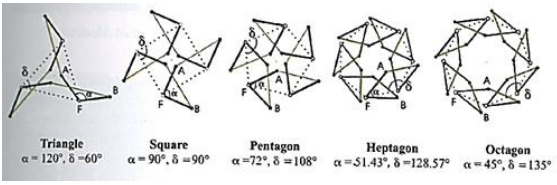


Fig 15: Examples of regular polygonal configurations with the swivel diaphragm (5)

be used for reconfiguring the wall modules however a new geometry is needed to be applicable to the research field in consideration i.e. Residential Interiors.

5 Project : QI ZHONG TENNIS CENTER
Shanghai, China

Architectural Firm :Mitsuru Senda in co-operation with SIADR (Shanghai Institute of Architectural Design & Research)

Year :August 2005

ReconfigurabilityAnalysis :***Retractable Roofs :The reason why textiles are most suited for kinetic /reconfigurable devices***

In recent decades retractable roofs have become commonly used for venues where variety of outdoor and indoor activities can be performed . The Qi Zhong Tennis Centerin Shanghai is the only known built project that uses a retractable ring roof structure .
This is the largest tennis facility in Asia with a seating capacity for 15,000 people. It has a 123m diameter retractable ring roof wbich comprises eight petal-shape steel pipe roof trusses.(3)

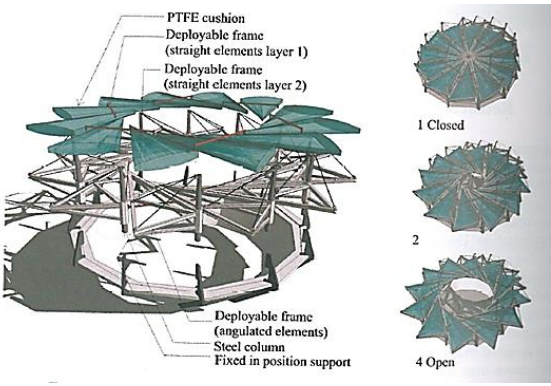
Each petal-shape truss tums around on one fulcrum at the same time allowing the roof to open or elose in approximately eight minutes.When the roof is closed the petal-shape trusses meet at the centre of the ring, when the roof is open they are placed around the perimeter **leaving gaps** between

*Fig 16: **BUILT DESIGN** of QI Zong Tennis centre, ShanghaiPetal form of retractable roof(5)*

them.[Fig 16]
The researcher J.Chilton has proposed an alternate design which utilizes **ETFE cushions** on a truss attached to swivel diaphragms in order to make the design more energy efficient and at the same time eliminating the gaps.

Project 5 Conclusion : Textiles and nonwoven materials are more often used within kinetic devices due to their flexibility, lightness and strength qualities.

*Fig 17 &18 :**PROPOSED DESIGN** of QI Zong Tennis centre, Shanghai and it's opening detail(5)*



Comparative Analysis of Reconfiguration Projects [Table 2]

Project	Reconfiguration Principle	Concept Applicability in context of this research	Inference
1.ROOF OVER SWIMMING POOL ,Unterluss, Germany.	Barrel Form, Double Layered membrane with air gap	Partly Applicable	• The internal pressure in the double layered skin gives it stability in a reconfigured position.[Fig 4]
2. COURTYARD CANOPIES Prophet's mosque,Medina.	Folding action	Yes	• Folding action is most appropriate for reconfiguring in this contextl as it leaves a barrier free zone on the floor level , if point of fixation is on roof level [Fig 8] • Membrane material transmits daylight , retaining the feeling of openness in the courtyard.
3.SOUTH FACADE OF THE INSTITUTE OF THE ARAB WORLD Paris, France.	Iris type diaphragm [works like the eye of a camera]	No	• Time consuming and complicated process of reconfiguration therefore not applicable in the context of this research. [Fig 10, 14] • Heavy metal is not apt for any reconfigurable design as it restricts movement .[Fig 9]
4.THE SWIVEL DIAPHRAGM	Swiveling action	Partly Applicable	• Simple mechanism allows easy reconfiguration in one plane,thereby activies on either side of the plane are not disrupted. [Fig12, 13]. • Polygonal configuration is not suitable for applicability in the context of this research, however best suitable for the roof plane [Fig 14]
5.QI ZHONG TENNIS CENTER [Proposed design] Shanghai, China	Swiveling action	Partly Applicable	• Combination of Swiveling action for the frame and PTFE Membrane cushion as a material of choice is an improvement to the current design .[Fig 19 &16] • Non wowen textiles like membranes are an apt choice for kinetic devices which reconfigure on a regular basis.

Specifications for a Reconfigurable module to be used as internal space dividers in Residential Interiors[Table 3]

Derived from comparative analysis of reconfiguration projects.

Reconfiguration Principle	• Folding action
Design	• Skeletal frame Attached to ceiling.using a point +line system of ceiling channel.

	• Double Layered Membrane defining each module
Scale	• Esay handling by home occupants
Material	• Adaptability to indigenous climate • Flexible properties • Glass based fabrics with high fire rating. • Prevents tear propagation.

Conceptual Design Solution Adhering to these Specifications

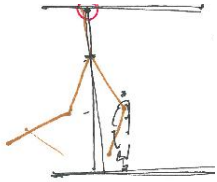


Fig 20 :Foldable module design fixed at the Ceiling.

ERGONOMIC DESIGN

Considering the human height and scale of the room of a general apartment [2.7 M] in metro cities of India, the overall vertical height of the room can be divided into 3 zones. [Fig 21] below

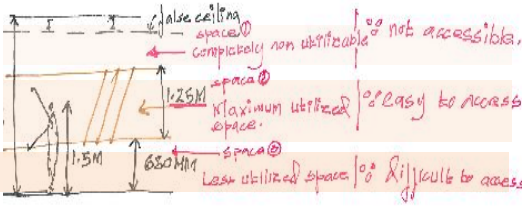
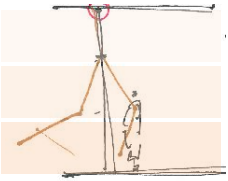
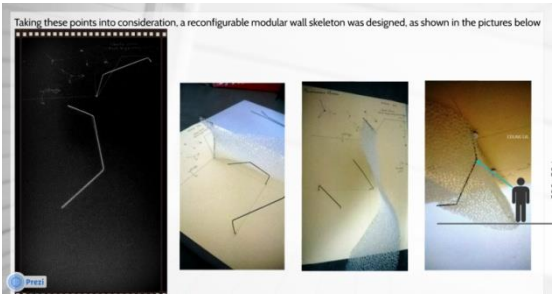


Fig 21:Division of vertical height of the room into 3 zones



On this basis the point of fold of the module is decided. [Fig 22]



PREPARATION OF A ROUGH MODEL[Fig 23]

The importance of building models cannot be overestimated. A scaled frame of the structure which is to support the fabric enclosures is a tool:

- It allows for experimentation with points of attachment.
- It shows the configuration a membrane's surface will take.
- It suggests the cutting patterns and positions of seams
- When finished, it produces a model essential to presentations which are volumetric by nature. (7)

This model gave an idea of levels of reconfiguration possible with the folding system and conceptually proved that complete reconfiguration is a possibility.

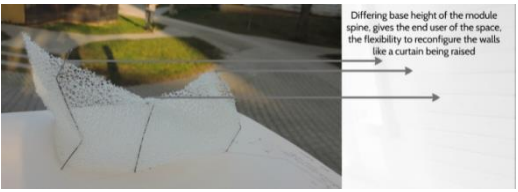
COMPLETE RECONFIGURATION

Fig 24: Model Experimentation showing complete reconfiguration.

Conceptual Design Solution answering "Space Crunch"

This design would be a lightweight modular , light transmitting alternative to conventional space divders like brick/ wooden partition walls. It is highly advantageous in comparison to the latter as it confirms to changing spatial needs of the occcupants of the space via "Spatial Transformation ".

It would allow for EXPANSION [Fig 1], REDUCTION [Fig 2], & SUBDIVISION [Fig 3], of a space with ease without involving permanent construction works .
Due to their easy reconfiguration properties, these internal subdivisions are not permanent, thereby saving on circulation spaces. [Fig 25 below]



It's modular nature and complete reconfiguration properties helps in saving valuable floor space thereby answering the "Space Crunch " issue through design.

Conclusion & Scope for Further Research

Lightweight modular walls defining flexible internal spaces is indeed a smart solution catering to the changing needs of the urban growing familes of India,& simultaneously allowing maximum utilization of space, thus enhancing functional efficiency of residential dwelling units with changing occupants.

SCOPE FOR FURTHER RESEARCH

Juxtaposing fabric membrane systems with conventional building systems has great potential for development.
The research and developmental model presented in this paper brings us to a point where tensile fabric space dividers can be envisioned as part of our day to day lives.

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