MATERIALITY IN HOME INTERIORS

An Exploration with Tensile Fabric

A Discussion Towards Development Of Partition Walls Made Of Reconfigurable Tensile Fabric Modules

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Tensile fabric has always been envisioned on the horizontal plane as roofing systems in the form of long spanned lightweight technology utilizing the material's inherent property to achieve minimalistic architecture. This research paper is an exploration of Tensile fabrics on the vertical plane as residential interior space dividers. It presents stage wise form development of reconfigurable fabric modules catering to the changing needs of the user. Whereby introduction of a new material allows us a novel approach towards envisioning adaptable environments enumerating the advantages and need for new material research.

Introduction

"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. Rigid internal partition walls occupying valuable floor space is one of the reasons contributing to this "Space Crunch". An estimated 20% of floor space can be saved by replacing rigid internal space partitions with flexible wall systems [1]. Thus a very important parameter when proposing cost effective solutions within the home environment is "Space Utilization". Spatial transformation is a means to achieve this space utilization and has been identified as an integral part of inhabitation [2].

Spatial transformations: Home Interiors and Tensile Fabric

It is the feeling of ownership & freedom to customize which distinguishes "My Home" from a "House". A freedom to change the furniture set up, to create an opening in an internal partition wall so as to join two spaces and inversely to cordon off a space for alternate use by the introduction of jaali partition walls. This freedom is an integral part of inhabitation. The occurrence being termed "Spatial Transformation" [2]. Needs chage with a growing family and one space sometimes needs to be used as different spaces in different seasons or days. This calls for transforming spaces which with the usual rigid partitions is not possible at ease bringing forth the need for reconfigurable wall concept.

RECONFIGURATION TO SAVE SPACE

As walls reconfigure, multiple activities can be carried out in the same space. The inherent material restriction of a Brick wall makes reconfiguration both time consuming and expensive requiring skilled labour and rigidly occupying valuable floor space. In such a scenario replacing **rigid** brick partition walls with **flexible** Fabric modular space dividers would help in utilizing every square inch of space. Lightweight technology and modular nature of these space dividers allows residential space occupiers the freedom to customise the space themselves with changing needs.

Related Work

From the point of view of Modular Design, Le Corbusier & Pierre Jeanerette's Weissenhofseidlung [1927] is one of the earliest examples of "Transformable House". Sliding wooden partition walls and beds integrated into the design of built in cupboards demonstrates how interweaving patterns of utilization and interlocking living spaces can create an impression of spaciousness even in small sized apartments. Humanistic scale of spaces makes the end user comfortable by imparting a sense of protection.

Fabrics shaping the spaces of an indoor environment have been experimented on by Alexandra Kasuba in "The Live in Environment 20th century" [3, 12]. The project aimed at abolishing the 90 degree angle and creating an environment that would capture the changes in daylight. This built experiment showed that spaces defined by curved surfaces were best experienced on the move, thereby creating a novel living experience. A similar approach was followed by Gisela Stromeyer in the design of Elie Tahari Fashion Showroom, New York [4]. In the words of the Architect "*The system* ***Attached at the ceiling / wall level but free at the floor level*** *makes it easy to change the shape and location of these space dividers, or to do away with them completely"[4].*Therefore, besides the effect of filtering and shading lights , textile membrane's free shape allows to arrange the spaces differently by freeing those spaces compressed by irregular, conventional structural cages . The proposed form of reconfigurable tensile space dividers is based on this very system of reconfigurability.

In order to be truly reconfigurable, the design should be responsive and kinetic. However kinetic membranes are most often seen as art or concept pieces. One example is the 2001 Expo.02 Nouvelle DestiNation in Biel, Switzerland, by Eckert Eckert Architecten of Zürich, in collaboration with the German artist Via Lewandowsky, which continually altered its form as a way of engaging visitors in a dialogue about politics in Switzerland[5]. Another example is the 2003 GEK Balance Roadshow, designed by Schienbein + Pier GmBH of Stuttgart, Germany [5]. This demountable membrane structure was designed to give attendees the experience of traveling through the interior of the human body. It was composed as a reconfigurable modular structure of organic volumes, as it had to be assembled in many different venues. Both these examples show how reconfigurability of membrane design imparts a novel interactive experience of movement through space, a quality essential to residential space design.

Mike Anusas and Tim Ingold (2013) argue that a focus on textiles might lead us to rethink the fundamental concepts of architecture. With form as *textilic,* the material world as comprising energetic lines, an interdisciplinary practice would lead to dissolving the barrier between inside and outside. "What is really at stake," remarks Susanne Kuechler, "is a new kind of surface ontology which replaces the opposition of inside and outside, invisible and visible, immaterial and material, with a complimentary relation that thrives on transformation rather than distinction" [7]. It is this very belief that led to envisioning reconfigurable membrane walls, which would transform to cater to changing user needs in a residential environment.

Practical Benefits and Corresponding Challenges

Built forms of Reconfigurable Membranes are more commonly seen on the roof plane instead of the wall plane. One reason for this is the lack of technical expertise and the development of new advanced materials, to cater to the challenges of a residential indoor environment [5]. However tensile fabrics have some practical benefits as enumerated below

ACOUSTICS

Highly reflective surfaces such as floors, furniture, glazing, etc. result in problematic acoustic reverberation by resulting in undesirable echo effects [8]. Several room acoustic solutions using membrane materials are on the market, from companies such as Birdair Inc., of Amherst ,N.Y. and Koch Membranen GmbH of Rimsting, Germany. However sound transmission remains a major challenge . "High frequency sound is reflected by many materials used in membrane architecture," explains Dr. Rosemarie Wagner of the Karlsruhe Institute of Technology, Germany. "But low frequency sounds pass through most membrane walls with little attenuation . Answering this challenge is a sandwich material called **TENSOTHERM** by Birdair Inc. It consists of an external skin of PTFE/Fiberglass , a middle layer of lumira aerogel material, and an inner layer of either PTFE/ Fiberglass or a vapour barrier material. This composite material promises to add insulation against sound transmission as well as heat while providing high levels of transparency [5] by causing sound and heat waves to pass through nano sized pores.

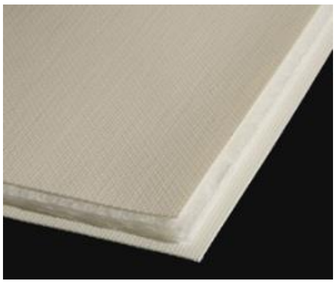


Fig 1 : Tensotherm components.

Source http://www.buildings.com/article-details

NATURAL DAYLIGHTING

Opaque building materials do not allow for light transmission , however this scenario is greatly reversed while envisioning a home environment defined by translucent membrane internal walls. Even though this transmission trough the external façade perforations [balconies, windows & doors] are minimal, natural daylight has a higher potential to be transmitted through membrane walls , thereby reducing electricity bills. The Aerogel layer in Tensotherm develops a U-value of 0.95 and an R-value of R-6 per inch of thickness [9] .

SCREENING

A reconfigurable fabric wall offers a simple, resource saving method of dividing up spaces, giving direction to foot flow and demarcating private and family zones. The fabric can be semi translucent or totally opaque, offering projection surfaces for viewing Television or playing video games, and include acoustic absorption to enhance privacy for areas like bedrooms.

THERMAL INSULATION AND VENTILATION

Aerogel insulating layer sandwiched between two membranes provides thermal insulation [9]. Conversely, if ventilation needs to be maintained, then open-cell fabrics of varying mesh sizes will allow natural (or controlled) airflow to permeate [8].

LIGHTING

The materiality of the tensile fabrics ensures ambient illumination. Lighting can be fully programmable, switchable or fully automatic and can be used to make the reconfigurable fabric walls glow, pulse, and change colours [8]. Transformational materials like the Give back curtain illustrated in Fig 2 is a techno fabric design which recycles light through a fabrication process, by integrating photo luminescent pigments in synthetic or natural fibres. Sunlight or fluorescent light having shorter wavelength can be absorbed by this fabric during daylight hours, retained and emitted back as visible light within another part of the colour spectrum [10].

Fig 2 : Give Back Curtain : Fabric woven with luminous phosphors
Source : Transmaterial, e book http://download.springer.com/ pg 192, Product courtesy : Sheila Kennedy

SUSPENDED CEILING

Replacing the traditional Plaster / Plywood ceiling with veneer finish/ Mineral board, reconfigurable tensile fabric panels may continue onto the ceiling level to form intelligent and ambient suspended ceilings. These ceiling panels being modular & lightweight could be easily removed for access and maintenance [8].

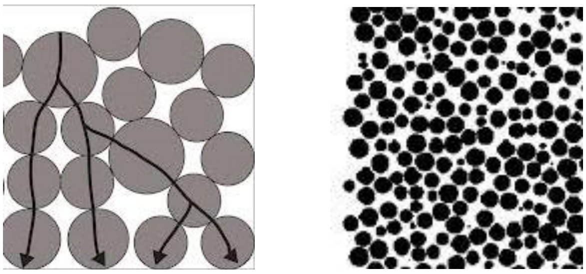
Thus proposing tensile fabric as a material of choice for reconfigurable partition walls has six major advantages from the point of view of applicability in home interiors as enumerated above. This and the study of Related Works further lead to certain discussions &Inferences, which then became the guidelines for form development of Reconfigurable fabric partition wall modules.

Guidelines for form development

1. **MATERIAL** : <u>Adaptability To Indigenous Climate</u>

The need for reconfigurable modules for tensile fabric is there and so is the technology available to satisfy this need. However one major hurdle to be overcome by any new building material is adaptability to the Indigenous climate. Even though this research focuses on catering to the needs of growing families in urban areas like Mumbai city, there is scope developing these membrane modules adaptable to other different regions of our country.
India has a prominent climatic diversity due to it's geographic location, and the traditional vernacular architecture of different parts of our country exemplifies this diversity. In such a scenario, how can one single material cater to the "Space Crunch" issues of a large populace spread over areas with different climatic conditions? Could a solution to this be nature? [Fig 3].

Inspiration for this idea came from studying the biomimetic approach followed by Frei Otto, the pioneering architect in the field of tensile architecture. In particular Otto's tensile web structures at the Olympic Stadium in Munich [11].



IN HOT & HUMID CLIMATE IN COLD CLIMATE

Fg 3 : Cross section through cell structure in different climates
Source : *Natural forms in Architecture, book by Frei Otto.*

BIOMIMICRY LEADING THE WAY

In hot climate our cell pores open up & we sweat so as to maintain the body temperature, the converse of this phenomenon happens when the same body is exposed to extreme cold, i.e. the cell pores shrink, so as to conserve body heat

A biomimetic membrane, which would mimic the cell function would therefore be adaptable to any kind of climate. This is the concept of **" PRINZIP LEICHTBAU " = To perform more with less i.e. BIOMIMICRY** [3, 11]

2. **DESIGN** : <u>Skeletal frame attached to ceiling./ floor using a point +line system</u>
   <u>Double layered membrane with accoustic insulation sandwich layer in each module.</u>

3. **SCALE** : <u>Easy handling by home occupants</u>

4. **RECONFIGURATION PRINCIPLE** : <u>Reconfigurable due to it's inherent form</u>

The above mentioned four points were the guidelines for form development of reconfigurable tensile fabric partition wall modules.

Evolving the form of reconfigurable fabric partition wall modules

Form development took place through development & analysis of scaled models.

CONCEPTUAL DESIGN MODEL

A conceptual design model [Fig 7] was first developed to help envision tensile fabrics as residential space dividers. As a subpart of which, modularity in internal space subdivision at the plan level was also experimented on through models [Fig 4, 5].This experiment proved the need for a regular ratio of floor area subdivision, for the wall modules to be truly reconfigurable. Inspired by the Japanese modular system of Tatami mat, research suggests the ideal ratio of floor area subdivision to be 1:1.618 [Golden Ratio] [Fig 4, 5]. The conceptual design model [Fig 6,7] paved the way for experimentation on the form of the wall module, which could reconfigure easily due to its inherent form.

Fig 7 : Conceptual design model
Angularity of the supports defines curvilinear spaces, utilizing flexible property of fabric .

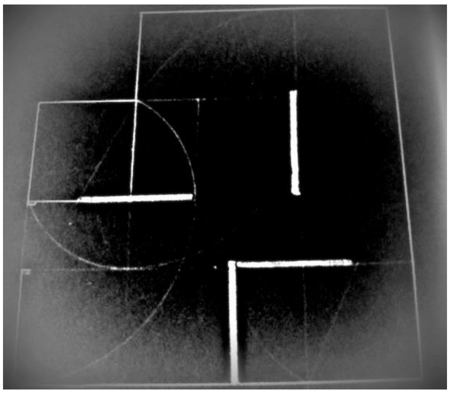


Fig 4 : Residential floor plan grid according to Golden Ratio

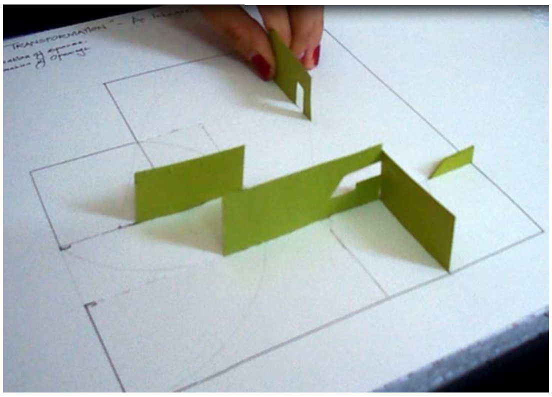


Fig 5 : Experimental modular wall arrangement on floor plan grid .

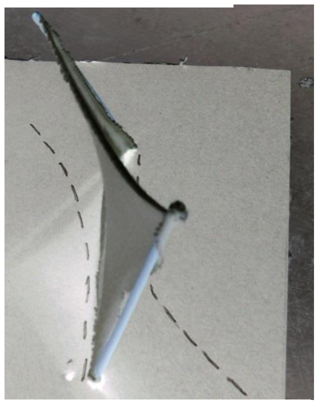


Fig 6 : Curvilinear spaces defined by tensile fabric wall

DEVELOPMENT OF MODULE 1 :
A Biomimetic Approach

BIOMIMETIC APPROACH TOWARDS FORM DEVELOPMENT OF MODULE 1

Biomimicry : An ancient principle of development in techniques and a continual principle of evolution in nature. Space utilization and optimization by planning here and biological selection by environmental conditions there. If looking for passable ways in which it could be successful to contribute to transforming our obstructed environment back into a viable and valuable biotope , then knowledge of the process in which natural forms and structures are generated is an inevitable essential. This inspired the form development of module 1.

The development of the modules 1 & 2 took place in the ILEK feel free lab at the Institut fur Leichtbau Entwerfen und Konstruieren, Germany [*Institute for Lightweight structures]*

Fig 8 : Dryad's Saddle
Source : http://commons.wikimedia.org , Photo :Jim Bain

Module 1 has a saddle shaped form inspired from Dryad's Saddle with flexible edge detailing, therefore easily reconfigurable [Fig 9]. Dryad's saddle is a fungus [Fig 8] having a saddle shaped form giving it stability, to grow at a 90 degree angle from the base trunk, and at the same time allows for overlapping and fixing of the upper saddle [12]. This stability of the form is explored in the design of wall module 1. As the partition wall modules are envisioned as lightweight reconfigurable designs, the saddle form with it's anticlastic surface design is inherently reconfigurable.

The three primary structural deciding factors for form development of a reconfigurable module are 1] choice of surface shape, 2] Levels of prestress & 3] surface reconfigurability.

Fig 7 : Conceptual Design model of Module 1 [Form and stability of the wall module inspired by the dryad's saddle.]

Surface shape : Most contemporary fabric structures have as their basis an "anticlastic" surface geometry. This is one in which a set of "arching" tensile elements [A] act in opposition to a similar set of "hanging "elements [B] [Fig 10]. Physically the two groups of elements represent the two directions of the textile yarns [Warp and Weft] within the membrane. This configuration has a valuable property in that the surface as a whole is prestressable without significant change occurring to it's overall shape[3].

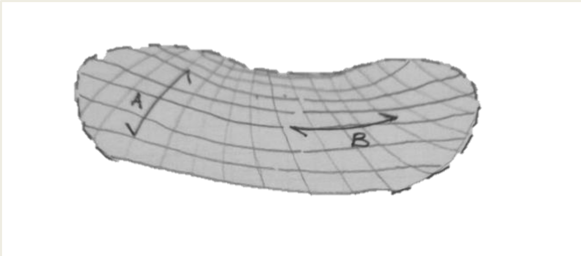


Fig 10 : Anticlastic surface geometry of Saddle shaped form

Prestress : For Anticlastic forms like the saddle, T= p X R , where T = Membrane tension, P= Pressure applied normal to the surface and R = Radius of curvature of surface [3]. Thus by knowing what the applied pressures are likely to be [human hand push and pull force] as well as what the membrane tensions should be limited to, then the radius or radii of curvature can be easily found.

Reconfigurability: Unlike in more conventional forms of building construction reconfigurability is seen as a useful and important characteristic of a fabric module. In a 3 dimensional frame, a saddle form, which is double curved in nature, has a maximum reconfigurable property [Fig 11, 12]. As seen in the images below this module design has 2 possible reconfigurations keeping one point of support \ contact to the base as constant [ ].

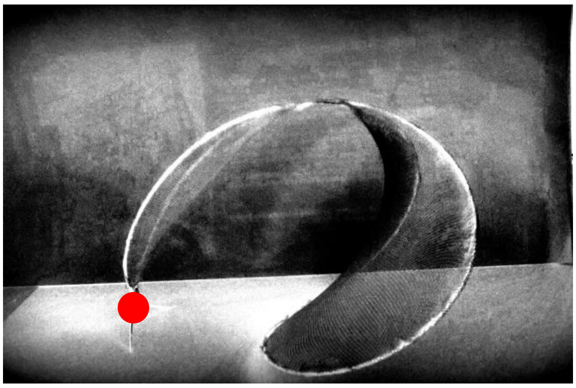


Fig 11 : Reconfigurable position 1 of module 1

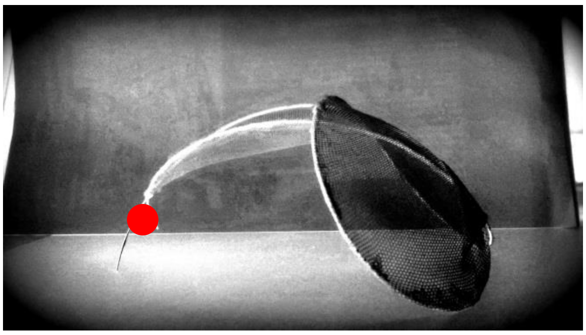


Fig 12 : Reconfigurable position 2 of module 1

These two reconfigurable positions are possible due to 3 major reasons:

1. Flexible & stable module framework [steel cable]
2. Stretch property of fabric
3. Inherent form of the module, the form of eight 8

RECONFIGURABILITY ANALYSIS OF MODULE 1

Through conceptual sectional drawings, advantages and disadvantages of this reconfigurable module are studied, from the point of view of a space dividing element in home interiors.

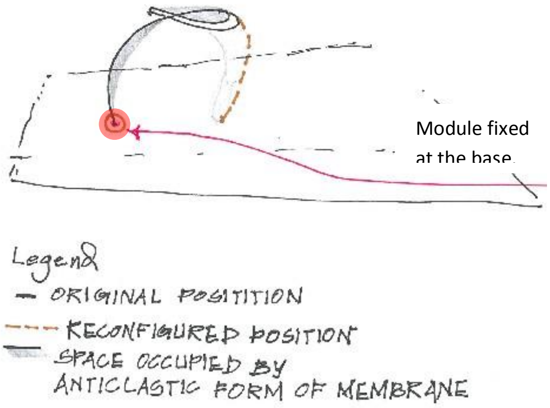
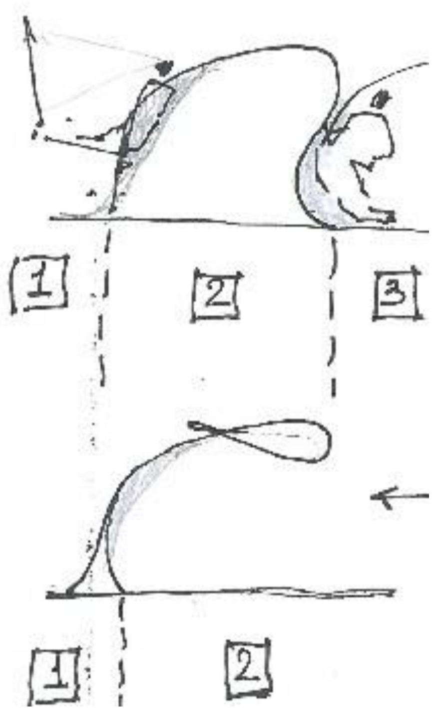


Fig 13 : Conceptual sectional drawing of Module 1

Advantages

The design shows the following advantages [Fig 14]



Curvilinear form of the module gives fluidity to the space so defined, thereby abolishing the 90 degree angle [3]

As the module is reconfigurable due to it's inherent form, it allows for multipurpose use of space [1,2,3]

Fig 14 : Design advantages of module 1

However further analysis of Module 1 resulted in bringing to light two major disadvantages as elaborated in figs 15 & 16.

Disadvantages

Doubly curved saddle shaped form while on one hand provides a niche which ergonomically lends a sense of protection to the user , on the other hand results in wastage of valuable space [hatched area]. This space can be further subdivided into two zones based on accessibility.

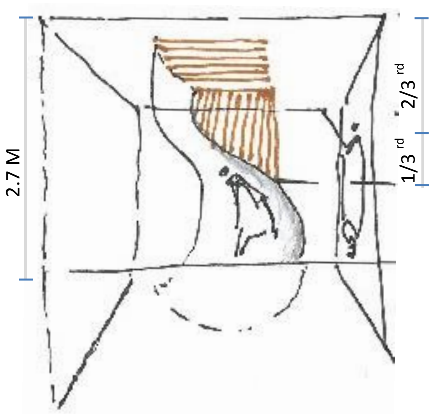


Fig 15 : Formation of positive and negative space due to saddle form of the module.

The second most major disadvantage of this module design is again caused due to it's form. Being saddle shaped with rounded edges, it cannot confirm to orthogonal surfaces of both the floor & ceiling and create a sound proof barrier. This is caused due to the compulsory air gap left above the wall module in order to reconfigure [Fig 16].

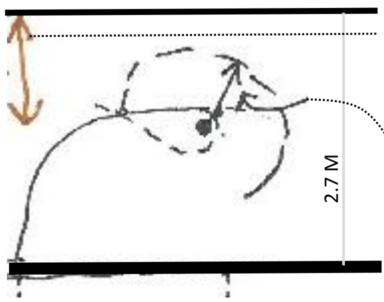


Fig 16 : Air gap above wall module prevents sound proof barrier.

Conclusion & Conceptualizing the form of module 2

The above elaborated disadvantages [Figs 15, 16] are majorly caused as the module was fixed at the base [Fig 13]. This causes a barrier to the smooth flow of activities, due to the inability of the design to achieve 100 % reconfiguration by merging more than two subdivided spaces into a large whole.

Instead, a wall module design which is fixed to the ceiling , utilizing a folding action for reconfiguration has the potential to achieve complete reconfiguration as elaborated in reconfiguration analysis of module 2.

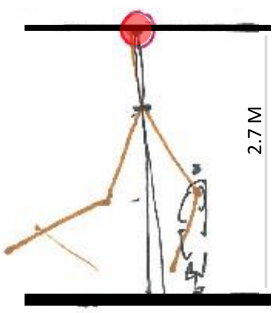


Fig 17 : Module 2 fixed at the ceiling, utilizing folding action for reconfiguration

DEVELOPMENT OF MODULE 2

An Ergonomic Approach

Ergonomics concern the creation of a product or an environment, where the connection between human skills and the surrounding is optimised [1].From the point of view of design of a modular reconfigurable wall for home interiors, ergonomy plays a major role in deciding the ease with which such walls may be reconfigured by the home owners themselves according to changing needs.

Considering the human height and that of a typical apartment in urban areas in India, the overall vertical height can be divided into three zones based on ergonomic studies [Fig 18].

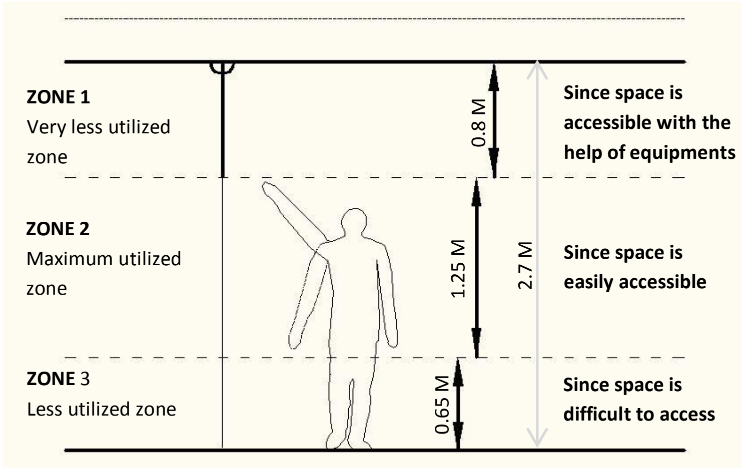


Fig 18 : Vertical space division of a typical apartment based on ergonomic studies

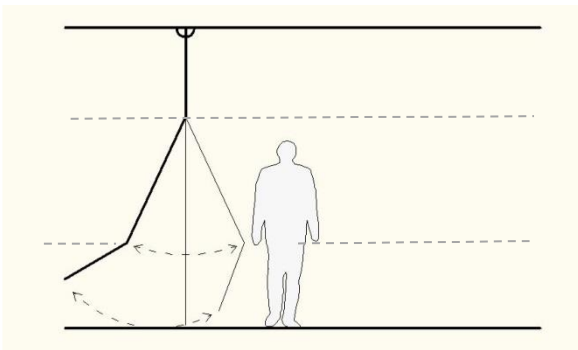


Fig 19 : Zone identification influencing the point of fold in the wall module for ease of access.

On that basis the point of fold of the wall module is decided since it's reconfiguration is envisioned as a passive action to be carried out by the home owners themselves [Fig 19]. The highest point of bending of the module is at 1.9M from the finished floor level, as this height is easily accessible by any fully grown human.

Developing a rough model

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

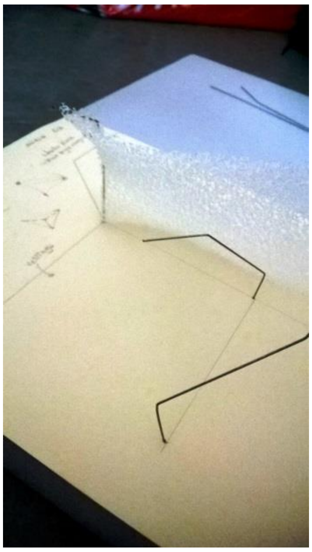


Fig 20 : Module 2 development [Stage 1]

Fig 21 : Module 2 development [Stage 2]

- It allows for experimentation with points of attachment.[Figs 20, 21]
- It shows the configuration a membrane's surface will take [Fig 21].
- It suggests the cutting patterns and positions of seams
- When finished, it produces a model essential to presentations which are volumetric by nature [12].

RECONFIGURABILITY ANALYSIS OF MODULE 2

This analysis is a qualtative analysis done by exploring the possible reconfigurations on the rough model of module 2. It explores the ceiling wall interactions in fabric.

Exploring the ceiling wall interactions in fabric

- Analysing the design ability to achieve complete reconfiguration
- Analysing the ease of access to space users for reconfiguration
- Analysing the experience of movement through space defined by module 2 reconfigurable walls.

Analysing the design ability to achieve complete reconfiguration

Experimentation with the module 2 model gave an idea of levels of reconfiguration possible with the folding system and conceptually proved that complete reconfiguration is a possibility [Fig 23].This is possible due to the module being attached to the ceiling with a [Point + Line] structural system [Fig 25] thereby allowing a barrier free zone on the floor level due to the folding action of reconfiguration. Minimum bending angle of 30^0 prevents occurrence of cross folds thereby preventing fabric tear propagation [Fig 24].

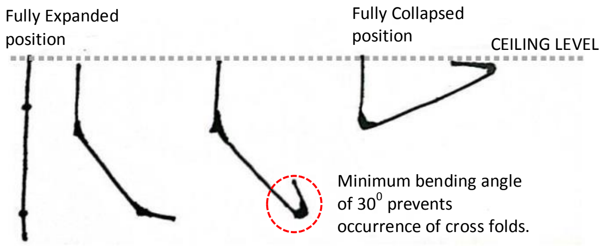


Fig 24 : complete reconfiguration of wall module allowing barrier free zone on floor level

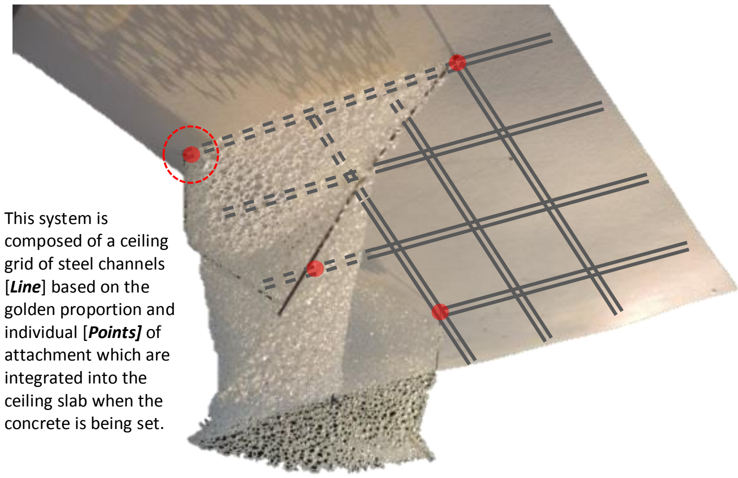


Fig 25:Reconfigurable modular wall attached to the ceiling grid via [Point+ Line] structural system

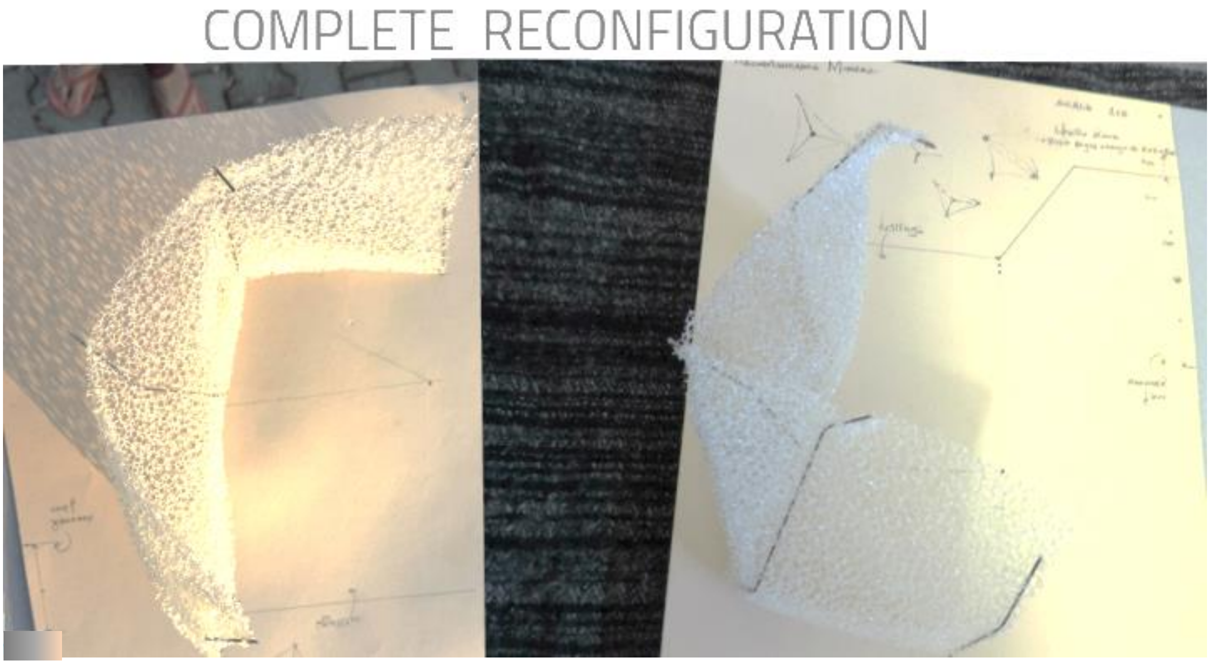


Fig 23 : Complete reconfiguration by changing the points of attachment to the ceiling .

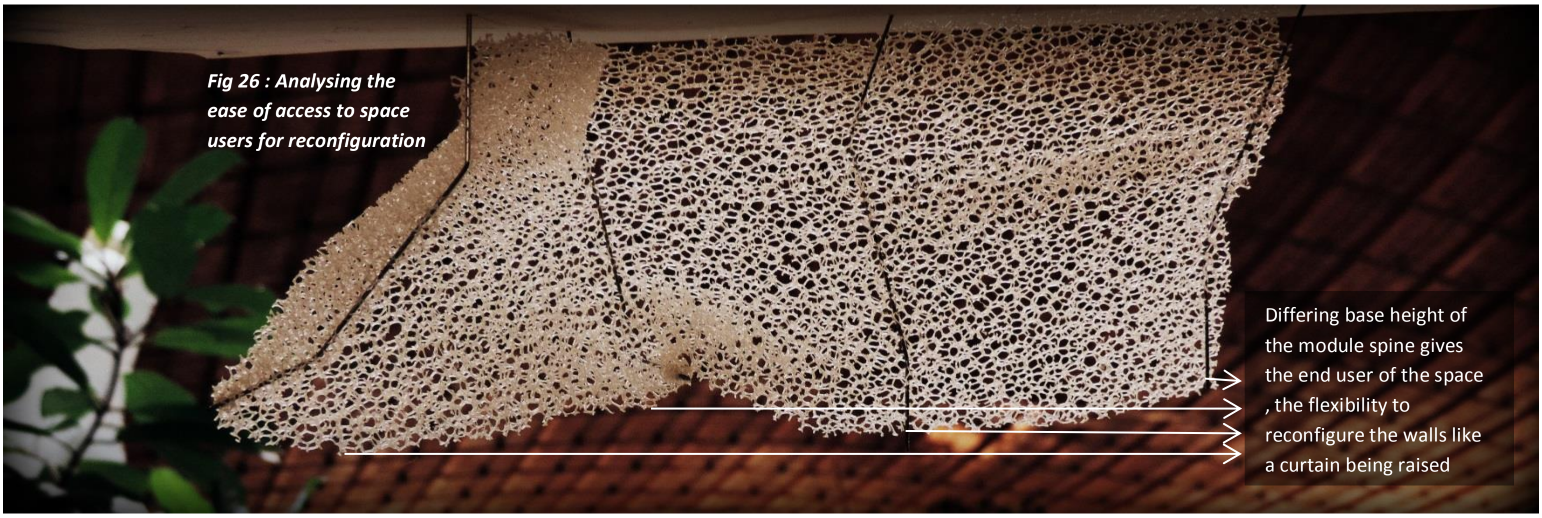


Fig 26 : Analysing the ease of access to space users for reconfiguration

Analysing the experience of movement through space defined by module 2 reconfigurable walls

Quoting the words of designer Alexandra Kasuba, "Spaces defined by curved surfaces are best experienced on the move[12]." In order to better understand this phenomenon, it is imperative to study the movement pattern & activities in a regular household. A basic layout of a 1 BHK apartment is taken as an underlay on which was traced the circulation pathway followed by an adult/ child as he/she goes about the daily chores.The activities happening in a typical household are further analysed from the point of view of the advantages brought by the introduction of Module 2 fabric space dividers as enumerated below :-

- Fabric space dividers being reconfigurable in nature alters the accessibility route to spaces, therby creating a novel experience each time one moves in the home from one space to the other.
- It changes the way we perceive light to permeate the space, creating an even level of illluminance in the interiors reducing the dependance on artificial light sources during daylight hours.
- Fabric being translucent in nature, animates the space it encloses by the play of light and shadow.
- It's easy reconfigurable property allows spaces to be subdivided on short notice. Eg : creating a guest bedroom for unexpected visitors.
- Being a screen on which items can be projected, home entertainment is given new definition.
- Experience of having meals would be enhanced by the combination of island kitchen with dining areas, due to easily reconfigurable partition walls defining these spaces thereby giving a new dimention to parties hosted at home.
- The absence of fixed walls, necessiates the presence of concealed wiring on the floor along with flexible furniture, truly defining an adaptable home environment, which thrives on transformation.
- Everyday a new experience , eliminates monotony and gives maximum creative freedom to customize space according to changing needs.

Conclusion

Module 2 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 achieves 100% reconfiguration and accoustic isolation, thereby overcoming the limitations of Module 1.

It would allow for expansion, reduction & subdivision 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. It's modular nature and complete reconfiguration properties helps in saving valuable floor space thereby answering the "Space Crunch " issue through design.

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.In the opinion of Dr. Ing. Walter Hasse, of the Institut fur Leichtbau Entwerfen und Konstruieren (Institute for Lightweightstructures and conceptual design) or ILEK at the University of Stuttgart Germany , material research needs to go hand in hand with design development showing energy effeciency and durability. It would be difficult to convince anyone to accept these proposals if the membranes need to be replaced every 5 years [5].

Juxtaposing fabric membrane systems with conventional building systems has great potential for development, however one of the biggest challenges that such ideas face is the availability of materials. There is scope for development of indigenous intelligent fabric membrane suitable for the internal climate within Indian apartment houses. Issues such as acoustics, fire rating, energy efficiency , transparency and elasticity must be resolved to the satisfaction of the authorities issuing construction approvals and home owners evaluating the long term advantages/disadvantages of such tensile fabric space dividers replacing the conventional brick wall design.

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