International Journal of Scientific & Engineering Research, Volume 11, Issue 2, February-2020
ISSN 2229-5518

Knitted Fabric as a Formwork & Reinforcement for Shell structures

Ar. Harshada Vazarkar , Ar. Deva Prasad

Abstract— As per Frei Otto 'construction is the basis of all architecture. Every minimal construction is a natural construction. However it may in general be assumed that structures which are more economical in either use of material and energy were more likely than others to survive in the course of evolution'.

Concrete shells were used extensively in the mid-twentieth century, but were used less as the complexity of the formwork required, using rigid materials became increasingly more costly .

Fabric formwork can produce similarly efficient shapes with much greater ease. The use of fabric as formwork for doubly curved shells could take advantage of the great inherent strength of shells and their comparative lightness.

Efficient shells carry load primarily through membrane forces . The absence of large bending forces keeps stresses low, reducing material demand. A shell's structural performance is therefore dictated by its form, particularly its curvature. The fluidity of concrete allows these required geometries to be realised. Eventually in shell structures important aspect is surface and surface curvature. Knitted fabric is a better option of fabric formwork as they can be designed and constructed with appropriate selection of stiches,patterns,fibre type, loop count. Flexibilility , strength, in knitted fabric can vary by manipulating knitting patterns by 4 different variables at microlevel . Knitting has self organising behaviour, all the resultant surfaces created are minimal surfaces. Every form has inherent natural surface pattern .

Research questions

How can a suitable knitting pattern which will provide exact formwork to acheive that curvature which is naturally evolved.

How a knitting pattern evolve in to form naturally and not applying pattern forcefully on any form ?

How can knitting pattern be used to create flexible form work to create shell structure ? especially doubly curved surfaces

Aim

The thesis aims at exploring and studying knitted fabric as stay in place formwork and reiforcement with diffferent knitting patterns which will help to create curvature naturally .

Index Terms—knitting patterns , shell structure, formwork, nonlinear surfaces, doubly curved surfaces, lightweight structure ,self supporting forms.

1 Introduction

Shells are well suited to domes and roof structures where height and free geometry are relatively unrestricted.
The strength comes from form, not mass. Hypar roofs gain its strength from double curvature that allows hypar structures the great resistance to bending. The doubly curved shape strikes a balance between tension and compression forces, allowing hypar structure to remain thin, yet surprisingly strong.

Shells Structure found in Nature

In Nature we see how a simple egg can acheive extraordinary efficiency using same principle.

Monocoques, where skin is the structure, visibly illustrate this and the aim was to extend this economy to other parameters of material, machine, infrastructure, energy, time by creating self structuring forms. The technique of knitting uses the potential of the continuous mono-materials of the fibre realm and presents the possibility to materialize unified structures act as structural reinforcement & integrated formwork , as against other textile techniques which require extensive machine setup and formwork.

Fig. 01 Egg (monocoque skin itself structure)

Fig. 03 Seashell

Fig. 02 Coconut shells

International Journal of Scientific & Engineering Research, Volume 11, Issue 2, February-2020
ISSN 2229-5518

SHELLS STRUCTURE - MAN MADE

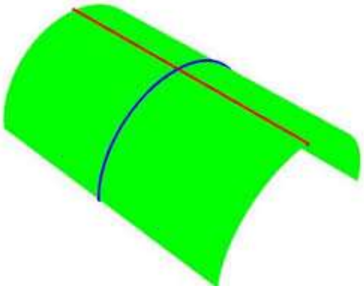


Fig. 01 Vault

Fig. 02 Dome

Fig. 03 A Coffee Mug

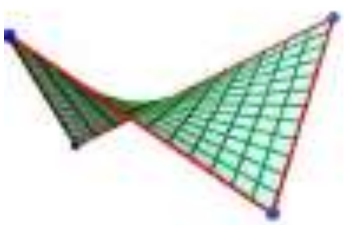


Fig. 04 Hyperbolic Paraboloid

Fig. 05 Metal cans

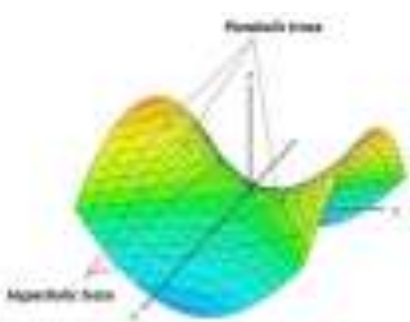


Fig. 06 Hyperbolic Paraboloid :saddle

2 METHODOLOGY

1. • Study /Data Collection
2. • Methodology
3. • Presedence Textile as Formwork
4. • Observation /Analysis
5. • Parameters extraction
6. • Material exploration
7. • Knitted Patterns Types & generation
8. • Knitted Patterns analysis
9. • Rhino model +GH
   • Digital curvature analysis Hyperbolic Paraboloid
10. • Fabrication
    • Hyperbolic Paraboloid-1,
    • Hyperbolic Paraboloid-2 stay in place formwork of wool knitted fabric
11. • Rhino model +GH Prototype -3
    • Triply periodic surface
12. • Digital curvature analysis
    • Hyperbolic Paraboloid
13. • Physical Paper model Prototype -3
    • Triply periodic surface
14. • Physical model Bamboo Prototype -3
    • to understand boundry condition
    • structural supporting ribs
    • Triply periodic surface
15. • Fabrication Prototype -3
    • Triply periodic surface module stay in place formwork of wool knitted fabric
16. • Architectural Application

International Journal of Scientific & Engineering Research, Volume 11, Issue 2, February-2020
ISSN 2229-5518

3 Precedence Textile as Formwork

Ever since the industrial revolution, techniques for manipulation of fibers into textiles & textile have been revolutionary, so much so that today they are used for various high performance purposes like aircraft building. All these techniques are about material placement, to differentiate surface pattern and form geometries. They are in close congruence to architecture but in absence of a design and visualization tool, their potential has not been fully harnessed.

The deep rooted relevance of textiles in architecture is apparent in the theoretical works of the 19th century German architect Gottfried Semper, who deduced textiles to be the first technical art (Semper, 1989). Lars Spuybroek further envisioned soft elements becoming rigid through collaboration using various textile techniques.

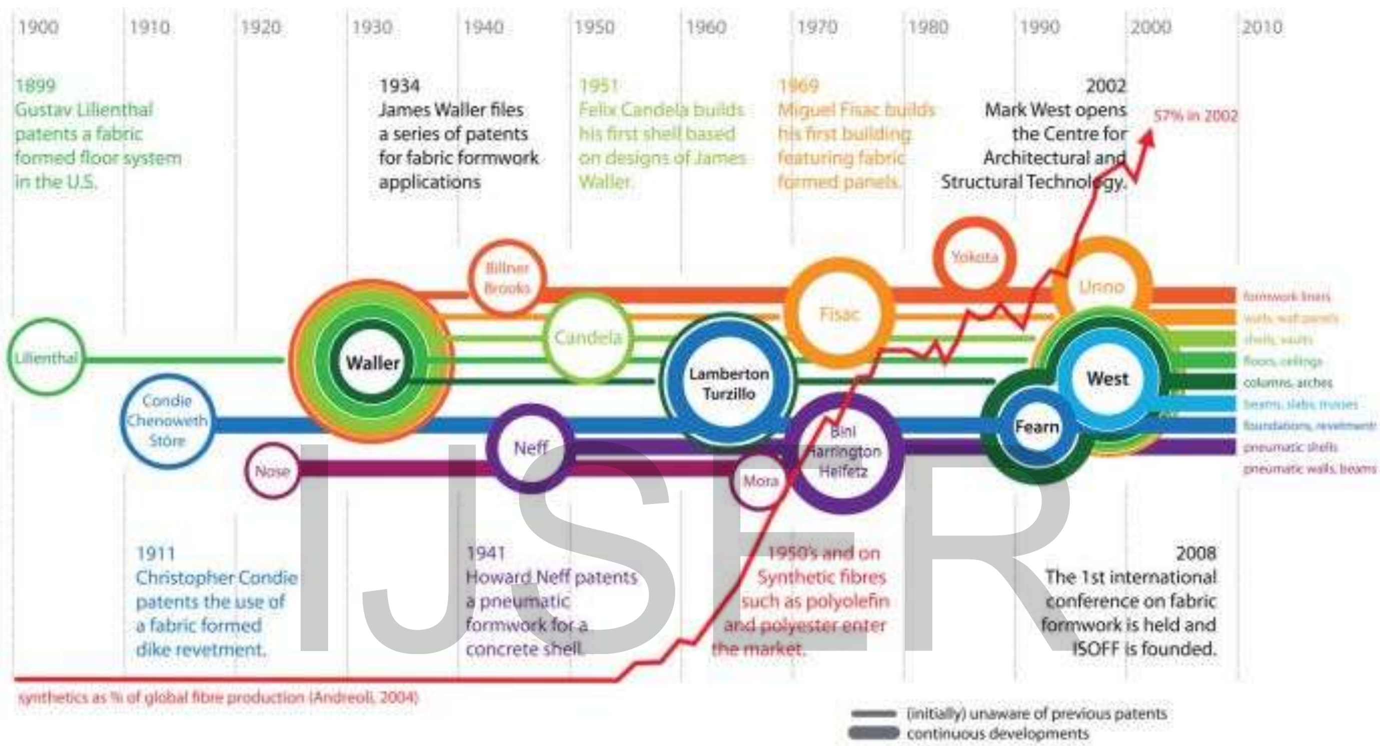


Fig. 30. Chronological diagram of fabric formwork and fabric formwork liners. *Andreoli, 2004 [53]

Fig.08

3.1 Inspirational Case Studies

Concrete shells by Diederik Veenendaal' Philippe Block Block Research Group 2014

First prototype anticlastic using a hybrid cable-net & fabric formwork shells constructed by West,Pronketal,Tysmans,Pedreschi and Lee, Seracino et al. Veenendaal & Block.Their main contribution is a complete computational design workflow for the prototype shell & its required formwork. The first fabric was a PP geotextile, Propex 60-7041, with a tensile strength of 42 kN/m, and a 5.2 m roll width.The second fabric was a PP Proserve F0899 with a tensile strength of 54–60 kN/m, and 3.6 m roll width, used for underwater fabric formworks.

Fig.09 Cutting patterns, cut along cable lines, stiched again used for the fabric shuttering and the textile reinforcement of the prototype.

International Journal of Scientific & Engineering Research, Volume 11, Issue 2, February-2020
ISSN 2229-5518

Fig10 Concrete shells by Diederik Veenendaal' Philippe Block Block Research Group 2014

The NEST HiLo 2017

This prototype is the most recent example of a structure built with the carbon-fibre reinforced concrete on a pre-stressed cable-net falsework with a tailored textile shuttering. The optimised & actively controlled formwork system allowed for the creation of a geometrically complex & highly efficient structure. Advantages systems can allow for an efficient construction without the traditional material & labour costs, & can be challenging in terms of layered integration, predicting & controlling the geometry while pouring the concrete,

Knit crete bridge prototype 2017

Mariana Popescu, Lex Reiter, Andrew Liew, Tom Van Mele, Robert J. Flatt, Philippe Block

Novel system for building bespoke doubly curved concrete geometries custom-made hybrid pre-stressed 3D knitted textile, bending-active rods to act as waste-free,stay-in-place,self-supporting formwork Advantages significant waste reduction, increased site accessibility, reduced labour and fewer or lighter foundations. lightweight, easy to manufacture, highly transportable & quick to assemble.

Act as structural reinforcement & integrated formwork,

Knit Candela,Zaha Hadid Architects & ETH Zurich , Mexico

This creates a waffle shell without the need for a complex formwork.Knitting minimises the need for cutting patterns to create spatial surfaces. Allows for directional variation of material properties, and simplifies the integration of channels and openings, according to the research.

The formwork was knitted in Switzerland and transported to Mexico, in suitcases. Knit crete is a material-saving, labour-reducing and cost-effective formwork system for casting of curved geometries in concrete.

Fig.11 Visualization of the preliminary design for NEST, with HiLo constructed at the top corner. EMPA and Gramazio & Kohler.

Fig.12 Knit crete bridge Hybrid Formwork

Fig. 13 knitted fabric, a technology KnitCrete, which was covered with 5 tonnes (5.5 US tons) of concrete.

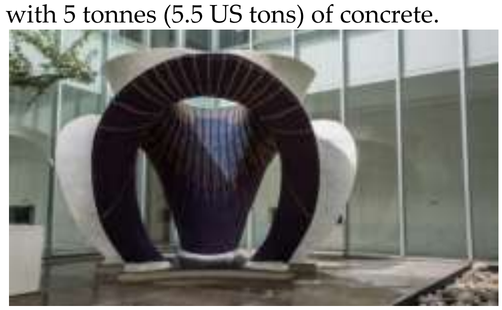


Fig. 14 The total weight - 55 kg (121 lbs) size -50 m2 (538 ft2) in. lightweight shuttering.

International Journal of Scientific & Engineering Research, Volume 11, Issue 2, February-2020
ISSN 2229-5518

Fig. 15 Plan KnitCandela is a thin, doubly-curved concrete shell

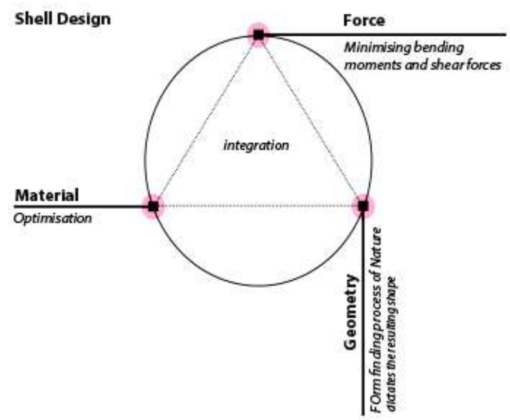
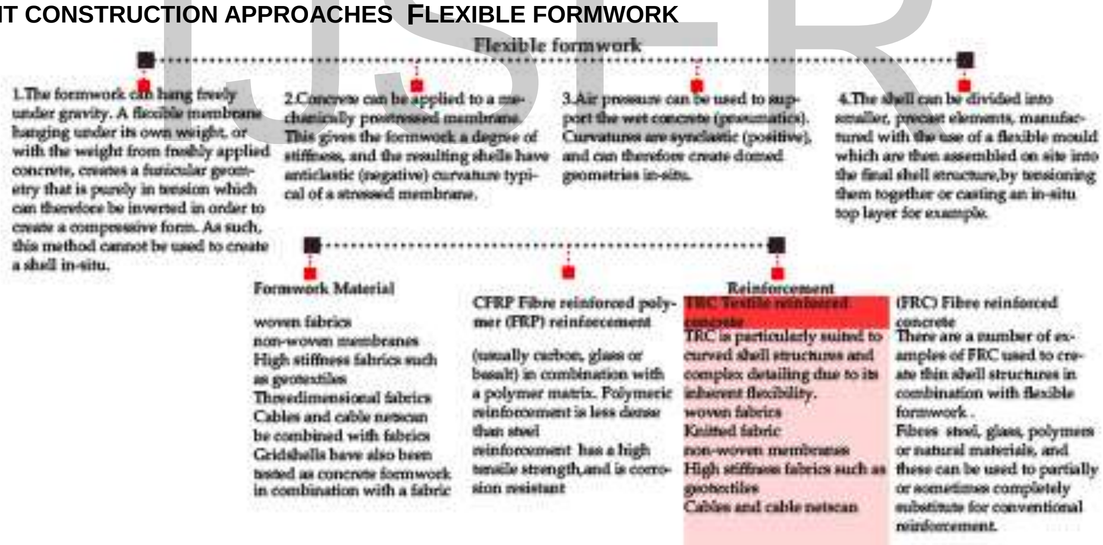


Fig. 16

4 Observation /Analysis

Shell and membrane structures are constrained by the laws of physics. For the integration and layering of formwork systems, knitted textiles offer several advantages, such as good draping qualities, direct 3D shaping, simple integration of openings, the possibility to locally customise material properties. significantly reduce the amount of time, labour, and material involved in the production of complex concrete geometries. Furthermore, knitting can be used to realise non-developable surfaces without patterning and discretisation schemes, and thus almost entirely without seams. A stay-in-place hybrid formwork system Combining the strengths of some of the previous work discussed above above, this paper exploresa novel, flexible, stay-in-place,hybrid formwork system.

4 .1 Different construction approaches Flexible formwork



4.2 Comparison between Knitting & Weaving

Weaved fabric -Weaved fabric needs cutting of pattern and again stitching to get desired shape.

Knitted fabric - whereas in knitted fabric desired shape can be achieved by manipulation of stitches and stitching pattern and it get self organised.

International Journal of Scientific & Engineering Research, Volume 11, Issue 2, February-2020
ISSN 2229-5518

Properties	Knitting	Weaving
Process	"Interlooping"	"Interlaced"
Number of yarns	• One set of yarn interlooped with itself.Require good quality of yarn.	• Two sets of yarns interlaced at right angles.Can use lower quality yarn.
Equipment Required	• Needles - could be hand knitting or machine knitting.	• A loom-could be a handloom or automatic loom.
Fabrics are	• knitted fabric can be stretched in any direction,Wrinkle resistant, drape very easily , are usually softer, more breathable than woven fabrics.	• Woven fabrics, on the other hand, will only stretch diagonally Firm, stable and maintain their stiffess.
Care & maintenance	• No ironing required but while drying have to be dried flat on ground.	• Need proper washing and ironing before re-use.
Designs	• Are created by using various knitting yarns and by changing stitches or colour	• Can be created by using different yarns (types and colours) and also weaves.
Cost	• Cheaper	• Expensive
Strength	• More strength	• Lesser strength

Fig. 17 Pattern- Textured -Triangle pattern Pearl stitch & stockinett stitch

4.3 Comparison between Knitting & Weaving

Rectangular Hand knitted Fabric

Pattern -P-001

Material -Wool

Size = 300 mm X 300 mm

Weight = 134 gm

Material cost = 100 Rs

Knitting cost = 160 Rs /100 gm

Streching Possibility

Weight applied = 5 kg

Warp dir = 50%

Weft dir = 29%

diagonal = 52%

Rectangular Hand Weaved Fabric

Material -Wool

Size = 300 mm X 300 mm

Weight = 80gm

Material cost = 100 Rs

Knitting cost = 160 Rs /100 gm

Streching Possibility

Weight applied = 5 kg

Warp dir = 8%

Weft dir = 18.5%

diagonal = 26%

Fig. 18 Pattern- Plain weave

5 PARAMETERS EXTRACTION IN KNITTED FABRIC

Produce by manipulating following variables. A great deal of variety could be possible.

- Fibre content
- Yarn Type
- Stich type
- Knit Pattern
- Stich count / stitch density

WHY I SELECTED KNITTED FABRIC AS FORMWORK AND REINFORCEMENT MATERIAL .

- Knitted material Fabric can be stretched in all direction very easily.
- Thickness of fabric can be acheived without changing thickness of yarn in the same fabric.
- Self organising behaviour.
- Great variety of structure bespoke geometry possible.
- Manipulation of variables in knitted fabric patterns at microlevel
- Fibre content can vary.
- It can get embeded in cement concrete mixture.

6 MATERIAL EXPLORATION & INSTRUMENTS

What is Knitting ?

Knitting is making of cloth with the help of needles to create a series of interlocking loops with a single yarn. There is only one ball of knitting yarn and with the help of two needles, loops are made and when one row of loops are made, the next row is formed by interlooping with the previous loops.

Fig. 19 Jig 650 X 650 X 650

Fig. 20 Hand knitting

Fig. 21 Circular stencil knitting

Fig. 22 Rectangular stencil knitting

Fig. 23 Croche Needle

Fig. 24 Semiautomatic knitting machine

Fig. 25 knitting punch card

Fig. 26 Jutesutali

Fig. 27 Macram Cotton rope

Fig. 28 Jute Craft twine

Fig. 29 Packing plastic thread

Fig. 30 Wool Yarn

Fig. 31 Leather Yarn

Fig. 32

Fig. 33 Macram Nylon cord

Fig. 34 Stretch rectangular knitted Þ ÏÌÕ cloth gives ÊÜÙÝÌ when streched strategic points.

International Journal of Scientific & Engineering Research, Volume 11, Issue 2, February-2020
ISSN 2229-5518

7 TYPES OF KNITTING PATTERNS & GENERATION

EXPLORING KNITTING PATTERN AND EVOLVED FORM

Knitted with Jute Rope

A cylinder is a closed solid that has two parallel (usually circular) bases connected by a curved surface.

Weft Knitting
Pattern - P-009
Stockinet stich
Material -Jute Rope
Size -Dia =100 mm
Ht =80mm
Weight = 125 gm
max .stretched in warp direction

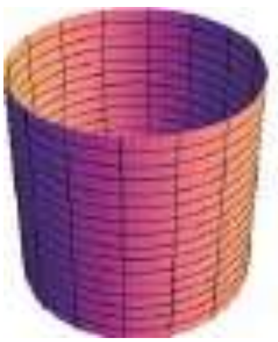


Fig.35

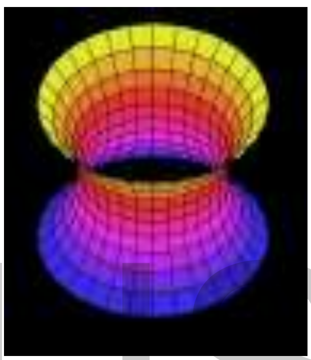


Fig.36

A catenoid is a type of surface, arising by rotating a catenary curve about an axis. It is a minimal surface.

Mobius Curve

we obtain a Möbius strip by turning regularly a segment of a line with constant length around a circle with a half-twist or, more generally, an odd number of half-twits;
Material- Jute Rope
Pattern -Natural Form evolved out of stockineet stich pattern on circular stencil.
stockineet s Natural curling of fabric
because of type of knitting pattern stich pattern
dia 4″ (100mm)
ht 5″ (125 mm)

Fig.37

Fig.38

Natural Form evolved out of stockineet stich pattern on circular stencil.

Fig.39

Material- Jute Rope
Pattern - stockineet stich pattern
Size -dia =4″ 100mm,
ht=5″125mm

Fig.40

International Journal of Scientific & Engineering Research, Volume 11, Issue 2, February-2020
ISSN 2229-5518

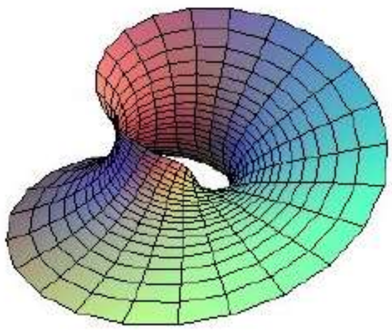


Fig. 41 Mobius Surface

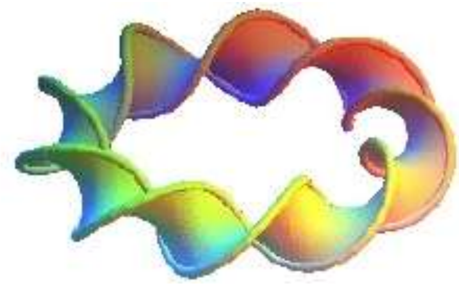


Fig. 42 right-handed strip- 9 half twist

7.1 Testing of knitted cloth

Material -Wool
Streching Possibility
Weight applied = 5 kg
Warp dir = 44%
Weft dir = 29 %
diagonal = 51%
Twisted rectangular knitted cloth gives curve when strerched strategic points.
Stretch rectangular knitted cloth gives curve when strerched strategic points.

Fig.42

Fig.43

7.2 TYPES OF KNITTING PATTERNS

PATTERN - P-001

Rectangular Hand knitted Fabric

Pattern -P-001

Material -Wool
Size = 300 mm X 300 mm
Weight = 134 gm
Material cost = 100 Rs
Knitting cost = 160 Rs /100 gm
Streching Possibility
Weight applied = 5 kg
Warp dir = 50%
Weft dir = 29%
diagonal = 52%

Fig. 44 Pattern- Textured -Triangle pattern
Pearl stitch & stockinett stitch

International Journal of Scientific & Engineering Research, Volume 11, Issue 2, February-2020
ISSN 2229-5518

PATTERN - P-002

Stitch Type - Purl stitch (Garter stitch)

Pattern -P-002

Material -Wool

Yarn -6 Ply

Size = 300 mm X 300 mm

Weight = 75 gm

Material cost = 100 Rs

Knitting cost = 160 Rs /100 gm

Streching Possibility

Weight applied = 5 kg

Warp dir = 60%

Weft dir = 35%

diagonal = 65%

Fig. 47

Fig. 45

Fig. 48

Fig. 46

- Stretchy
- Dense
- Good strength
- Look exactly same from both side
- Lies flat

International Journal of Scientific & Engineering Research, Volume 11, Issue 2, February-2020
ISSN 2229-5518

PATTERN -00 3

Stitch Type - Rib stitch 1x1

Material -Wool

Yarn -6 Ply

Size = 300 mm X 300mm

Weight = 70gm

Material cost = Rs

Knitting cost = 100 Rs

Streching Possibility

Weight applied = 5 kg

Warp dir = 75 %

Weft dir = 45 %

diagonal = 80 %

Fig. 50

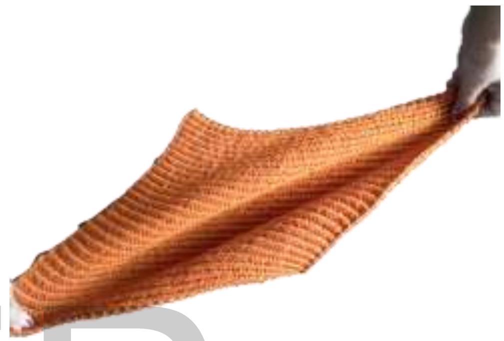


Fig. 51

Fig. 49

- Super Stretchy
- Dense
- Good strength
- Look exactly same from both side

Fig. 52

International Journal of Scientific & Engineering Research, Volume 11, Issue 2, February-2020
ISSN 2229-5518

PATTERN -00 4
Rectangular knitted fabric

Stitch Type - Simple stockinett stitch

Material -Wool

Yarn -3 Ply

Pattern -Plain Knit stitch

Size = 300 mm X 300 mm

Streching Possibility

Weight applied = 5 kg

Warp dir = 20 %

Weft dir = 40 %

diagonal = 45 %

Fig. 53 Pattern Simple stockinett stitch

- Low stretch
- Dense
- Good strength
- Different look on both side
- Form curl on edges

PATTERN -P-005
Rectangular knitted fabric

Stitch Type - Rib stich pattern

Textured Pattern -right side

Material -Wool

Yarn -4 Ply

Size = 150 mm X 300mm

Weight = gm

Material cost = 50Rs /sqft

Knitting cost =50 Rs/sqft

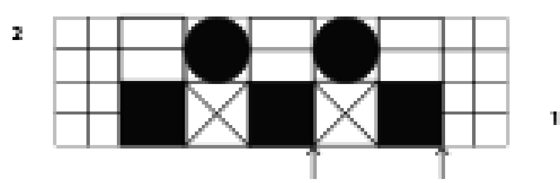
Pattern -Stockinet stich pattern

Fig. 54 Textured Pattern -right side

Pattern -Rib stich pattern & Stockinet stich pattern

Fig. 55 Textured Pattern -left side

Coding



International Journal of Scientific & Engineering Research, Volume 11, Issue 2, February-2020
ISSN 2229-5518

PATTERN -P-006A
Rectangular knitted fabric
P-006A Basket weave

Stitch Type - Purl stich & Simple stockinett stitch

Material -Wool

Yarn -4 Ply

Size = 75 mm X 200mm

Weight = gm

Material cost = Rs

Knitting cost = 50 Rs

Streching Possibility

Weight applied = 5 kg

Warp dir = 40 %

Weft dir = 35 %

diagonal = 50 %

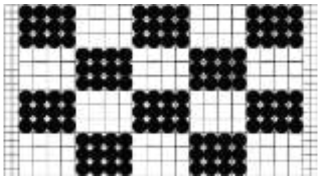


Fig. 56 Coding

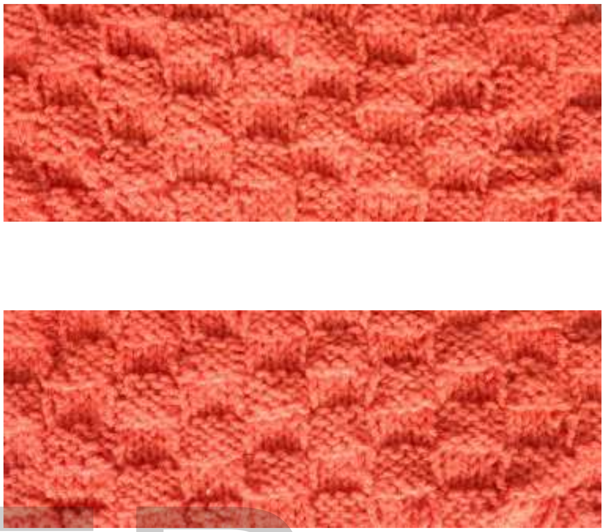


Fig. 57 Front side

PATTERN -P-006B
Rectangular knitted fabric
Stitch Type - Purl stich & Simple stockinett stitch

Material -Wool

Yarn -4 Ply

Size = 75 mm X 200mm

Weight = gm

Material cost = Rs

Knitting cost = 50 Rs/sqft

Streching Possibility

Weight applied = 5 kg

Warp dir = 45 %

Weft dir = 30 %

diagonal = 50 %

fg. 58 Front side

Fig. 59 Back side

International Journal of Scientific & Engineering Research, Volume 11, Issue 2, February-2020
ISSN 2229-5518

PATTERN -P-007B

Material -Wool

Yarn -4 Ply

Size = 150 mm X 300mm

Weight = gm

Material cost = 50Rs

Knitting cost = 50 Rs

Streching Possibility

Weight applied = 5 kg

Warp dir = 50 %

Weft dir = 45 %

diagonal = 50 %

Fig. 60 Front side

Fig. 61 Back side

Fig. 63 Punch card

PATTERN -P-008

Material -Wool

Yarn -2Ply

Size = 280mm X 180 mm

Weight = gm

Material cost = 30 Rs

knitting cost = 30 Rs

Streching Possibility

Weight applied = 5 kg

Warp dir = 53 %

Weft dir = 40 %

diagonal = 50 %

Fig. 62

International Journal of Scientific & Engineering Research, Volume 11, Issue 2, February-2020
ISSN 2229-5518

8 Catlogue of Knitting Patterns & Analysis

Pattern Number	Pattern		Pattern + stitch type	Yarn material	Yarn thickness	Stitch density	Stretchability
P-001		Handmade	**Pattern** Trangle pattern **stitch type** Stockinett stitch + Purl stitch	Wool	8 ply	49 sq inch	Warp dir = 50% Weft dir = 30% diagonal = 52%
P-002		Handmade	**Pattern** Garter pattern **stitch type** Purl stitch	Wool	6 ply	36 sq inch	Warp dir = 60% Weft dir = 35% diagonal = 65%
P-003		Handmade	**Pattern** Rib 1x1 **stitch type** Stockinett stitch	Wool	6 ply	36 sq inch	Warp dir = 75% Weft dir = 45% diagonal = 80%
P-004		Machine made	**Pattern** Stockinett stitch **stitch type** Stockinett stitch	Wool	4 ply	36 sq inch	Warp dir = 20% Weft dir = 40% diagonal = 45%
Pattern Number	**Pattern**		**Pattern + stitch type**	**Yarn material**	**Yarn thickness**	**Stitch density**	**Stretchability**
P-005		Handmade	**Pattern type** Ribbed **stitch type** Stockinett stitch + Purl stitch	Wool	4 ply	144 sq inch	
P-006		Handmade	**Pattern type** Basket weave **stitch type** Stockinett stitch + Purl stitch	Wool	4 ply	25 sq inch	Warp dir = 45% Weft dir = 30% diagonal = 50%
P-007		Handmade	**Pattern type** **stitch type** Back loop+ half double stitch	Wool	4 ply	49 sq inch	Warp dir = 40% Weft dir = 45% diagonal = 50%
P-008		Machine made	**Pattern type** **Punch card**	Wool	2 ply	100 sq inch	Warp dir = 20% Weft dir = 50% diagonal = 54%

International Journal of Scientific & Engineering Research, Volume 11, Issue 2, February-2020
ISSN 2229-5518

P-009		Hand made	Pattern type Stockinett stitch	Jute rope	8 ply	9 sq inch	Warp dir = 20% Weft dir = 40% diagonal = 45%

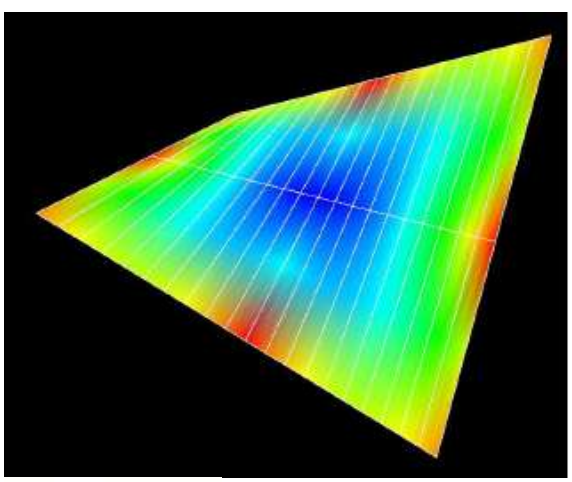
FROM ABOVE TABLE HIGHLIGHTED PATTERNS WERE SELECTED FOR FABRICATING PROTOTYPE.

9 HYPERBOLIC PARABLOID PROTOTYPE -1

Hyperbolic Paraboloid in hand knitted cloth 300x300 mm Rise 150mm

Fig.64 View of Hyperbolic Paraboloid structure in Rhino

10 Curvature Analysis in Rhino



Curvature analysis
Min Radius
Auto range

Fig.65

Zero Gaussian curvature
positive Gaussian curvature
Negative Gaussian curvature

9.2 Mesh formation

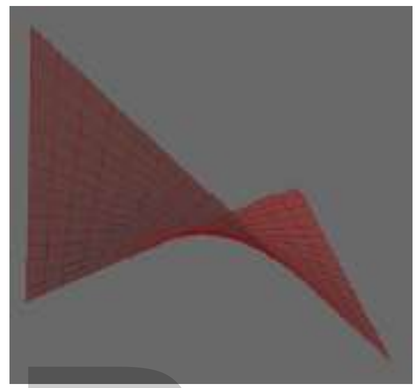


Fig.66 Hyperbolic Paraboloid surface in Rhino

9.3 Stress Analysis -Karamba

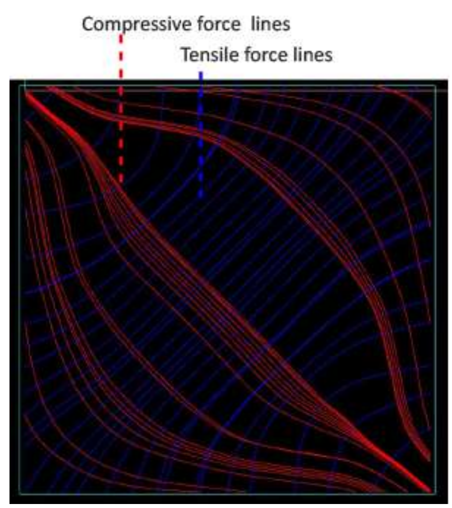


Fig.67 In the images below, red is assigned to a positive value of Gaussian curvature, green is assigned to zero Gaussian curvature, and blue to a negative value of Gaussian curvature.

International Journal of Scientific & Engineering Research, Volume 11, Issue 2, February-2020
ISSN 2229-5518

10 PROTOTYPE -1 FABRICATION

Hyperbolic Paraboloid in hand knitted fabric Size - 300 mm x 300mm

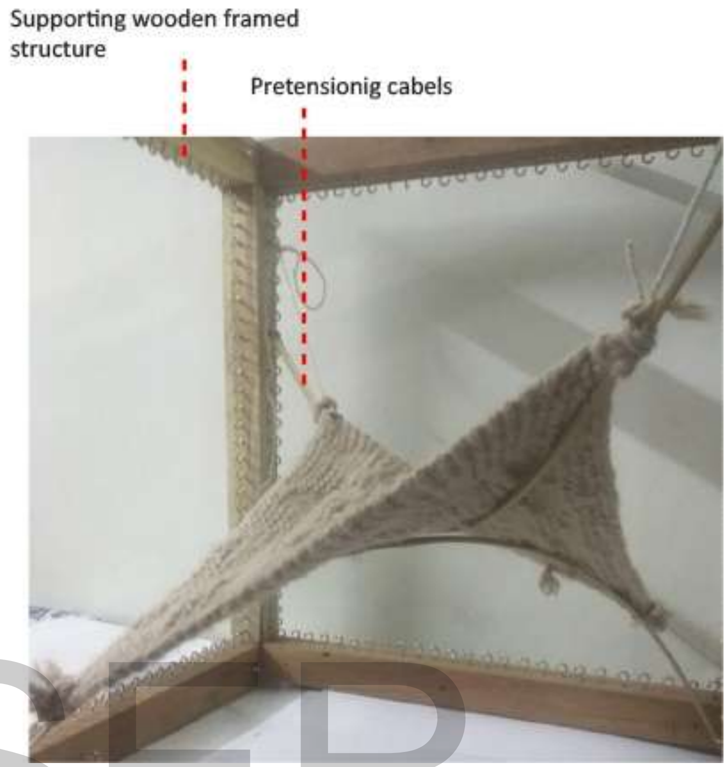


Fig. 68 Plan View Prestressed knitted cloth as stay in place formwork **Fig.69** View Prestressed knitted cloth as stay in place formwork stay in place formwork

Knitted fabric Pattern -P001, Plastic cables used as supporting ribs .

Original fabric size 300x300 mm ,After casting size ,470x550 mmx150 mm rise

Fig. 70 Applied layer of cement Paster & the layer of cement sand 1:4 mortar layer by layer . **Fig. 71** Final Prototype

International Journal of Scientific & Engineering Research, Volume 11, Issue 2, February-2020
ISSN 2229-5518

10.1 PROTOTYPE - 2 FABRICATION

Hyperbolic Paraboloid -2 in hand knitted fabric

Knitted fabric Pattern - P003 ,Plastic cables used as supporting ribs .

Original fabric size 300x300 mmx150 mm.

After casting size

350x450 mmx144 mm rise

Fig. 72 Plan View Prestressed knitted cloth as stay in place formwork

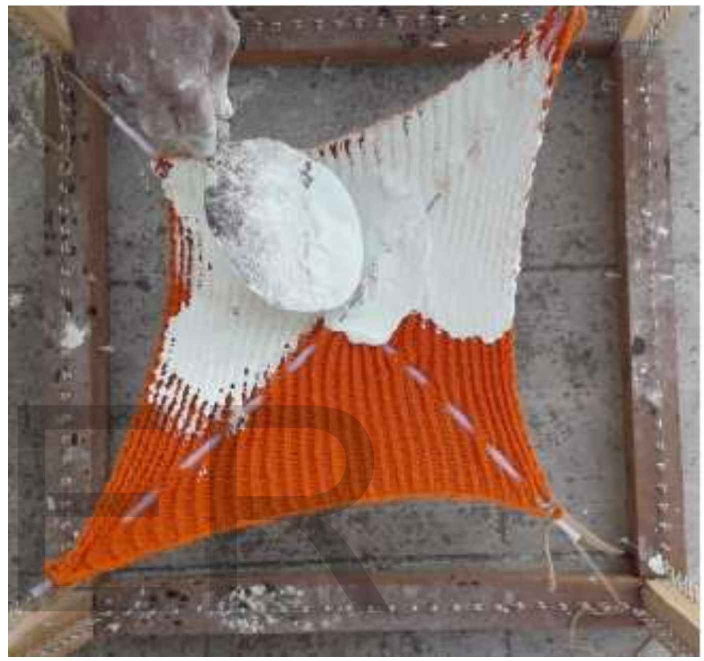


Fig. 73 Top View Applying cement paster

Prestressed knitted cloth as stay in place formwork

Fig. 74 Top View After applying cement sand morter

Fig. 75 Final Prototype

International Journal of Scientific & Engineering Research, Volume 11, Issue 2, February-2020
ISSN 2229-5518

11 PROTOTYPE - 3 TRIPLY PERIODIC GEOMETRY

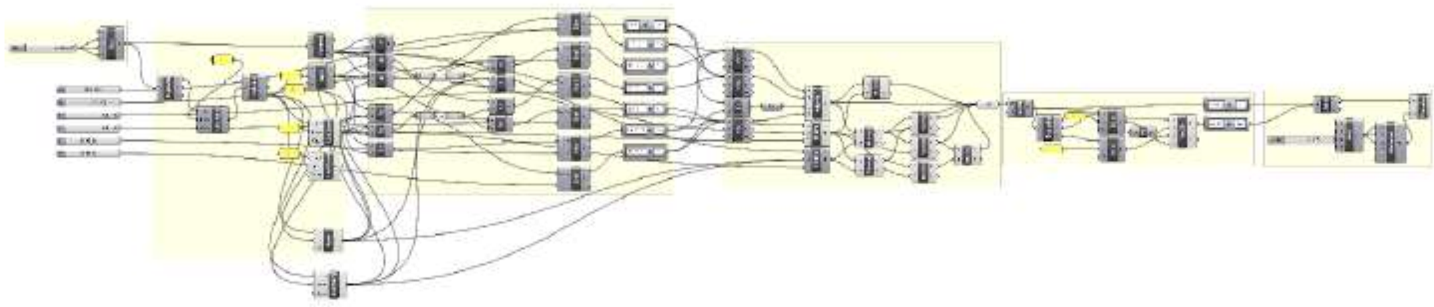


Fig. 76 Grasshopper Definition of Triply Periodic surface geometry

Prototype in MS bars 450x450x450 mm

knittpatterns and with Material -Wool

Why selected this geometry ?

- Challenging
- Surface grows in all directions.
- This module can be replicated, mirrored and copied rotated .
- Self supporting Form .
- By connecting these modules continuous spaces can be formed vertically and horizontally.
- Interesting spaces can be created .
- They are minimal surfaces.

How and what mesh Triply periodic Surface have?

- Understanding Mesh pattern generated with Rhino and grasshoper Relating knitting pattern with mesh formed.

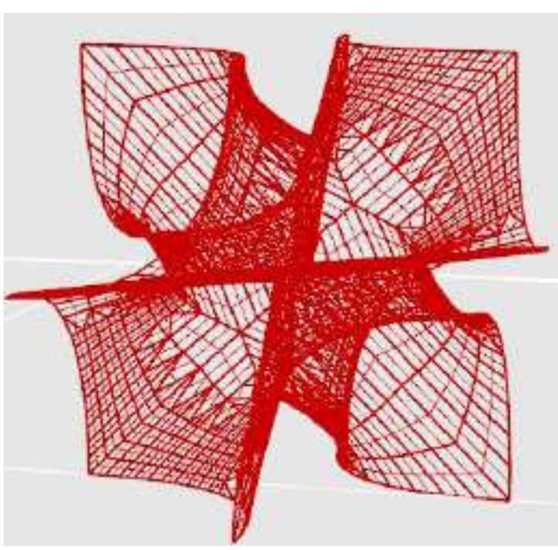


Fig. 77 B Mesh pattern generated with Rhino and grasshoper

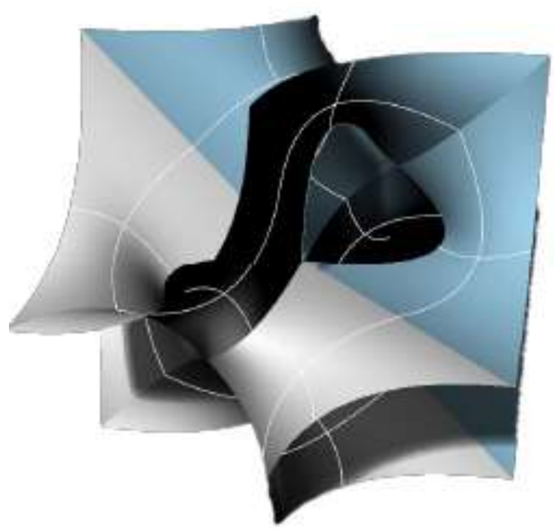


Fig. 78 Parametric 3d Rhino model

International Journal of Scientific & Engineering Research, Volume 11, Issue 2, February-2020
ISSN 2229-5518

12 TRIPLY PERIODIC GEOMETRY
Surface Curvature Analysis in Rhino

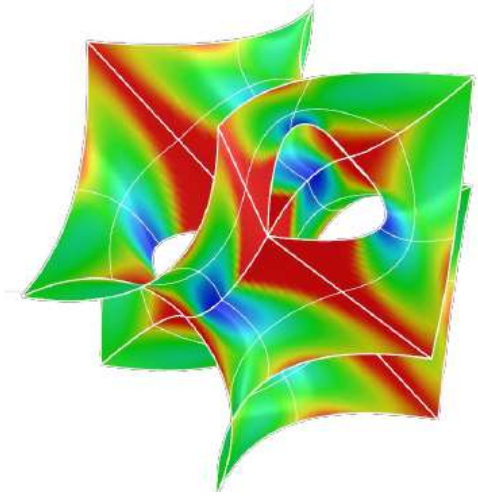


Fig. 79 Top view

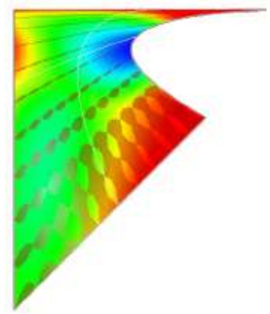
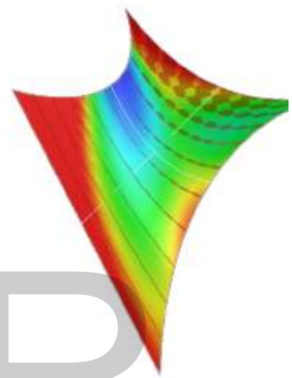


Fig. 80 Front view



13 PROTOTYPE (PAPER MODEL) 450X450X450 MM
Triply Periodic Surface

Paper model done to understand surfaces and curvature and to create machine knitted surface.

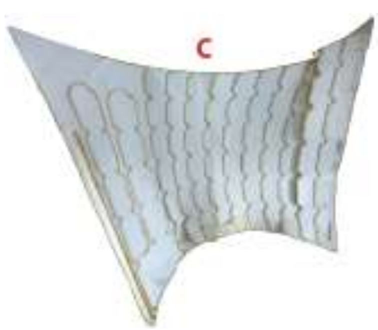


Fig. 81 Top view Single surface

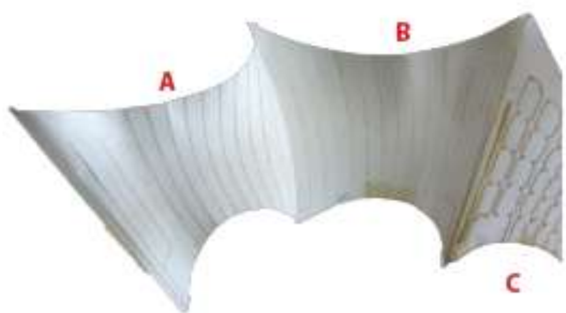


Fig.82 Front view joined two surfaces

Study model done to understand structure , Boundry conditions, supporting curved frames of Triply periodic surface,

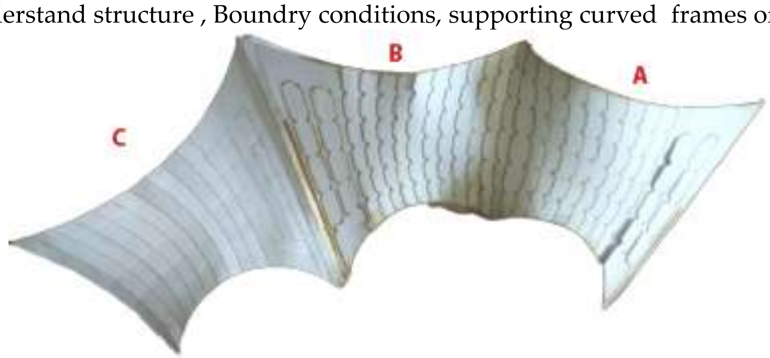


Fig. 83 Back side view joined two surfaces

International Journal of Scientific & Engineering Research, Volume 11, Issue 2, February-2020
ISSN 2229-5518

Fig. 84 Paper model & Rhino 3d model of Triply Periodic Surface in a square module.

TRIPLY PERIODIC GEOMETRY

Machine knitted fabric as a stay in place formwork 12 pieces of single surface stiched to form single surface

Fig. 86 Singel surface knitted in knitted in fabric

14 PROTOTYPE IN BAMBOO & FABRIC

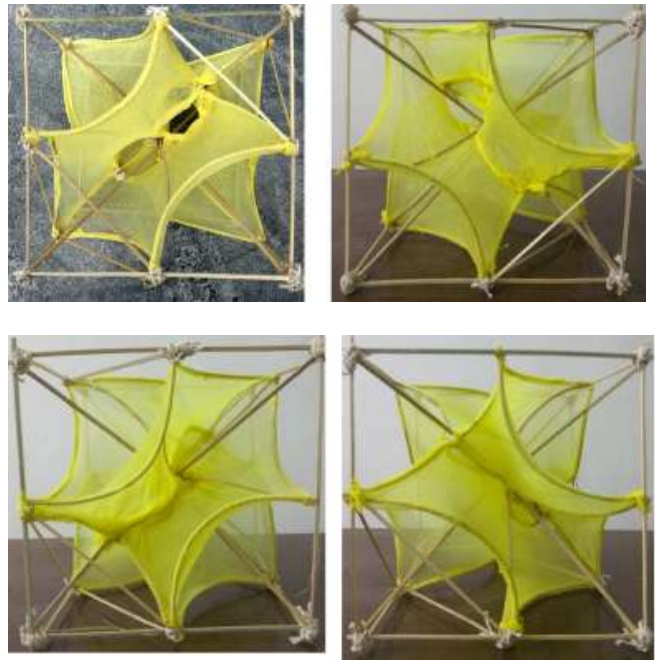


Fig. 85 Study model in fabric & Bamboo 300x300mm

Fig. 87 Unrolled surfaces of paper model and all knitted surfaces joined

International Journal of Scientific & Engineering Research, Volume 11, Issue 2, February-2020
ISSN 2229-5518

KNITTED FABRIC OF HALF SURFACE

HALF SURFACE OF TRIPLY PERIODIC GEOMETRY (knitted single surface)

Rib Stich 1x1

Material -Wool
Pattern - Rib stitch 1x1
Yarn -6 Ply
Size = 300 mm X 180mm
Weight = 70gm
Material cost = Rs
Knitting cost = 100 Rs
Streching Possibility
Weight applied = 5 kg
Warp dir = %
Weft dir = %
diagonal = %

Fig. 88 knitted single surface

Fig. 89 Streching weft wise

Fig. 90 Streching warp wise

Purl Stich

Material -Jute Rope
Yarn -6 Ply
Pattern - Purl stitch 1x1

Size = 300 mm X 180mm
Weight = 90gm
Material cost = Rs
Knitting cost = 100 Rs
Streching Possibility
Weight applied = 5 kg
Warp dir = %
Weft dir = %
diagonal = %

Fig. 91 knitted single surface

International Journal of Scientific & Engineering Research, Volume 11, Issue 2, February-2020
ISSN 2229-5518

Fig. 92 Streching warp wise

Fig. 93 Streching diagonal

Fig. 94 Streching weft wise

Purl Stich

Material -Wool

Pattern - Rib stitch 1x1

Yarn -6 Ply

Size = 300 mm X 180mm

Weight = 45gm

Material cost = Rs

Knitting cost = 100 Rs

Streching Possibility

Weight applied = 5 kg

Warp dir = %

Weft dir = %

diagonal = %

Fig. 96

Fig.97 Streching diagonal

Fig. 95 knitted single surface

Fig. 98

International Journal of Scientific & Engineering Research, Volume 11, Issue 2, February-2020
ISSN 2229-5518

15 Triply Periodic Geometry - Prototype in MS Bars 450x450x450 mm

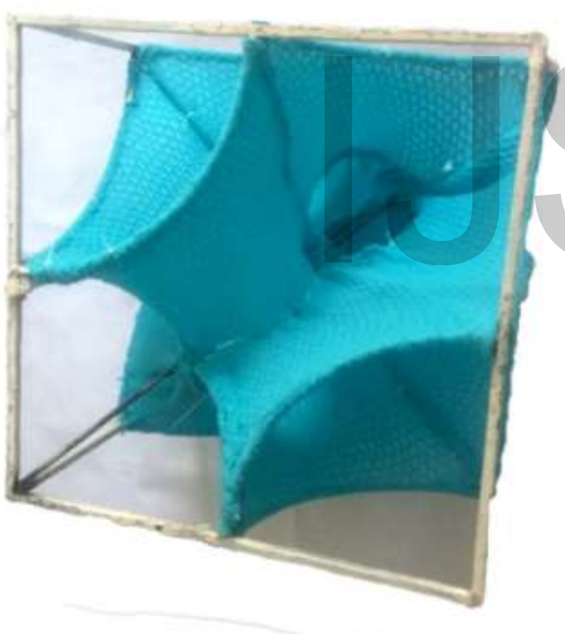
Concept

Here Triply periodic surface is used as a module that connect larger square modules .
Considering future expansion , phase wise those can be repeated vertivally and horizontally . These will help to form connection, continuity ,and can make spaces interesting , element of surprise and natural sky light and ventilation is possible.Some of them are fabricated in steel frame and fabric without casting in concrete will act as sculpures.

Prototype in MS Bars 450x450x450 mm

Knittpatterns and with Material -Wool

Knitting Pattern used -P-008
Supporting frame - MS Steel
Size -450X450X450 mm
Weight of fabric -240 gm



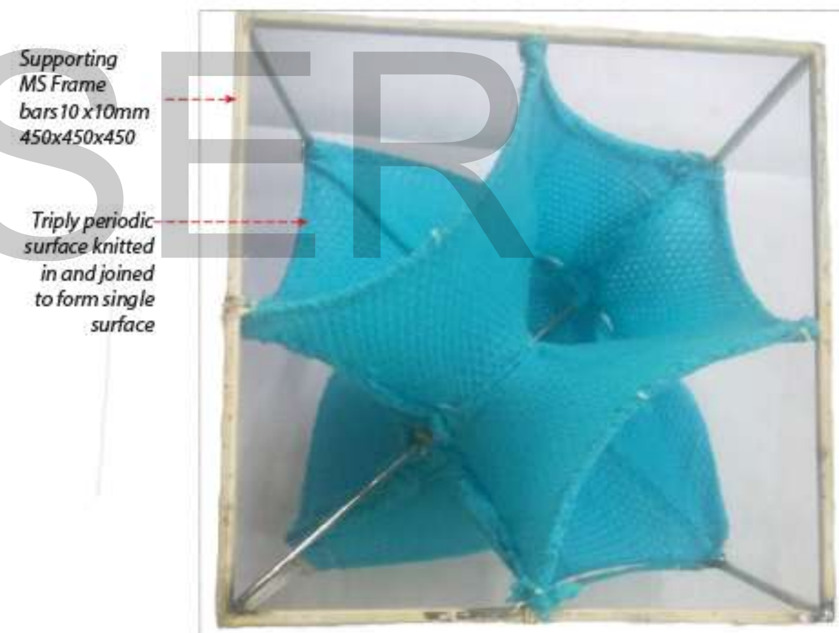


Fig. 99 A Prototype completed with Prestressed knitted cloth as stay in place formwork.

Fig.100 After tensioning, the flexible knitted fabric will be covered with thin layers of a high-strength cement paste until it is sufficiently stiff to be used as a self-supporting mould for traditional concrete casting

.

International Journal of Scientific & Engineering Research, Volume 11, Issue 2, February-2020
ISSN 2229-5518

16 Architectural Application
Proposed Textile Museum

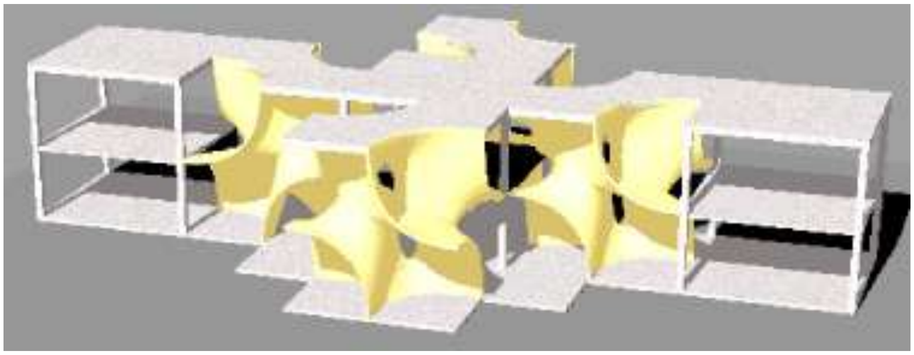


Fig. 101 View

Fig. 102 Schematic Elevation

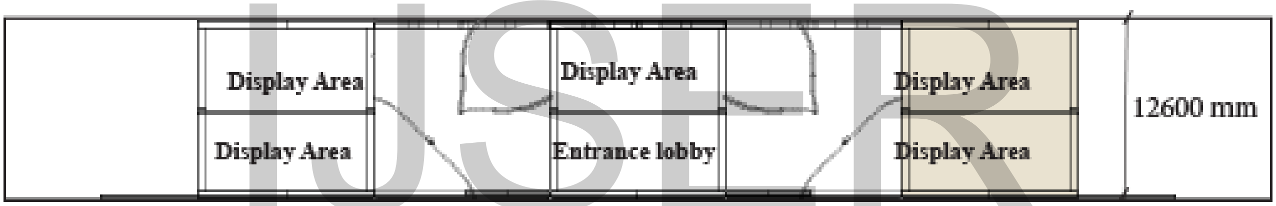


Fig. 103 Schematic Sectional Elevation

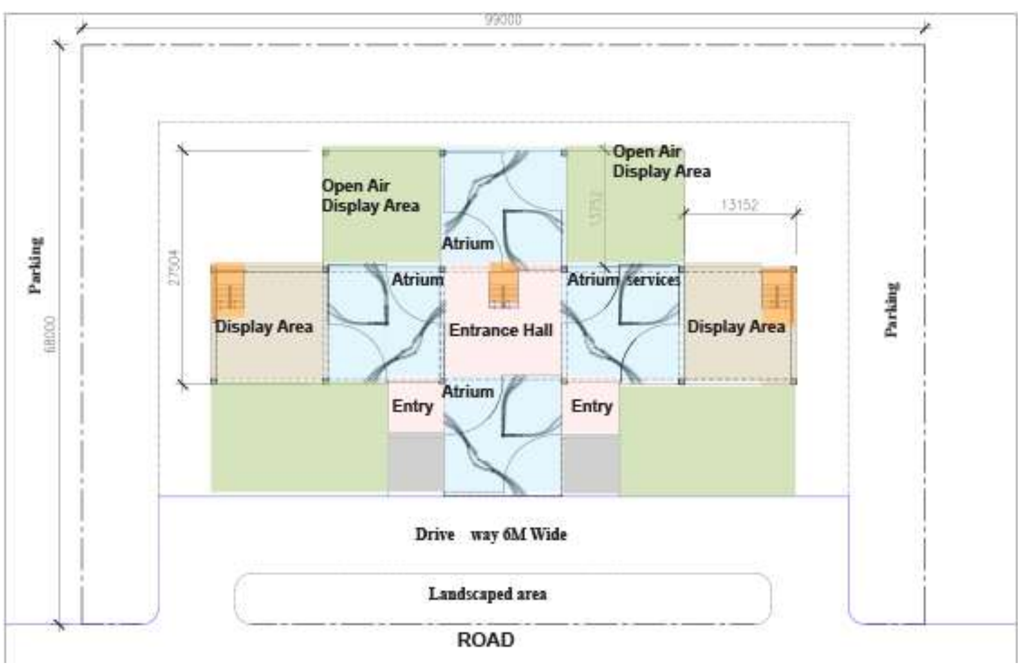


Fig. 104 Floor Plan

International Journal of Scientific & Engineering Research, Volume 11, Issue 2, February-2020
ISSN 2229-5518

CONCLUSION

The results presented in this thesis demonstrated the use of a bespoke knitted textile as a shape-giving formwork through a small-scale hyperbolic paraboloid (Fig.52,55)

A hyperbolic paraboloid is a doubly-curved surface that resembles the shape of a saddle, that is, it has a convex form along one axis, and a concave form on along the other. It is also a doubly-ruled surface, that is, every point on its surface lies on two straight lines across the surface.

The 3 rd prototype is Triply Periodic surface Fig.66 built to investigate the possibility of constructing handmade knitted fabric formwork in combination with bending-active elements and stiffened using cement paste and mortar.

Rather than derive their strength from mass, like many conventional roofs, thin shell roofs gain strength through their shape. Shell's structural performance is therefore defined by its form, particularly its curvature. The fluidity of concrete allows these required geometries to be realised. Eventually in shell structures important aspect is surface and surface curvature. Accuracy of curvature can be acheived by flexible formwork of knitted fabric because of its inherent self organising quality and control over fabric structure and hence knitting pattern.

Every form has inherent natural surface pattern if we understand that and provide suitable knitting pattern it will provide exact formwork to achieve that curvature.

Knitted fabric is a better option of fabric formwork as slab thickness of shell is very small ,less dead load is there and they can be designed and constructed with appropriate selection of stiches,patterns ,fibre type, loop count. Flexibilility , strength, in knitted fabric can vary by manipulating knitting patterns by 4 different variables at microlevel.

The system has several potential benefits over traditional approaches to concrete formwork, as it is easy to manufacture ,lightweight, highly transportable and quick to assemble. Additionally, the use of a knitted fabric offers extended advantages with respect to integrating features such as channels for guiding other structural elements and changing the surface texture, all in a single fabrication process. Furthermore, the stay-in-place knitted formwork used in this paper could later be extended to act as structural reinforcement as an integrated formwork, forming a composite cross-section.

The knit-pattern generation worked well, producing the designed geometry of the formwork in its tensioned state.

Author-1 Ar. Harshada Vazarkar , M Arch student of Digital Architecture, B. N. College of Architecture , Pune, India.
Email - harshadavazarkar@gmail.com
Author-2 Guide- Ar. Deva Prasad , M Arch of Digital Architecture, Faculty at B. N. College of Architecture ,Pune, India.

REFERENCES

*1. History and overview of fabric formwork:using fabrics for concrete casting Diederik Veenendaal*Mark West ,Philippe Block.*
2. 3D Fabrics for Technical Textile Applications http://dx.doi.org/10.5772/6122489
3. Knit tectonics , Sanhita Chaturvedi, Esteban Colmenares and Thiago S. Mundim
4. www.YarnStandards.com.
5. History and overview of fabric formwork:
using fabrics for concrete casting
6. Flexible formwork technologies: A state of the art review W J Hawkins. PhD candidate in Civil Engineering, Department of Architecture and Civil Engineering, University of Bath, Bath, UK
Corresponding Author: w.j.hawkins@bath.ac.uk,M Herrmann Str.ucture GmbH, Lindenspürstraße 32, 70176 Stuttgart, GermanyT J Ibell
Professor of Civil Engineering, Department of Architecture and Civil Engineering, University of Bath, Bath, UK B Kromoser
Research Associate, Vienna University of Technology, Institute for Structural Engineering, Karlsplatz 13, E212-2 A Michaelski Str.ucture GmbH, Lindenspürstraße 32, 70176 Stuttgart, Germany
J J Orr Lecturer (Assistant Professor) in Civil Engineering, Department of Architecture and Civil Engineering, University of Bath,Bath, UK Pedreschi
Professor of Architectural Technology, University of Edinburgh, Edinburgh, EH3 9DF A Pronk,Assistant Professor in Innovative Structural Design, Eindhoven University of Technology
H R Schipper Lecturer-researcher in Structural and Building Engineering, Delft University of Technology
P Shepherd,Lecturer in Digital Architectonics, Department of Architecture and Civil Engineering, University of Bath, Bath, UK
D Veenendaal, PhD Candidate, ETH Zurich, Institute of Technology in Architecture, Block Research Group
6. Veenendaal, D., Block, P.: Design process for prototype concrete shells using a hybrid cable-net and fabric formwork. Engineering Structures, 2014.
7. The potential of advanced textiles for fabric formwork. Julie Brennan BA, PhD, PGCert ,Reader in Constructed Textiles, School of Art and Design, University of Ulster, Belfast, UK Remo Pedreschi BSc, PhD, CEng, MICE Chair in Architectural Technology, University of Edinburgh, Edinburgh, UK
Pete Walker BSc, PhD, MIEAust, CPEng, CEng, MICE BRE Trust Chair in Innovative Construction Materials, University of Bath, Bath, UK
Martin Ansell BSc, PhD, FIMMM Reader in Engineering Materials, University of Bath, Bath, UK.