Affordable cyclone resilient houses for fishermen village in Somolo island, Chilika, Odisha

Ananya Das[1], Narendra Mandala[2]
[1]Architect, [2]Architect

ABSTRACT

The human-made changes towards nature have led to an adverse impact on the climatic condition across the globe. In the present scenario, global warming is the major factor in climate change. Rise in the Earth's surface temperature also led to ocean warming, which intensifies natural disasters, especially cyclones.

As India lies near to the equator, it has a maximum effect of annual cyclone due to the constant fluctuation of hot and cold air.

Odisha lying to the coast of the Bay of Bengal faces annual cyclone for which the maximum revenue generated by the state is utilized as a disaster relief fund. The most likely affected amenities are the houses, especially the vernacular non-engineered constructions are being unable to withstand the present climatic conditions.

Somolo island situated on the shore of Chilika Lake, Ganjam, Odisha is one of such places that has been facing the adverse effects of cyclone for ages. There is a fishermen settlement, where most of the houses are kutcha houses made up of vernacular building materials that are annually getting damaged due to cyclones.

This research focuses on the proposal of cyclone resilient houses for the fishermen of the place using vernacular building materials that are Mud Cylinders as the building blocks. It also focuses on sustainable approach of designing the houses making it affordable for the fishermen by innovative material and construction management techniques.

KEYWORDS

Mud Cylinders, Affordable construction techniques, Cyclone resilient residences, Fishermen community

1. INTRODUCTION

The era of industrialization brought with it an increase in the demand and supply of goods and other essential products contributing to the increase in the industries and transportation, which in return contributed to the excessive release of carbon dioxide and other harmful gases to the atmosphere leading to global warming.

1.1. Climate Variability.

According to the ongoing temperature analysis conducted by scientists at NASA's Goddard Institute for Space Studies (GISS), the average global temperature of the Earth has increased by 1^0 Celsius since 1880 C.E. The two-thirds of the warming has occurred since 1975 during the rapid growth in industrial sector across the globe, at a rate of roughly 0.15-0.20^0 Celsius per decade. This rise in temperature significantly affects the entire land surface, ocean warming and atmosphere heating. (NASA Goddard Institute for Space Studies, 2020)

According to NASA's Jet Propulsion Laboratory, California Institute of Technology, (Buis, 2020)to the date the ocean contains 93 percentage of the heat from human- induced global warming.

1.2. Climate Variability impacting the strength of tropical cyclones.

According to NASA study from late 2018, global warming is causing the number of extreme storms to increase, at least over the Earth's tropical oceans (between 30^0 North and South of the equator). The study also found that extreme storms are formed when sea surface temperatures were hotter than 28^0 Celsius. Every 1^0 Celsius of increase in the sea surface temperature, the number of extreme storms went up by 21%. Based on the current climate model projections, the researchers concluded that extreme storms may increase by 60% by the year 2100. (Buis, 2020)

1.3. Tropical Cyclone.

Tropical cyclone uses moist and warm air as fuel. That is the reason they are formed only over warm ocean water near the equator.

1.3.1. Tropical Cyclone in India.

Indian sub-continent is the most affected region of the world, having a coast line of 7516 kms, which is exposed to nearly 10% of the world's tropical cyclones. Out of 13 coastal states/Union Territories encompassing 84 coastal districts are affected by cyclone. Four states Andhra Pradesh, Odisha, Tamil Nadu and West Bengal and one Union Territory Pondicherry on the west coast are more vulnerable to cyclone disasters.

Although cyclones affect the entire coasts of India, the east coast is more prone compared to the west coast.

1.3.2. Tropical Cyclone in Odisha.

Odisha is one of the states facing extreme cyclones along with neighbouring states of Andhra Pradesh and West Bengal since 1891. The state was hit by about 110 extreme cyclones, says tropical meteorologist Uma Charan Mohanty, a visiting professor at Indian Institutes of Technology, Bhubaneswar, Odisha (Nature India, 2020).

2. CONSTRUCTION OF BUILDINGS PRACTICED IN ODISHA.

As per census data of 2011, majority of the total population in Odisha lives in rural areas where they are dependent on the kutcha houses for living due to locally available materials and weaker economic condition of the people.

Rice being the staple food of the entire population of Odisha, it is the major crop of the state. It covers about 69 percentage of the total cultivated area. That is how most of the building construction are based on vernacular materials that are extracted from the agricultural sectors and other locally available materials, such as rice straws, hays, mud, bamboos and locally available woods.

But due to the variation in the climatic conditions, leading to the intensification of tropical cyclone, the strength of the initially practiced styles of making kutcha houses using vernacular materials may be doubted at the present times.

3. IMPACT ON VERNACULAR CONSTRUCTION OF BUILDINGS AT PRESENT TIMES

Even if there are records of failure of vernacular building materials and construction techniques at the present times due to natural calamities, but these vernacular building products are eco-friendly and have least impact towards the nature. Hence the materials and construction techniques can be strengthened with innovative techniques to result in a cyclone resilient building.

4. BRIEF ON THE AFFECTED SITE.

Somolo island situated on the shore of Chilika Lake, Ganjam, Odisha is one of such places that has been facing the adverse effects of cyclone since ages. The island is there since a longer period of time, where initially the fishermen from the neighbouring villages started settling near the shore of the lake to access the lake and sea through the routes of the lake connecting the sea for fishing. In the fishermen settlement, where most of the houses are kutcha houses made up of vernacular building materials, are getting damaged due to cyclones. Rice being the staple food some residents also practice cultivating food crop, where they used the rice straws and other locally available materials like mud, wood and bamboos for constructing kutcha houses.

Some of the residents have made semi-pukka houses with asbestos roofing and cement pillars and beams, but still they are not surviving the tropical storms with these non-engineered constructional practices of house.

Figure 1 Damage of kutcha houses and semi-pukka houses of fishermen due to tropical cyclone, 2019, Somolo Island. Source: (Author).

The houses made up of load bearing burnt brick walls without adequate joinery to the foundation and the roof collapses during the cyclones. The thatch roofs and mud walls wash away with the intense wind accompanied by heavy rainfall. The lack of intervention of adequate building materials and construction techniques the design of the non-engineered houses is not being able to resist the tropical cyclonic effects at the present times.

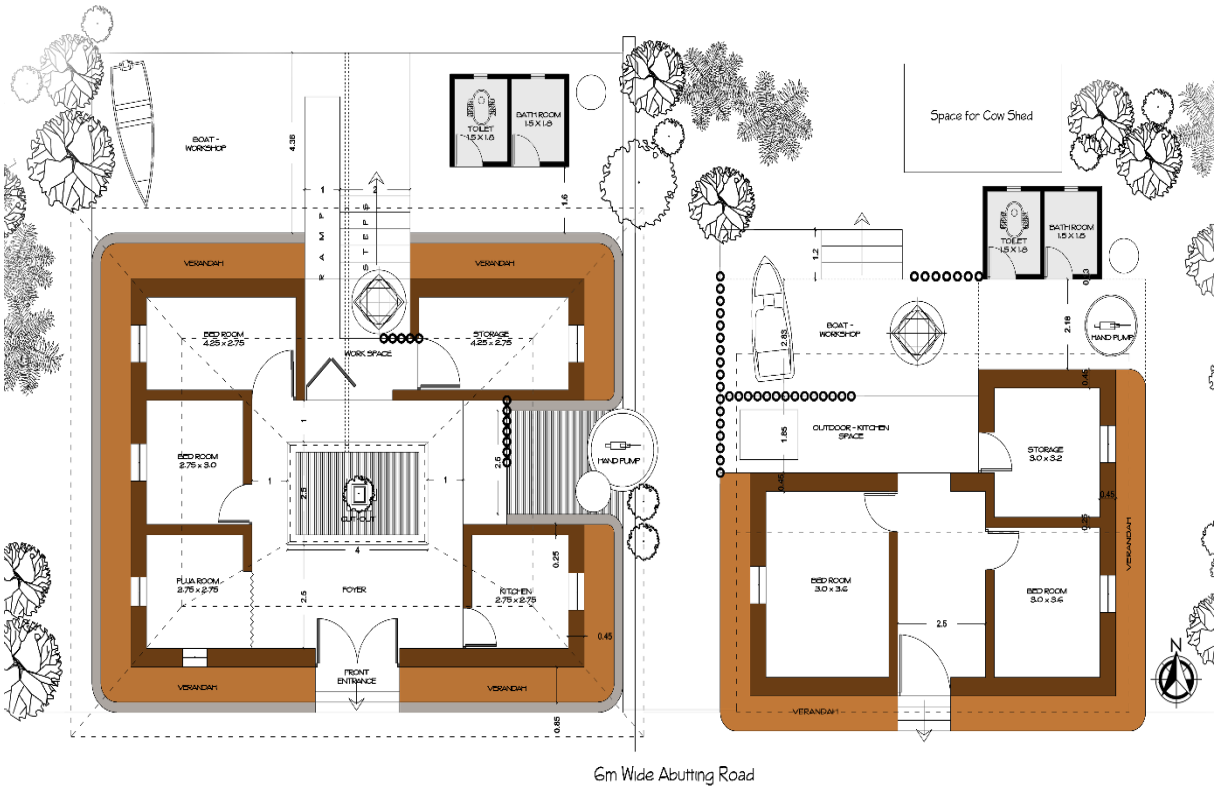

Figure 2 Existing typical floor plans of fishermen houses (Kutcha house), 2019. Source: (Author).

These kutcha houses have entrance spaces with a foyer, kitchen space near the entrance. Next, they have worship space (puja room), two bedrooms and a storage space at the rear area of the house which contains the fishing equipment, store dry fish and some also have potable cold storage to fishes for trade. The rear side of the house faces towards the Chilika lake, from where they drag their boat from the shore till the house veranda to hoist or repair.

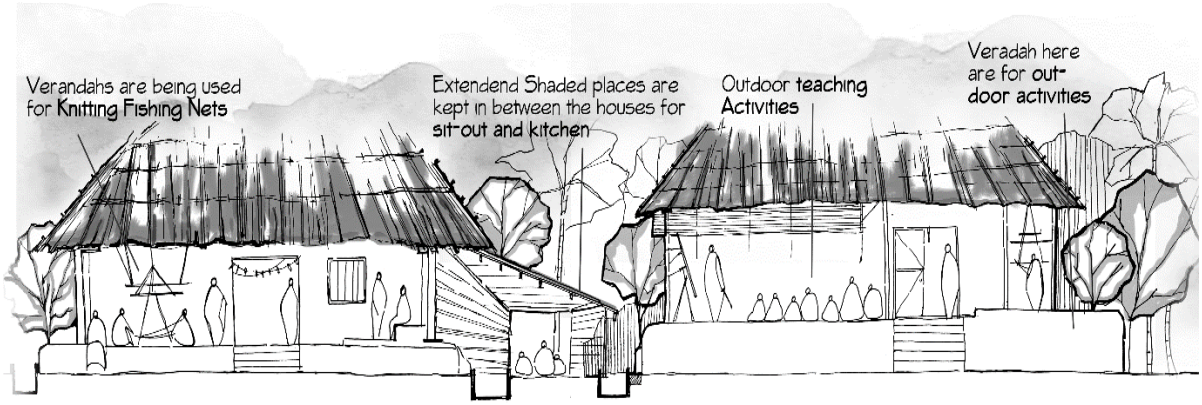

Figure 3 Sketches showing outdoor activities on front verandas of the houses. Source: (Author).

Veranda plays an important role in their daily activities. The high-rise verandas all around the houses not only protect the house from flooding during the rain but are also use to sit-out and talk to neighbours, children in the morning and evenings sit and study in groups. Verandas are also used to dry fishes, knit fish nets, repair boats, outdoor kitchen and other outdoor activities.

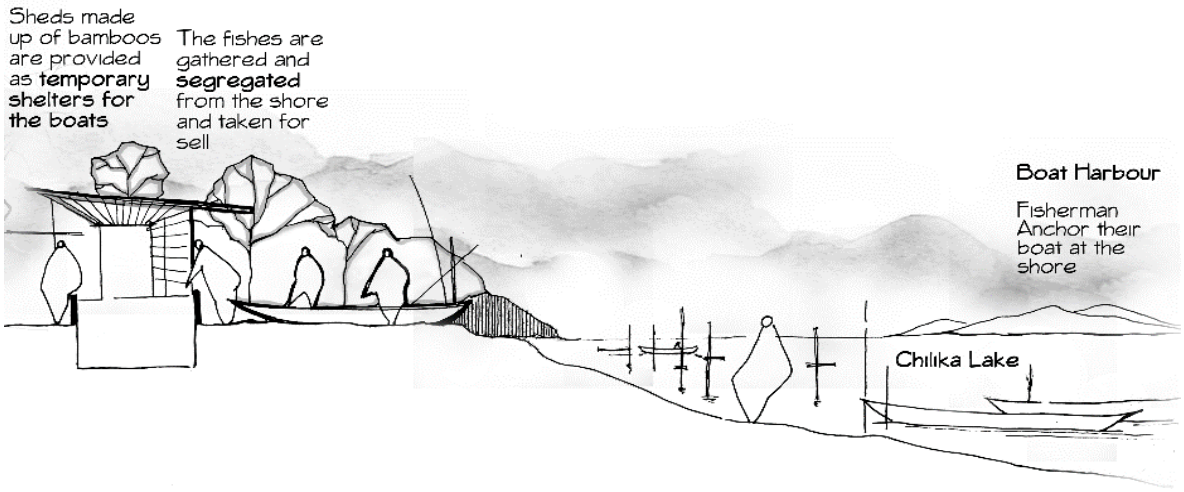

Figure 4 Sketches showing outdoor activities on the rear side of the houses towards the Chilika lake. Source: (Author).

Sheds are made up of bamboo and plastic sheets to hoist boat when not in use in the rear side of the houses towards the Chilika lake. Cement tanks are made near the shore of the lake to store fish temporarily after fishing. The boats are anchored to the wooden post on the shore.

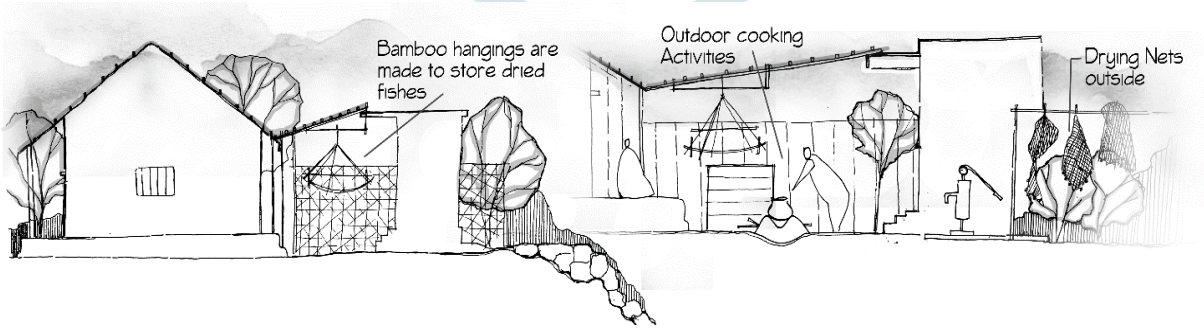

Figure 5 Sketches showing outdoor activities on the rear side of the houses. Source: (Author).

In the rear side of the houses are used as outdoor kitchen and other outdoor activities. There they create hangings ("Sika" in Odiya language it means hangings to store things especially food items) to store dry fishes near the outdoor cooking space.

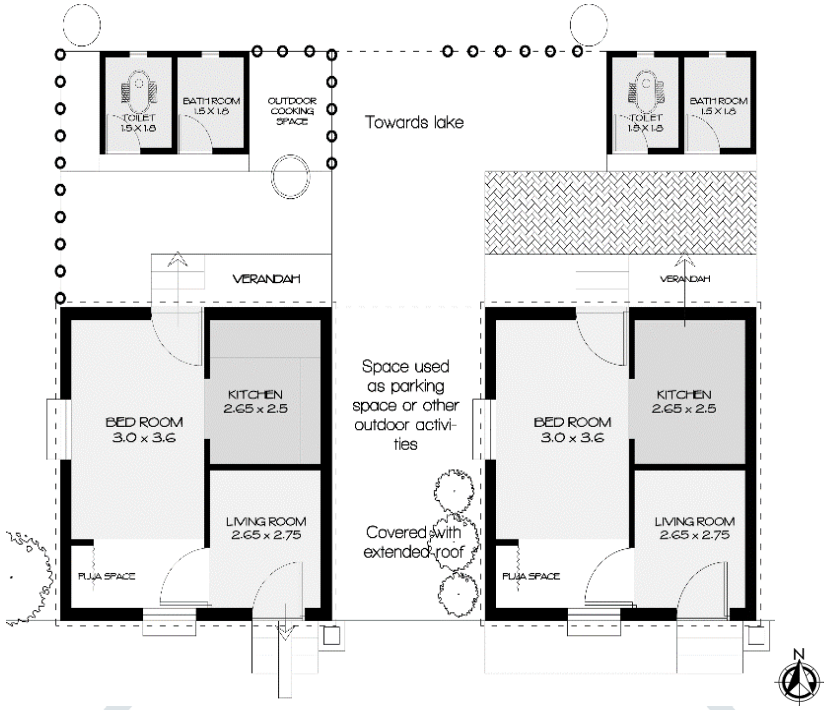

Figure 6 Existing typical floor plans of fishermen houses provided by the Odisha government, 2019. Source: (Author).

Even if government has taken initiatives by providing single dwellings of pukka houses for the affected people but still, majority of them un-occupied by the fishermen community as the proposed designed spaces fails to meet the spatial requirements of the people according to their lifestyle and occupation.

Figure 7 Issues identified in the proposed pukka houses provided by the Odisha government to the fishermen of the Somolo island. Source: (Author).

Some of the people of the place who have occupied the pukka dwellings are projecting the front and the rear side of the houses with materials like bamboo or wooden posts, plastic sheets and asbestos to meet the requirement of the spaces for storage, outdoor kitchen and other activities.

5. PROPOSED DESIGN OF RESIDENCES FOR FISHERMEN

The proposed concept of the cyclone resilient residences for the fishermen has been derived from the cyclonic wind analysis and impact of wind to the site. Mostly the spatial requirement of the fishermen group of people has been taken into consideration while designing for their residences.

5.1. Proposed residence design according to the lifestyle study, spatial requirement and occupation of the fishermen.

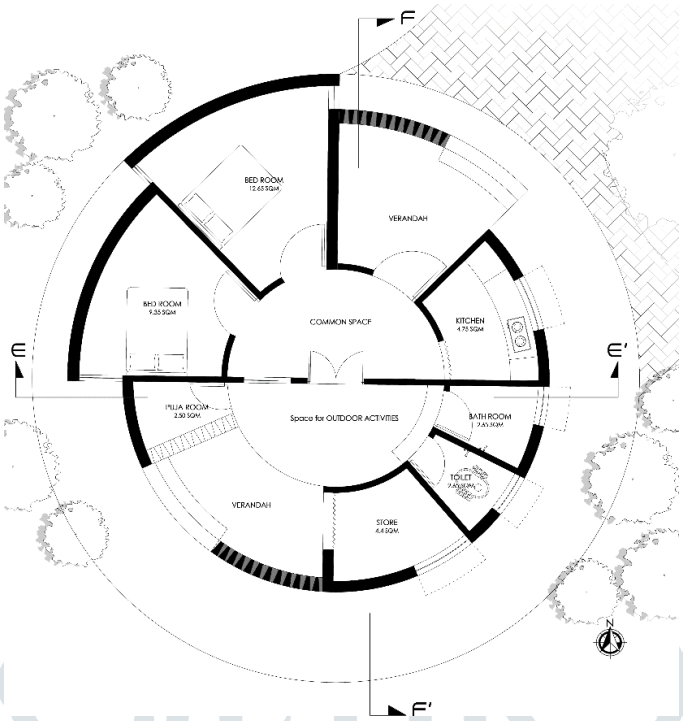

Figure 8 Proposed typical floor plan of 70sqm of fishermen residence. Source: (Author).

The dwellings are oriented with the main entrance from the south direction and the backyards towards the lake facing north. Verandas are provided all around the residence to have maximum outdoor activities, like which are semi closed with mud Jali to allow required light and ventilation to the space. These verandas can be used for knitting fishing nets, hoisting and repairing private fishing boats. Bedrooms are provided towards the northwest direction getting least radiation and constant required velocity of wind throughout the year. The houses also consist of the kitchen, bathroom, toilet, storage and a puja room.

Table 1 Details of the proposed domical residence of fishermen. Source: (Author).

Area and Volume of the dome	
Walls *(includes wall thickness and plastering)*	
Outer radius of the dome	4.45 m
Inner radius of the dome	4.31 m
Total height of the dome	5.40 m
Total surface area of the dome	224.85 sqm
Total volume of the dome	33.74 cum
Fenestration	
Total surface area of fenestration	8.56 sqm
Total volume of fenestration	2.08 cum
Total surface area of the dome with fenestration voids	216.29 sqm
Total volume of the dome with fenestration voids	31.66 cum

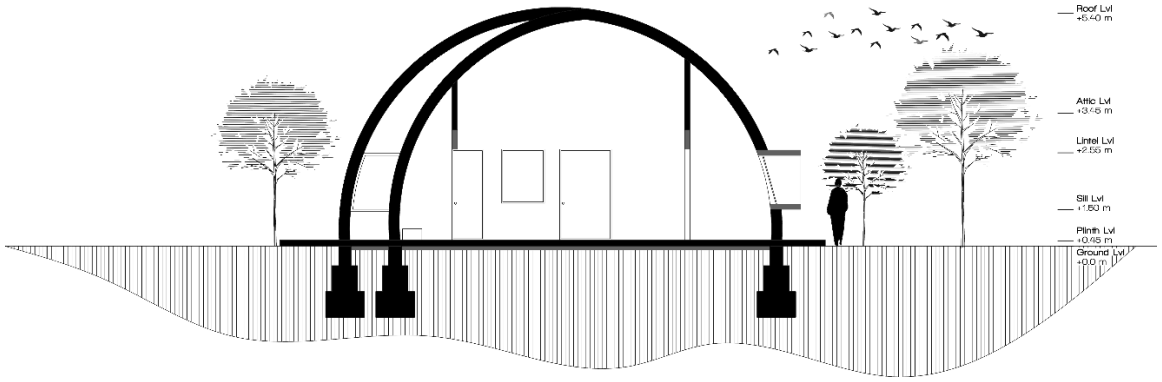

Figure 9 Section at E-E'. Source: (Author).

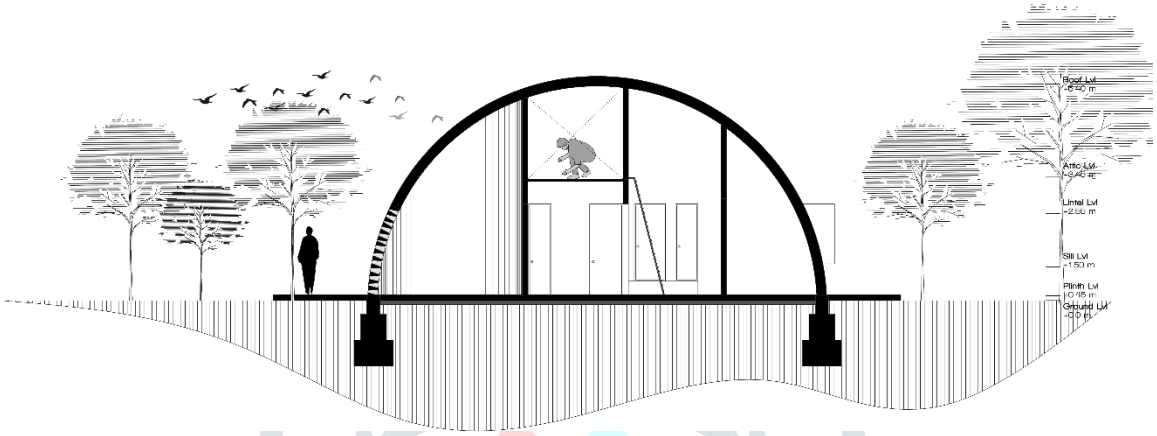

Figure 10 Section at F-F'. Source: (Author).

An attic has been provided within the house for storage purpose according to their daily activity requirement, which can be accessed with the help of a potable ladder.

Figure 11 Elevation facing north of the proposed fishermen houses in the settlement. Source: (Author).

A schematic elevation of the proposed houses in the settlement is shown in the figure 11. The elevation is shown facing the north direction form where there is the proposed main entrance to the houses from the existing abutting 6m wide road.

5.2. Cyclone resilient design of proposed residences for fishermen.

The selection of the shape of the building as a domical shape is done according to the wind flow, wind pressure and impact of the wind to the building on the site (Somolo island, Chilika, Ganjam District, Odisha).

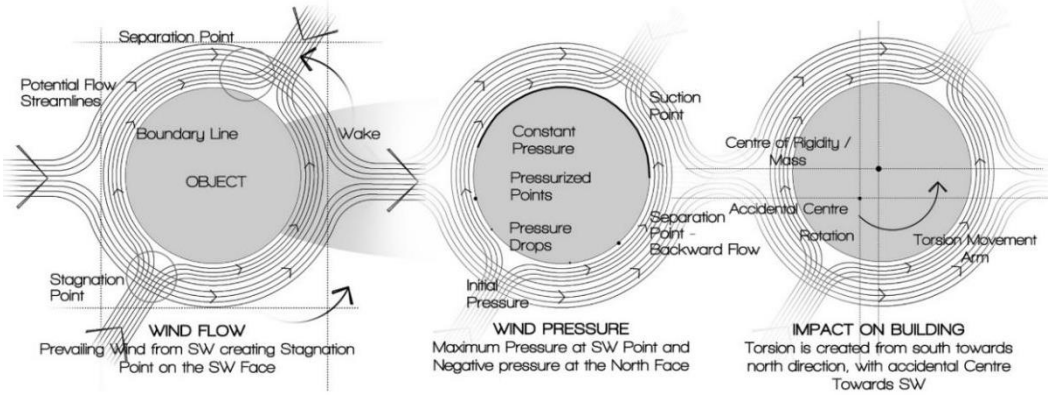

Figure 12 Impact of wind on the domical shaped building. Source: (Author).

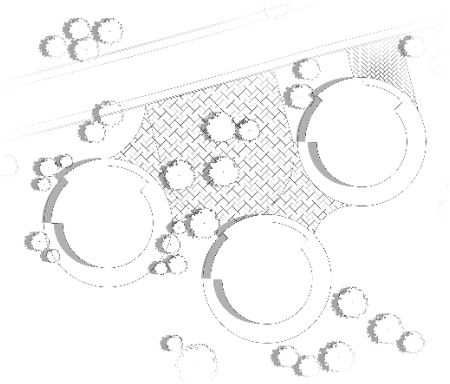

Figure 13 Proposed top view of a cluster of fishermen houses. Source: (Author).

The houses are built in a Cluster of three to avoid the wind impact. The arrangement is designed such to break the wind speed as it moves along the settlement.

5.2.1. Wind analysis of the Site.

According to the meteorological department of Odisha, the average wind force per day (January 1999 to December 2020) is 2.66 m/s and maximum air temperature is 33.2^0C. (Weatheronline.in, 2020).

Table 2 Annual wind force per day and maximum air temperature of Odisha (January 1999 to December 2020).

Month	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Wind Force (m/s) per day	1.75	2.41	3.50	5.02	4.25	3.60	2.91	2.90	2.50	1.60	1.36	1.20
Air temperature (^{0}C)	29.6	32.5	35.6	37.2	38.2	35.1	32.5	31.9	32.3	32.3	30.8	29.3

According to the Alipore Meteorological office the average cyclone wind speed in Odisha is 30.55 m/s where the Odisha Super cyclone wind speed was 72.22 m/s. The cyclones mostly occur in Odisha in the month of May-June and October-November.

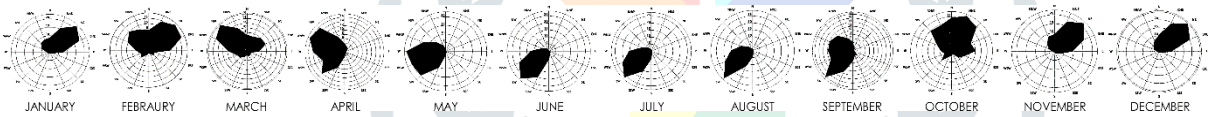

Figure 14 Wind flow analysis from the directions through-out the year (Climate Consultant software)

The graphs show the wind flow from different direction in the particular months throughout the year.

Table 3 Percentage of wind flow from different directions (January 1999 to December 2020)

Direction	N	NE	E	SE	S	SW	W	NW
Wind Direction %	13	7	9	4	39	12	11	4

According to the meteorological department of Odisha, the maximum wind flow throughout the year is from the south direction with 39% and the minimum wind flow is from southeast and northwest direction with 4%. (Weatheronline.in, 2020).

5.2.2. Simulation showing wind analysis, using Autodesk Flow Design software.

A virtual wind analysis is done using “Autodesk Flow Design” wind analysis simulation software, where the wind velocity and the wind pressure on the proposed houses in clusters are analysed according to the wind flow from the predominant directions in different months of the year.

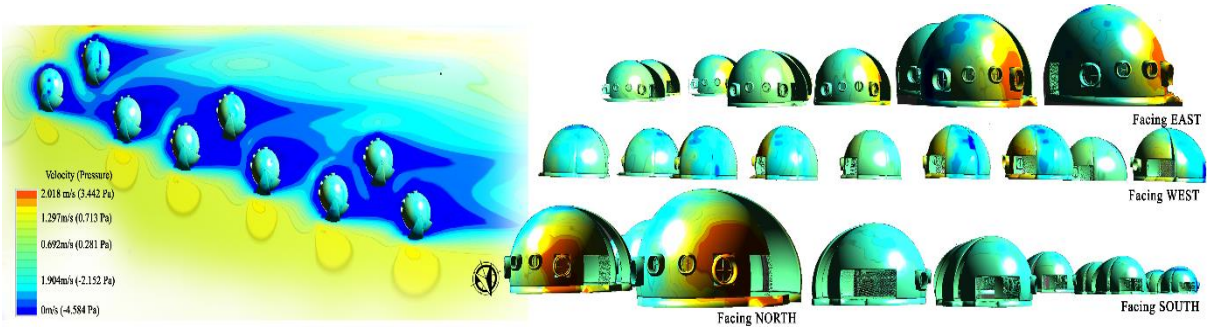

Figure 15 Wind flows from the northeast direction with an average speed of 2.018 m/s

On a normal day when the wind blows from the northeast direction (7% of the wind flow from south annually) with an average speed of 2.018 m/s, the wind pressure is 3.442 Pa (Pascal) on the east and north wall and 0.713 Pa to 0.281 Pa on the other sides of the wall. A negative wind pressure is observed to the leeward side of the house of -2.152 Pa to -4.58 Pa.

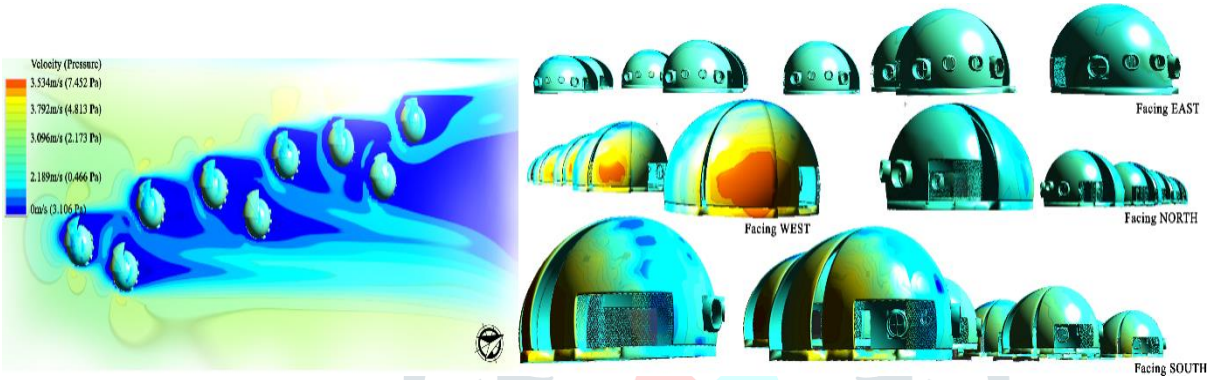

Figure 16 Wind flows from the southwest direction with an average speed of 3.16m/s

On a normal day when the wind blows from the southwest direction (12% of the wind flow from southwest annually) with an average speed of 3.53 m/s, the wind pressure is 7.452 Pa (Pascal) on the western wall and 2.173 Pa to 0.466 Pa on the other sides of the wall. Southwest is the direction of cyclonic wind mostly during the month of May, June and September. Hence the proposed houses are oriented as such, the designed wall with no voids and projections on the west directly faces the wind then splits the wind smoothly along the curve walls of the house.

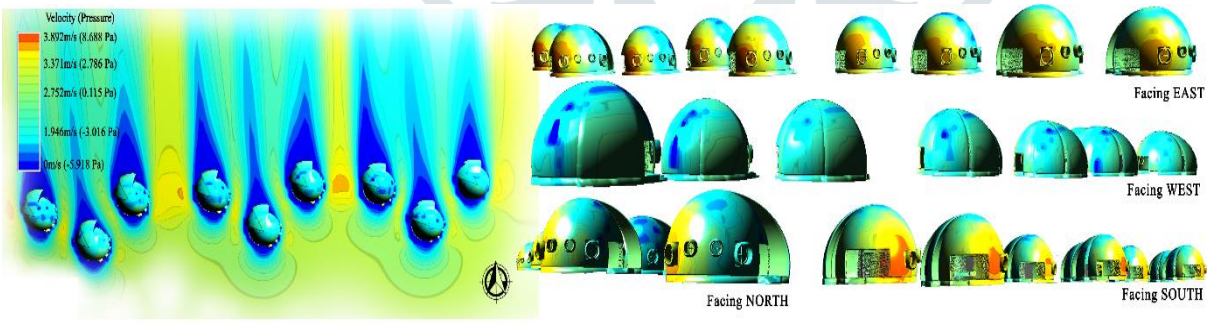

Figure 17 Wind flows from the south direction with an average speed of 3.89 m/s

On a normal day when the wind blows from the south direction (42% of the wind flow from south annually) with an average speed of 3.892 m/s, the wind pressure is 8.68 Pa (Pascal) on the south and east wall and 2.786 Pa to 0.115 Pa on the other sides of the wall. A negative wind pressure is observed to the leeward side of the house of -3.016 Pa to -5.918 Pa.

5.3. Proposed affordable residences for the fishermen using low cost vernacular building materials and construction techniques.

The entire construction of the dome is proposed to be constructed with mud cylinders, steel reinforcement and mud-cement mortar for joints and plaster on the domes.

5.3.1. Proposed affordable building materials for the construction of dome houses.

Mud is the vernacular material that is easily available which can be used for the construction as the people are practicing kutcha house construction on the island. Hence hollow cylindrical mud blocks are proposed for the construction of the dome shaped houses for fishermen.

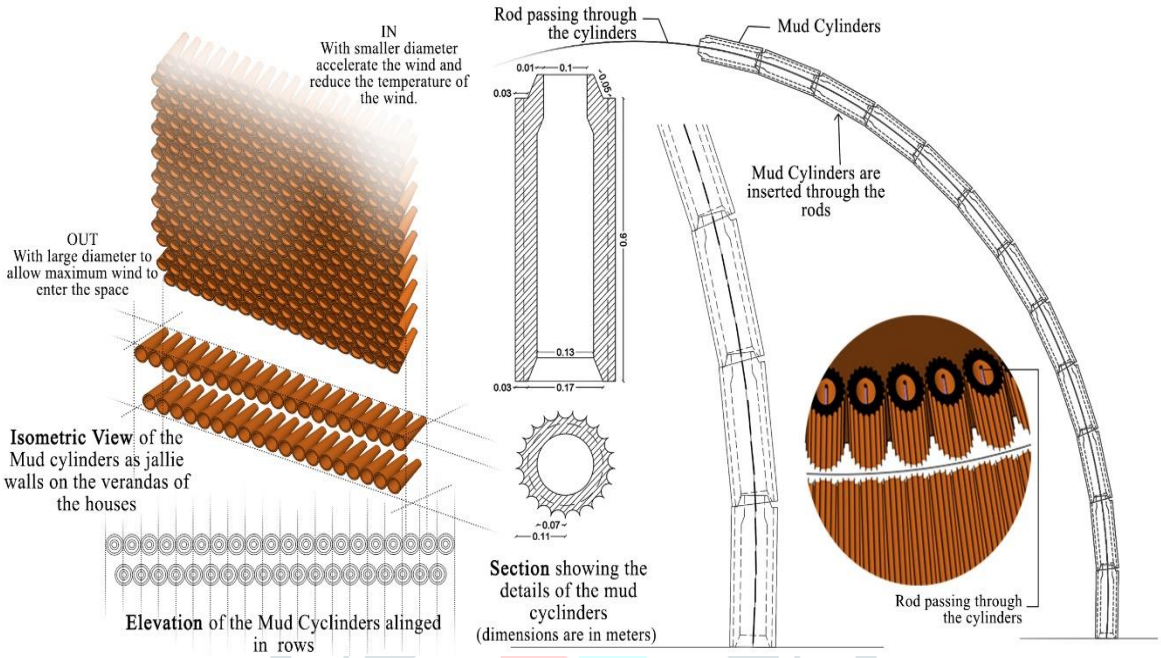

Figure 18 Details of proposed mud cylinder with steel reinforcement used for the construction of the dome houses

Hollow cylindrical shaped building blocks made up of a mixture of mud, water proofing agents, fibre and 7% of cement that can be casted in wooden/metal moulds. The fibre in the mixture are strong in tension help to reduce the cracks and adds value to the strength of the blocks. These building blocks are kiln burnt enhancing the strength of the blocks. Groves are made on the cylinder outer surfaces to hold the plaster easily during the construction. These mud hollow cylinders are places one above the other by inserting a steel reinforcement through the void of the cylinders. The gaps in between the adjacent cylinders are filled with mud-cement mortars, which can also be used for the finished outer and inner plastering of the dome.

5.3.2. Proposed affordable building construction techniques of dome houses.

The proposed houses of the fishermen are proposed to be hollow dome shaped which resist the impacts of the wind as proved in virtual wind simulation in 5.2.2

For the construction of the dome structures, for the foundation a ring beam foundation can be adopted with random rubbles, with required amount of cement for adequate strength to the base. Steel rods can be used as reinforcement, that can be bent in shape of a dome. At first, vertically the rods are bend in curve shape till the lintel level of the dome house. The proposed hollow mud cylinders are staked one above the other through the steel rods. Then a horizontal ring-shaped frame can be created with the reinforcement, tied to the vertical bars till the lintel level acting as a lintel beam. The required openings for fenestration are created by cutting, bending and tying the rods for doors and windows. The same procedure of wall making and casting ring beams are created at another couple of levels till the dome shape is achieved. At last the extended rods are tied at the top. The surface areas of the dome can be plastered and the gaps between the joints can be filled with mud-cement mortar, giving it protection and a finished look.

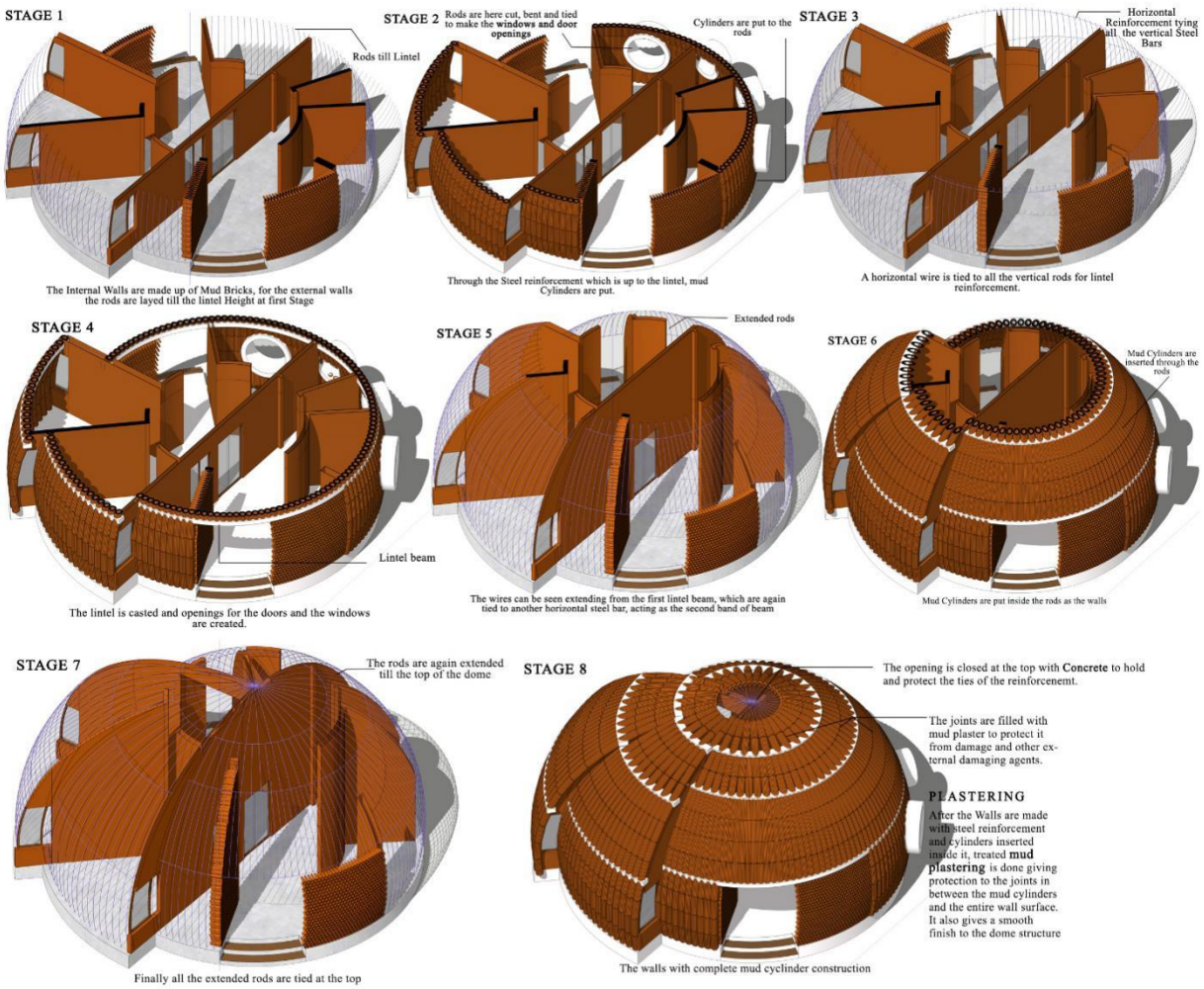

Figure 19 Stage wise process construction of the domical houses for the fishermen

5.3.3. Comparative analysis showing cost of construction of a domical house with a conventional house.

To verify the affordability of the proposed mud dome house a comparative analysis is done showing the cost of construction of the 70sqm dome house with the same volume of a conventional pukka house.

Table 4 Comparative analysis of the cost of construction of a proposed mud dome house with a conventional pukka house. Source: (Author).

Dome Mud House				
Names	**No.**		**Unit Price**	**Amount**
R.R. Masonry (300 mm thick)	20	cu.m		₹ 50,000.00
C.C. Flooring (10 mm thick)	10	cu.m		₹ 35,000.00
No. of Cylinders	1232	cu.m	₹ 15.00	₹ 18,480.00
Jali Walls	1866	no.	₹ 15.00	₹ 27,990.00
Inner Walls	20	cu.m		₹ 6,750.00
Plastering (Mud Cement)		sq.m	₹ 15.00	₹ 2,250.00
Lintels	1.97	cu.m		₹ 6,895.00
Reinforcement (12 mm rods)	135	no.		₹ 47,250.00
Doors	2		₹ 1,600.00	₹ 3,200.00
Windows	6	no.	₹ 3,000.00	₹ 18,000.00

Plastering around the dome (Mud Cement)	432.58	sq.m	₹ 15.00	₹ 6,488.70
Total				**₹ 2,22,303.70**
Pukka House				
Names	**No.**		**Unit Price**	**Amount**
R.R. Masonry (300 mm thick)	20	cu.m		₹ 50,000.00
C.C. Flooring (10 mm thick)	10	cu.m		₹ 35,000.00
Jali Walls	1866	no.	₹ 15.00	₹ 27,990.00
Inner Walls	20	cu.m		₹ 6,750.00
Lintels	1.97	cu.m		₹ 6,895.00
Plastering (Cement Mortar)		sq.m	₹ 20.00	₹ 2,250.00
Doors	2		₹ 1,600.00	₹ 3,200.00
Windows	6	no.	₹ 3,000.00	₹ 18,000.00
Plastering around the dome (Cement Mortar)	432.58	sq.m	₹ 20.00	₹ 8,651.60
R.C.C. Dome casting				₹ 2,36,862.00
Total				**₹ 3,95,598.60**

In the above table all the building elements of the proposed mud dome house and a pukka house are estimated with the current market price at Ganjam district. Hence it is found that the total cost of the proposed mud dome house is ₹ 2,22,303.70, whereas, the cost of a single dwelling of a conventional pukka house of same volume is ₹ 3,95,598.60. Hence it is concluded that the proposed dome house has 44% less costly than the convectional pukka house.

6. CONCLUSION

The building materials can be locally available and construction techniques doesn't need active technology and skilled workers; hence the dome house can easily be constructed. As the construction of the houses are proposed to use hollow mud cylinders, it reduces the demands of the materials making the cost of the construction less. The cost of the proposed mud dome house construction is found to be 56% less costly as compared to the same volume of a conventional pukka house in the rural areas of the Somolo island. The shape of the building demands less effort, time and use of materials as compared to the equal volume of a rectangular building. Hence it is "affordable" enough for the fishermen group of people to construct and live in it.

According to the proposed design, the dome shape and the height of the house, along with appropriate design of required projection and openings, it allows the structure to resist the cyclonic wind as proved according to the simulations in 5.2.2 figure 16. Also, the proposed orientation and cluster arrangement of the houses according to the study of the windward and leeward directions of the site as shown in figure 13, make it "cyclone resilient".

Moreover, the planning of the houses is done to achieve the spatial needs of the occupants, mostly with respect to their occupation.

Therefore, the proposed dome houses for the fishermen of the Somolo island is proved to be "affordable and cyclone resilient houses".

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