ISSN 2729-7640

sciendo

ALFA ARCHITECTURE PAPERS
OF THE FACULTY OF ARCHITECTURE AND DESIGN STU
www.alfa.stuba.sk

4/2021
DOI: 10.2478/alfa-2021-0020

Challenges in sustaining resilience in the coastal settlements of south-eastern Bangladesh: Achieving self-sustenance through architectural synthesis

AUTHORS:

Anika Imraana Sohaana[1]

Md Arifur Rahman[2]*

[1,2] *Shahjalal University of Science and Technology, School of Applied Sciences and Technology, Department of Architecture, Sylhet, Bangladesh*

***CORRESPONDING AUTHOR**
E-mail: ar.kaushik-arc@sust.edu

ARTICLE INFORMATION
***Sent**: Aug 9, 2021*
***Accepted**: Oct 11, 2021*

ABSTRACT:

The coastal settlements in Bangladesh experienced recurring tropical cyclones and tidal surges in recent history because of geographical influences and global climate change. Despite improved evacuation management and adequate cyclone shelters patronized by donors, lately resulting in a reduced mortality rate, the property and economic losses were still substantial due to vulnerability of the settlements. As the short-term adaptative approaches such as migrating to the closest cyclone shelters have failed to sustain resilience, comprehensive and inclusive mitigation planning should be implemented to achieve more resilience in the long term. The research aimed to revise the conventional culturally-void concept and propose a prolonged solution by planning a self-sustained model of the cyclone-resilient village for the south-western coastal communities of Bangladesh. Initially, it searched for the identification and analysis of socio-cultural, economic, and environmental challenges in sustaining community resilience and later synthesizing architectural interventions to achieve self-sustenance. The synthesis focused on reducing the vulnerability of the coastal communities by enhancing their preparedness, resistance, and recovery from the prolonged impacts of coastal disasters through designing structurally and environmentally resilient homesteads, defensive landscape plans, and socio-economic-communal development. The ultimate proposal offers more flexibility in selecting homesteads according to suitable materials, affordability, and profession.

KEYWORDS:

climate resilience, self-sustainability, cyclone-resilient homestead, housing clusters, planned landscape, community development

INTRODUCTION

Bangladesh is ranked amongst the most extremely climate-induced disaster-prone countries in the world **[1]** due to its geographical location, wide and shallow continental shelf, high tidal range, low and flat topography, funnel-shaped coastline, and high population density **[2,3]**. Unsurprisingly, the southern coastal region of Bangladesh along the Bay of Bengal is exceptionally vulnerable to frequent tropical cyclones and tidal surges associated with salinity intrusion, flash-flooding, and water-logging. The substandard economic condition of the marginal communities, dependent on natural resources for livelihood **[4]**, and the poor state of their vernacular settlements further enhance the region's vulnerability **[5]**. Tropical cyclones regularly hit Bangladesh's coast in pre-monsoon (April-May) or post-monsoon (October – December) season, with at least one severe cyclone every three years **[6]**. Cyclones, accompanied by storm surges, caused a massive human catastrophe, enormous economic loss, and extensive damage to settlements, agricultural lands, and infrastructures in the earlier years **[7]**. Despite the high exposure to tropical cyclones, the subsequent death toll had significantly reduced over the recent years through substantial development in disaster forecasting and evacuation system and effective management **[8]**. However, cyclones had continued to destroy housing, livelihood, and infrastructures, with a substantial financial loss **[9]**. Moreover, due to adverse climate change, the vulnerability of the coastal zones of Bangladesh was anticipated to be higher in the future **[10]**. According to an estimation, the cyclone-exposed areas in Bangladesh were predicted to rise by 26% and the affected population by 122% by 2050 **[11]**.

The history of cyclones on Bangladesh's coast

The coastal region in Bangladesh constitutes 32% of the country as an active part of the Ganges-Brahmaputra-Meghna delta and a 710 km coastline alongside the Bay of Bengal **[12]**. Geographically, Bangladesh's coastal region can be categorized into three distinct zones: (i) the south-western coastal zone with mangrove forest, (ii) the central coastal zone

© 2021 Authors. This is an open access article licensed under the Creative Commons Attribution-NonCommercial-NoDerivs License (http://creativecommons.org/licenses/by-nc-nd/3.0/). Published by the Faculty of Architecture and Design, Slovak University of Technology in Bratislava, Slovakia

with numerous offshore islands, and (iii) the slender south-eastern coastal zone with a series of hills parallel to the coast **[4,13]**. The severe tropical storms generated over warm oceans travel with sustained winds of 120 km/h or more towards the north of the Bay of Bengal. The funnel-shaped bay causes the storms to surge higher along Bangladesh's coast than other neighbouring countries, traveling at up to 48 km inlands **[6]**. These storm surges cause severe casualties and catastrophic landfall during high tide. The height of the storm surge rises with the cyclone's intensity and ranges typically between 1.5 - 9.0 m, even recorded as high as 10 m **[14,15].**

Overall, a total of 49 tropical cyclones hit Bangladesh's coast over the last three decades **[16]**, most notably, Cyclone Gorky (1991), Cyclone Sidr (2007), Cyclone Aila (2013), and Cyclone Mahasen (2014) (**Fig. 1**). Furthermore, Cyclones passing over Indian and Myanmar's coasts, such as Odisha (1999), Nargis (2008), Hudhud (2014), Bulbul (2019), and Amphan (2020), also had a severe impact on Bangladesh's coast **[17]**. According to global disaster statistics, these cyclones, occurring in the coastal belt surrounding the Bay of Bengal, were responsible for the death of approximately 0.2 million people and an economic loss of roughly USD 44 billion **[17,18]**.

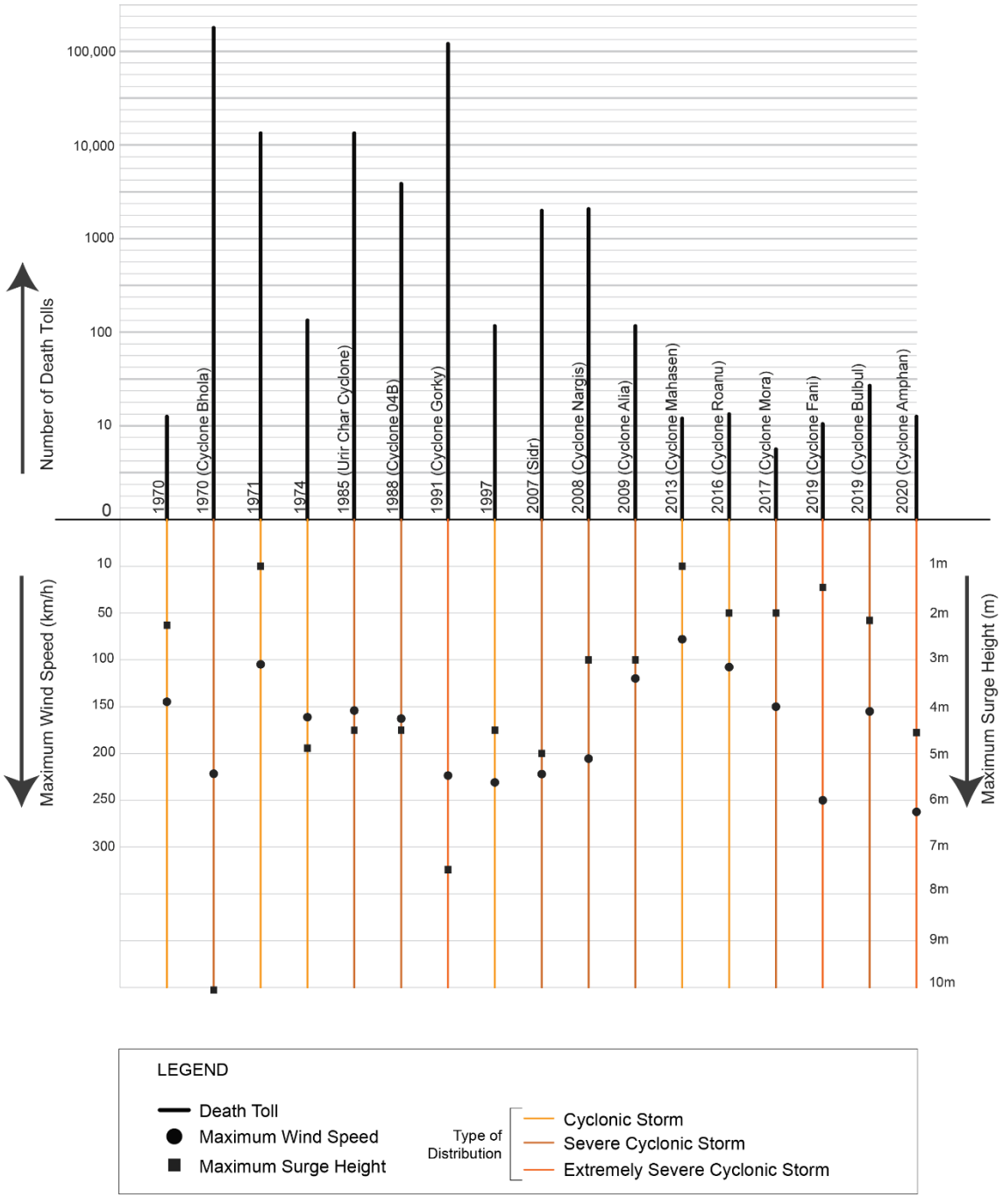


Figure 1: Historical timeline and statistical overview of recent cyclones in Bangladesh. Author: Anika Imraana Sohaana

Literature review

Resilience is a widely used term derived from the Latin word *resilio*, which means to leap or spring back **[19]**. It is a concept related to the post-disaster strategy to recover and bounce back in the previous state. Different authors have defined resilience from different social, ecological, and environmental perspectives. Sameen reviewed resilience as a whole process rather than an ultimate result **[20]**. The author emphasized the inclusive design process from a social perspective compared to the reconstruction process from an environmental perspective. The inclusive design process includes providing local mechanisms and practices, utilizing local skills, participation of the local community, involvement of women, and consideration of physically challenged people. The author recommended developing resilience from a community scale instead of a single household scale.

Another possible concept of achieving resilience is through alternative building techniques **[20]**. It includes reducing natural resources, introducing alternative building materials, modifying construction technologies, and alternating built form designs from a technical point of view **[20]**. However, to make the built form cyclone-resilient, the manner of using material is as important as the material itself **[21]**. According to **[22]**, building resilient housing has to encounter three crucial challenges: (1) inadequacies in existing building codes, (2) scarcity of skilled human resources, and (3) limited coverage and implementation of building regulations. The authors insisted on revising the building regulations incorporating wind-resistant structures for all building types in the coastal areas **[22,23]**. Apart from building codes, land use planning and land use control can play vital roles in the preparedness of disaster-resilient communities **[24]**. Preparedness of disaster resilience is a tertiary-level policy that consists of three primary-level policies: (1) prevention (land use planning and controls), (2) response (rescue and encounter), and (3) recovery (counselling and financial aid) and several secondary-level policies such as energy reduction, warning, evacuation, accommodation, restoration, community action, and advocacy **[24]**. Mitigation and adaptation are two elemental responses to encounter disasters around the globe. Mitigation is a long-term precautionary response, whereas adaptation is a short-term response meaning the adjustments or coping mechanism with the context to enhance the liveable quality **[25]**. However, Mowla & Kabir **[26]** indicated that adaptation approaches are more appropriate for the least developed countries like Bangladesh. The authors proposed three potential adaptation approaches for the coastal settlements depending on the degree of vulnerability: protection, accommodation, and retreat.

Tran identified two types of reconstruction approaches in post-disaster housing: (1) beneficiary houses where rebuilding is patronized by donors and (2) non-beneficiary houses where houses are self-built with no outside patronization **[27]**. The author found that regular consultation is key to promote disaster-resilient housing in the design process. Formal community meetings on common aspects and household-level consultation on technical issues are predominant within the beneficiary groups, whereas non-beneficiary groups circumstantially communicate through informal local talks **[27]**. However, in the reconstructed post-disaster housing, cultural aspects are often neglected and rarely addressed. These ignored cultural elements, including family-kinship mutual relations, livelihood, gender-responsive spaces, social interaction through physical and visual permeability, and street fronts, appeared dominantly in the pre-disaster housing **[28]**. Gender inequalities, lack of private spaces for domestic activities, and lack of parochial spaces for economic and social activities affecting climate resilience were also discussed in **[29]**.

Islam, Paull, Griffin, and Murshed were pioneers in considering resilience assessment based on ecosystem services in the pre-cyclone, post-cyclone, and recovery phases **[30]**. Planting more resilient, salinity-tolerant, and high-yielding coastal species can accelerate the recovery phase. It will also provide more resilience to the environment and livelihoods of marginalized communities dependent on the coastal ecosystem. Besides, Dasgupta, Huq, Khan, Ahmed, Mukherjee, Khan, and Pandey had appreciated the planned landscape measures such as increasing the coastal polders' height and extensive foreshore afforestation to protect sea-facing polders **[31]**. The authors also insisted on building private houses as single or multi-family cyclone shelters parallel to the multi-purpose cyclone shelters in Bangladesh **[31]**. Though the existing cyclone shelters network in Bangladesh has acclaimed its global reputation as a critical approach in cyclone preparedness strategies, the system is not sustainable in the long term. The significant constraints against their sustainability are (i) limited accommodation capacity, (ii) uneven distribution of shelters, (iii) poor performance of multi-purpose spaces, and (iv) disintegrated social activities and inadequate economic opportunities **[32]**. Jia identified a research gap in the site planning process of cyclone shelters, as there is strong segregation between the architectural and social approaches **[32]**. These cyclone shelters also neglect variations in landscape, culture, and environment.

Problem statement

Numerous researchers addressed technical aspects of the cyclone-resilient structures and construction techniques of built forms. Agarwal researched cyclone-resistant building architecture and provided guidelines for safe construction techniques based on catastrophic structural failures due to storms **[33]**. Haq and Dutt documented how to make traditional structures more cyclone-resistant and less prone to wind damage by analysing existing housing practices in the coastal areas of Bangladesh **[34]**. Furthermore, studies had shown that the use of bracings and windbreakers minimized the effects of wind on rural huts and proper roofing design prevents roofs from blowing off during storms **[35,36]**. Design of cyclone-resilient house modules had been developed based on affordability following the proper construction techniques, material selection, and structural designs **[5,37]**. Apart from technical aspects, local skills, community engagement, gender inclusion, and concern for disabilities are essential aspects of disaster resilience **[20]**. Implementation of 'Coastal Green Belt' project; structural and non-structural measures such as

nucleated settlement, construction of a safe house, rainwater harvesting, use of renewable energy source and alternative livelihood options; restructuring settlement masterplan could be several adaptive measures to reduce the vulnerability of the coastal people **[26]**. According to Mallick and Rahman **[38]**, improvements in construction and planning of the houses, community organizations, neighbourhoods, and connectivity in the settlements could reduce disaster risk by saving personal, communal, and public assets.

However, studies on synthesizing these perspectives including culture, technique and affordability to achieve a sustainable cyclone-resilient model were limited. Therefore, this paper aims to develop a self-sustaining cyclone-resilient village by adopting the masterplan approach, from designing individual homesteads to planning community facilities and infrastructures. Improving the standard living condition of the coastal community, adapting their housing patterns and lifestyles to mitigate the damage during disastrous events, and ensuring post-disaster quick recovery were the three primary goals in achieving a self-sustaining cyclone-resilient village.

Research objectives

This research focuses on the architectural interventions to encounter the key challenges faced by the south-eastern coastal communities. The aim is to reduce the coastal inhabitants' vulnerability and develop a resilient cyclone settlement by providing them with the resisting and recovering capacity from the prolonged impacts of cyclone-induced disasters. The primary objectives include:

- Identifying the key environmental, social, and economic challenges the community faces and propose macro and micro-level architectural interventions for each issue;
- Proposing a new masterplan approach with planned landscaping;
- Enhancing community involvement;
- Designing cyclone-resilient homestead clusters and built forms according to socio-economic conditions of the community; and
- Exploring techniques to enhance resilient homestead features.

MATERIALS AND METHODS

The research was primarily designed in two phases to attain the research objectives: (i) vulnerability assessment and settlement analysis, and (ii) architectural synthesis and propositions for achieving a cyclone-resilient settlement.

Physical survey for vulnerability analysis

For settlement and vulnerability analysis, a physical survey was conducted during 2020-2021 in an extremely remote coastal village named Khudukkhali in Chhanua, Banshkhali Upazila, Chattogram district. During the survey, the settlement zone, its surroundings, landscape, agricultural and salt fields were meticulously studied. The surveyed houses were marked with numbers, and their floor plans were drawn using mini drone cameras and drawing tools. Through a questionnaire survey, information on the household conditions and their level of vulnerability, the source of freshwater, sanitation, and hygiene conditions were noted. Similarly, the coastal people's regular lifestyle and experience during and after the disaster were documented in direct interviews. Information on the local construction system and deterioration of dwellings by the cyclones was collected during the inspection.

Theoretical framework for architectural synthesis

For architectural synthesis, a participatory and inclusive approach was adopted based on interviewing the affected dwellers, and the theoretical framework suggested by Fien, Charlesworth, Lee, Morris, Baker, and Grice **[39]**. The authors established a cyclic process consisting of six interrelated dimensions of sustainability as a key framework for designing indigenous housing **[39]**. The adopted framework (**Fig. 2**) incorporated the healthy living, environmental, cultural, technical, communal, and economic sustainability within masterplan zoning, followed by cluster design and individual built form design. Following the conceptual framework for disaster-resilient housing suggested in **[40]** and the suggestions of the dwellers, design frameworks for the master plan, housing clusters, and built forms were prepared.

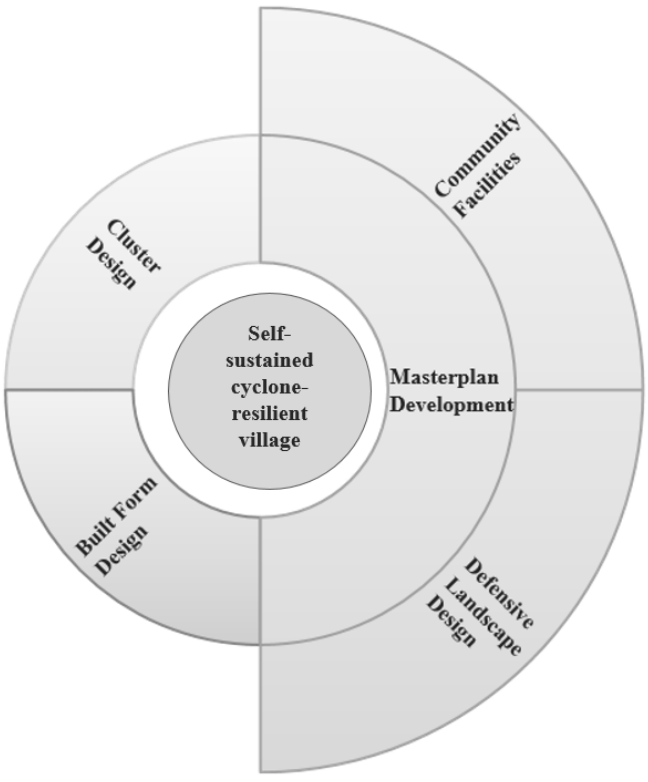


Figure 2: Theoretical framework of the research. Author: Anika Imraana Sohaana

Masterplan design

Firstly, a comprehensive master plan was developed incorporating site and hazard analysis, landscape planning, infrastructures, community facilities, and employment development (**Fig. 3**). A defensive landscape plan was proposed with vegetation layers to reduce wind effects from cyclones and connect the existing canals for a proper drainage system. Besides, the existing primary road was connected with the peripheral roads surrounding the settlement clusters. According to the population analysis, amenities and community facilities were placed at the settlement clusters' intersections and the nodes.

Housing cluster design

Secondly, the plan and organization of housing clusters was developed according to different socio-economic groups – primary clusters, farmers, and fishermen. Cluster designs were intended to reduce high-wind impact, encourage community involvement and minimize cost (**Fig. 4**).

Built form design

Thirdly, the individual built form design followed cyclone-resilient design guidelines (**Fig. 5**). A basic house module was proposed with the scope of future expansion for accommodating population growth and economic growth. House modules were planned according to affordability and incremental phases, where they could also act as pre-cyclone shelters.

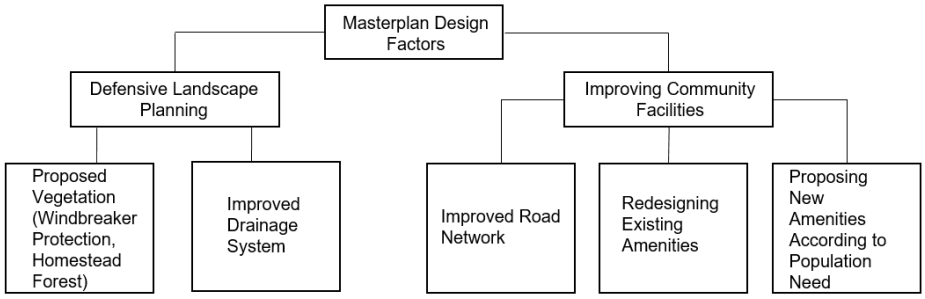


Figure 3: Factors considered for the master plan proposal.

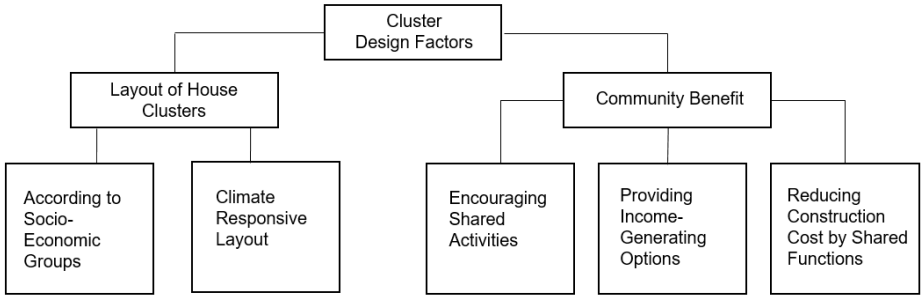


Figure 4: Factors considered for the housing cluster design.

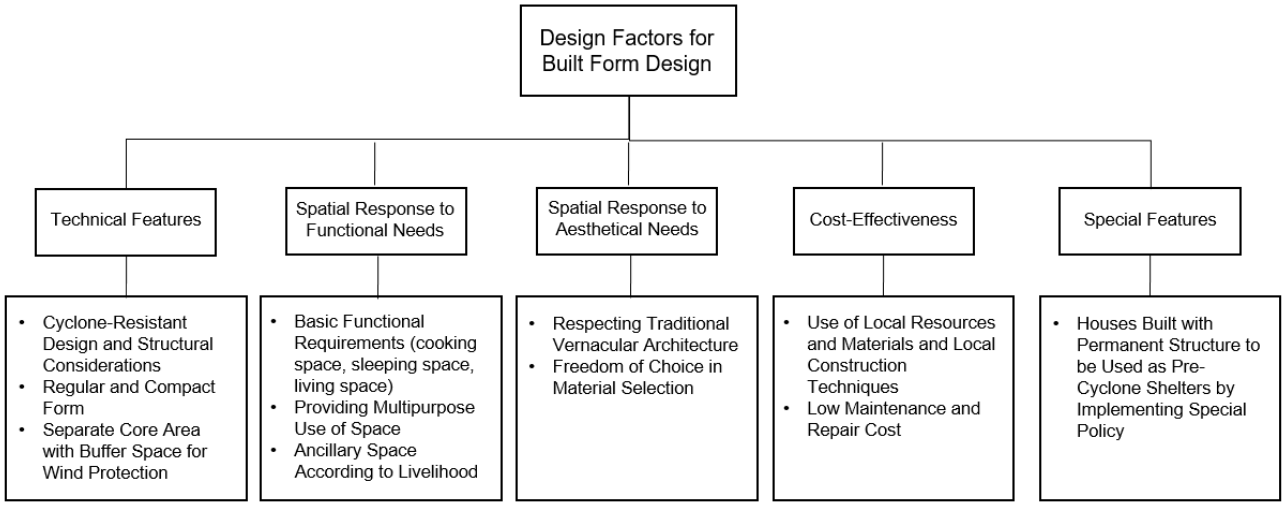


Figure 5: Factors considered for the built form design.
Author (Fig. 3-5): Anika Imraana Sohaana

Geographical and community profile of the study area

The surveyed area was located in the exposed zone of Chattogram coastal plain in the south-eastern coastal region (**Fig. 6a**). The Kutubdia channel of the Bay of Bengal flowed on the west of the union. A 2.14 m high mud embankment protected the village, was constructed 190 m from the coastline and 100 m from the shoreline. Human settlements were elevated 5-6 m above sea level, whereas the lower lands of 2-4 m elevation were predominantly agricultural lands and salt fields.

The settlement mapping and demographic data showed that almost 160 households with around 800 people lived in the village. Every household had an average of 6 family members. The whole settlement area was 50 acres and cultivable fields covered 68 acres of land. Almost 60% of the inhabitants owned livestock and poultry. The settlement also had a multi-purpose cyclone shelter, a mosque, a primary school with shelter facilities, and a community clinic.

The socio-economic statistics (**Fig. 6b**) illustrated that almost 80% of the inhabitants depended on three significant occupations – day-labouring (salt fields, paddy fields, and fishery), sharecropping (rice, vegetables, salt), and fishing. Due to less scope of work around the whole year, many inhabitants migrated temporarily or permanently to the neighbouring cities searching for employment.

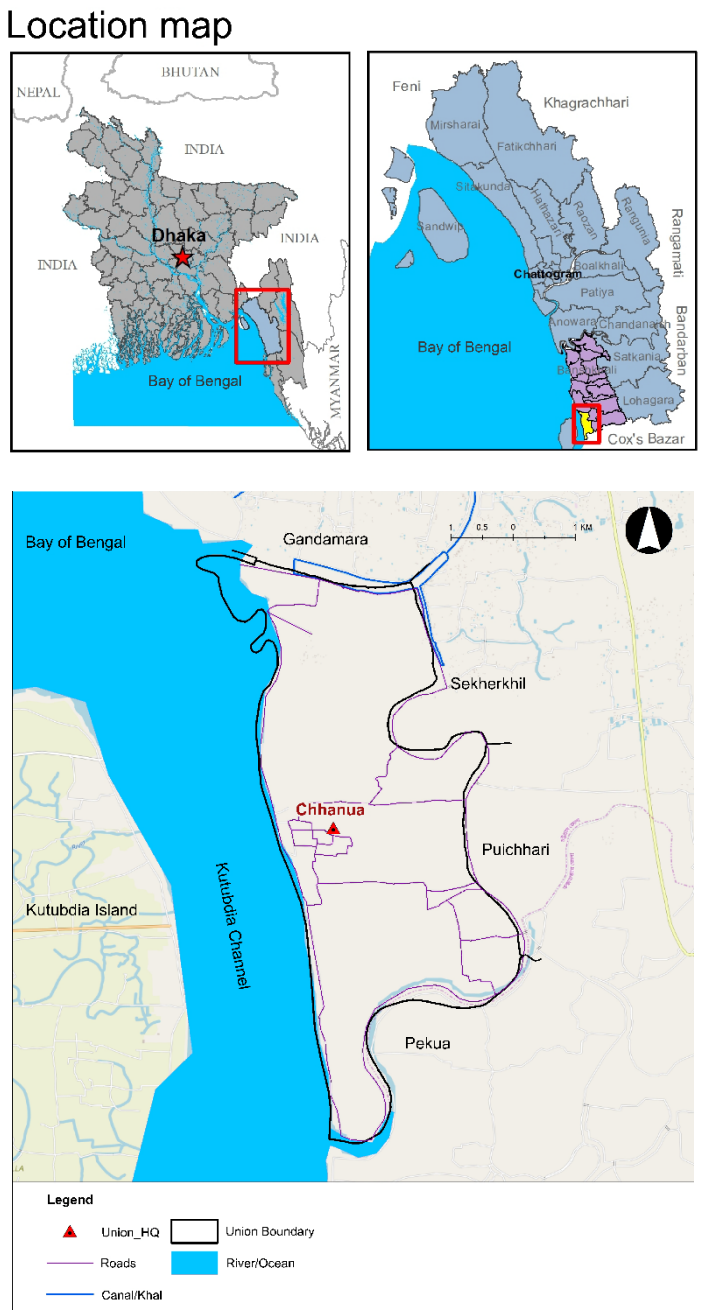


Figure 6a: Geographic profile of the community.
Author: Anika Imraana Sohaana
Source: CARITAS, Bangladesh

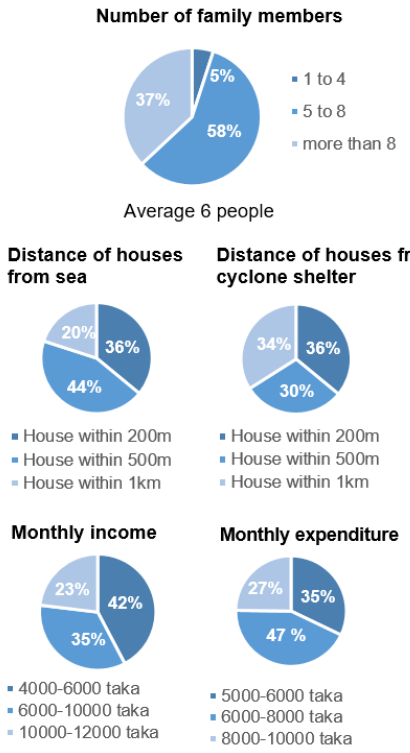


Figure 6b: Demographic profile of the community.
Author: Anika Imraana Sobaana

SETTLEMENT ANALYSIS AND VULNERABILITY ASSESSMENT

The existing settlements in the surveyed coastal village were located sparsely across the area. Three particular types of communities with varying occupations were identified. The three predominant settlements were the fishermen community, farming community, and salt-producer community. The vulnerability in their settlements was assessed at two scales – macro (collective) and micro (individual) scale.

Macro-scale assessment

The research found that all three types of settlements had varying degrees of vulnerability. The fishermen community had an isolated location along the mud embankment. Due to its adjacency to the sea, the community had the most vulnerable condition and least protection from high wind. Conversely, the nucleated settlements of the farmers and day labourers in the inner village were less exposed to tropical cyclones. Most of the existing homesteads were oriented improperly in the along-wind direction (**Fig. 7**).

The coast was exposed in most places with negligible plantation barriers. Alarmingly, settlements were expanding by destroying agricultural lands and forests. They had less buffer space with the road, and the evacuation road was not safe due to unsatisfactory conditions. A canal connected to the Kutubdiia channel was the single source of stormwater drainage during the high surges. Although the settlement had a single cyclone shelter within the evacuation range, no facilities for physically challenged were present. Overall, collective communal approaches to precaution against disasters were absent. However, the fishermen and the farmers' community had strong cultural interrelations.

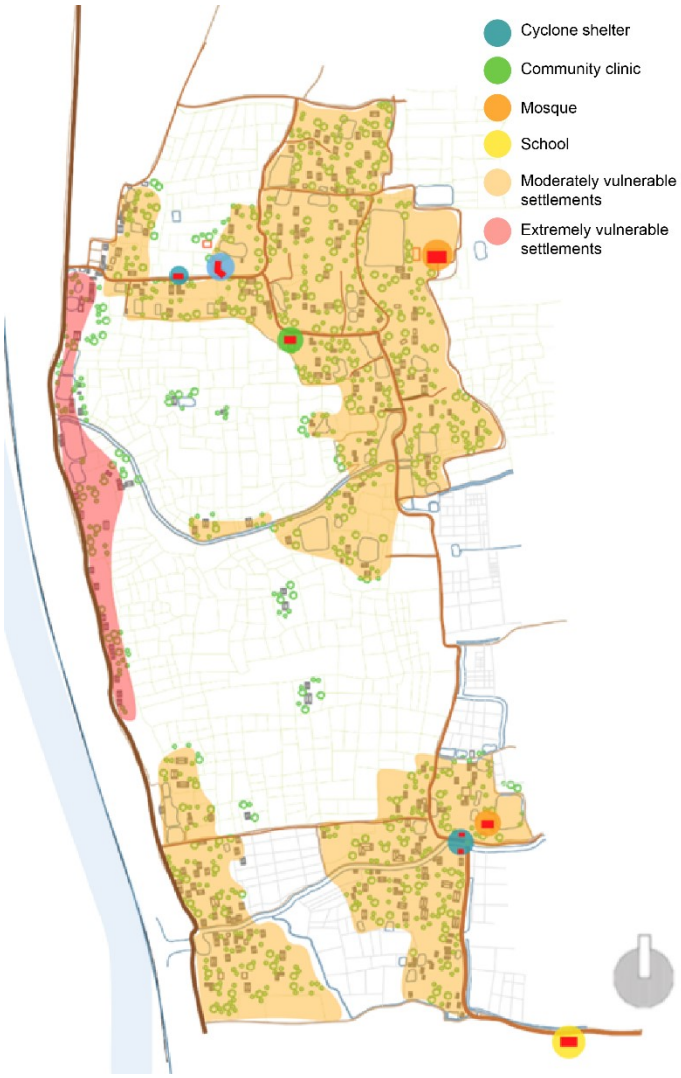


Figure 7: Macro-scale mapping of the existing settlements
Author: Anika Imraana Sohaana

Micro-scale assessment

Table 1: Vulnerability assessment of four house types.
Authors: Anika Imraana Sohaana, Md Arifur Rahman

	House Type 1	House Type 2	House Type 3	House Type 4
Settlement type and location	Linear, isolated, along the embankment	Scattered, 500 m away from the shoreline	Nucleated, 1 km away from the shoreline	Nucleated, 1 km from the shoreline
Occupation	Fishermen	Salt-farmers	Farmers, day labourers	Farmers
Economic vulnerability	Very poor	Poor	Poor, marginal	Poor
Disaster vulnerability	Extremely vulnerable to cyclone and tidal surge	Vulnerable to cyclone	Vulnerable to cyclone	Vulnerable to cyclone
Structural vulnerability	Exposed walls, fragile materials	Collapsing roof, inferior materials	Perilous (L-shape) extension	Gable roof, core house relatively safe

House Type 1



House Type 2



House Type 3



House Type 4



The research of the existing settlements found four types of houses. **Tab. 1** summarized their characteristics and vulnerability conditions. Most households had a very compact functional arrangement as the granary, kitchen, and the storage space was inside the main house. Use of local materials such as mud, bamboo, and thatch was preferred. However, most house forms were in vulnerable structural conditions. The low mud plinths were very prone to coastal flooding and heavy showers. The structural junctions were fragile to withstand high wind. The living and sanitation facilities inside the houses were also substandard.

Identification of key challenges

The settlement and vulnerability analysis identified fundamental design issues, and architectural interventions were proposed accordingly. The design issues were categorized by three broader aspects of sustainability: environmental, social, and economic challenges. **Fig. 8** illustrates the macro and micro-level architectural interventions for those challenges.

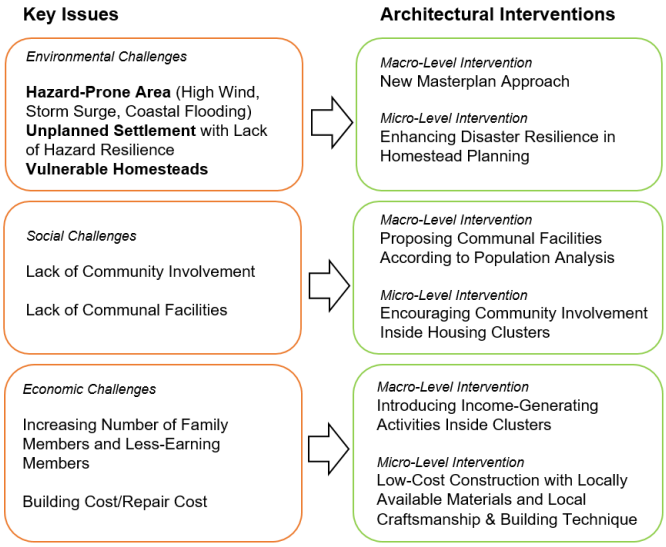


Figure 8: Key challenges and their architectural interventions. Author: Anika Imraana Sohaana

ARCHITECTURAL SYNTHESIS

The resilient homestead, cluster development, and landscape master plan represented the architectural synthesis of economic, social, and environmental interventions. To enhance resilience, the coastal inhabitant's lifestyle, adaptation capabilities, and post-disaster recovery were considered.

Resilient homestead

The inhabitants were provided multiple design options with flexible materials to select according to their affordability and profession. Households with better financial stability could build their houses on stilt using permanent materials. In farmers' homesteads, a square-shaped courtyard (9.5 m x 9.5 m), suitable for crop harvesting, was developed. Similarly, a linear yard for dry-fish processing and net-weaving works was created in fishermen's homesteads.

Form generation

The primary form was generated by creating an internal core space as the dwelling unit, surrounded by a multi-purpose 'pashchati' space that worked as the buffer space for the core area to withstand strong winds. Granaries and ancillary facilities could be added to the multi-purpose room, creating a compact form during future extension (**Fig. 9**). With further economic development, the replacement with stronger material and structural junctions could further strengthen the house.

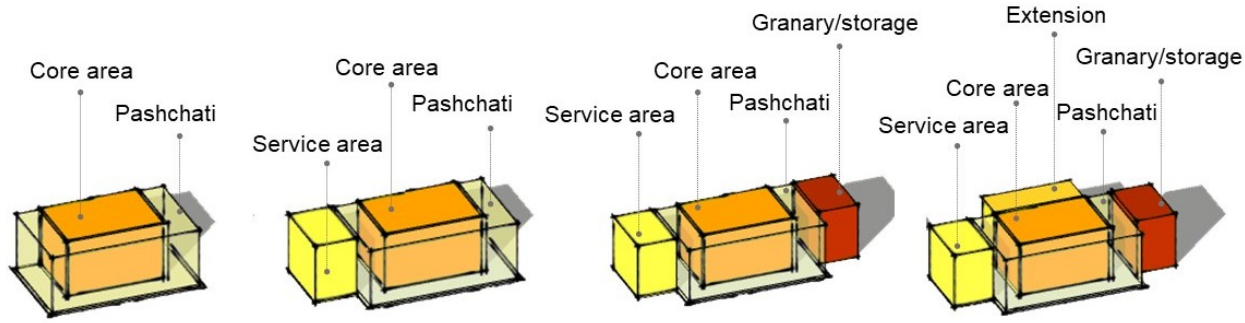


Figure 9: Built form generation processes
Author: Anika Imraana Sohaana

Basic homestead module

The basic module had a 15.6 sqm sleeping space as the core area surrounded by a 17.7 sqm multi-purpose pashchati space (**Fig. 10**). A 5.8 sqm cooking space was proposed beside the pashchati. Ancillary spaces such as granaries, fishing accessories storage, etc., were placed adjacent to the pashchati. An additional 10.3 sqm sleeping space could be added behind the core room.



Figure 10: Proposed homestead modules.
Author: Anika Imraana Sohaana

Construction techniques

In detail design, various construction techniques were studied and applied to make the structure more resilient and withstand the cyclonic impact. Low-cost, locally available, and sustainable materials were chosen to ease the repairing and retrofitting process.

The overall construction phases shown in **Fig. 11** could be summarized as:

a. Construction of concrete stamp footings and a 1 m high mud plinth.

b. Erection of bamboo posts connected to the concrete stamps for structural support.

c. Building bamboo mat walls supported with diagonal bracings.

d. Building roof frame using bamboo or wood.

e. Placing thatched roof over the pashchati and corrugated sheet over the core space.

f. Covering the pashchati space with operable screens of low-cost materials for multi-purpose use.

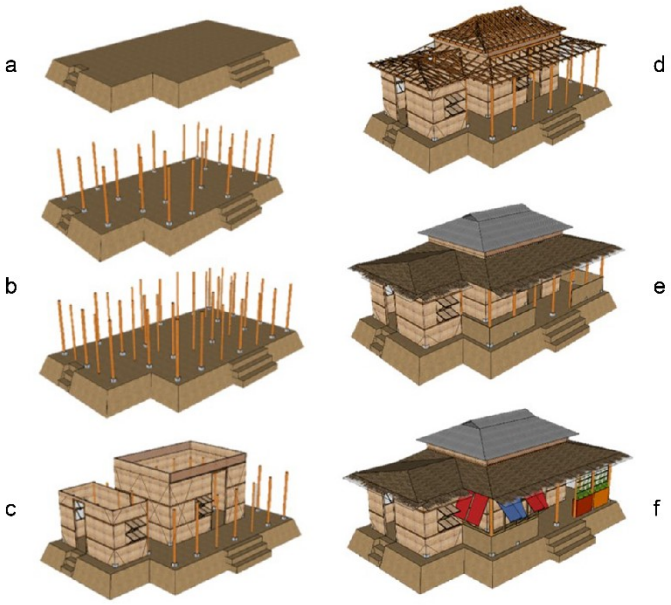
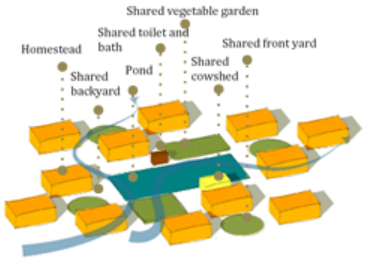
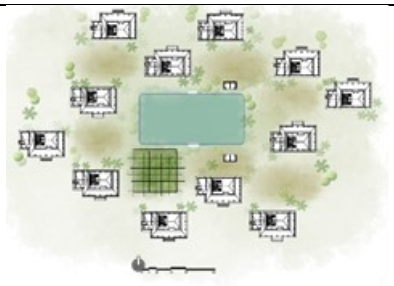
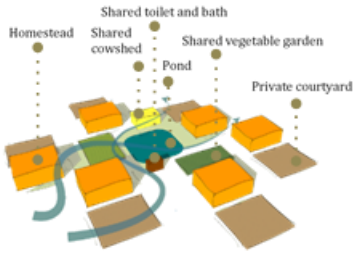
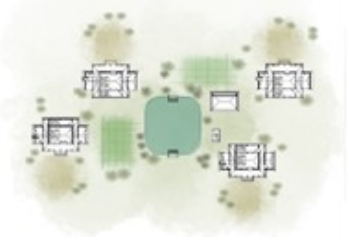


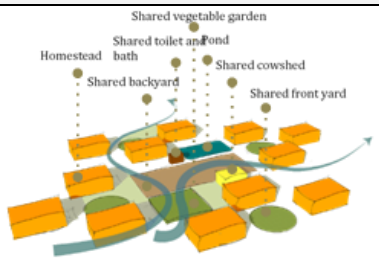
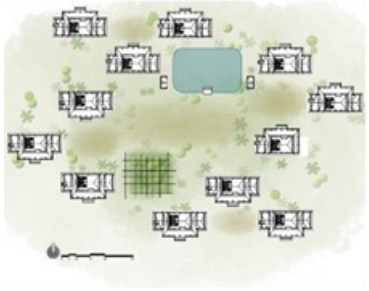
Figure 11: Construction phases and structural materials
Author: Anika Imraana Sohaana

Cluster formation and community development

Three types of house clusters, including the general layout, farmer houses, and fishermen houses were proposed, as illustrated in **Tab. 2**. Homesteads in the clusters were organized in an irregular grid pattern to reduce wind pressure. Community involvement through shared activities was encouraged. Construction of a shared cowshed and toilet in the backyard was proposed to minimize the cost. The introvert backyard also provided female members additional income-generating options such as kitchen gardening and poultry farming. Homestead clusters were further developed according to socio-economic hierarchies and occupation. A shared inner backyard was created for the fishermen community instead of extrovert courtyards like for the farmers' community. The zones for amenities and community facilities were proposed at the intersection points of the clusters and the major road. An informal school was established to serve the community with informal education such as health, sports, adult, and extracurricular activities. It would also act as an emergency cyclone shelter during an emergency.

Table 2: Formation of different clusters.
Author: Anika Imraana Sohaana

Type 1	**General cluster development**
Schematic zoning	
Cluster Plan (phase 1)	
Cluster Plan (phase 2)	
Type 2	**Cluster development for farmers**
Schematic zoning	
Cluster Plan (phase 1)	

Cluster Plan (phase 2)	
Type 3	**Cluster development for fishermen**
Schematic zoning	
Cluster Plan (phase 1)	
Cluster Plan (phase 2)	

Selected homesteads with better financial and structural stability were encouraged to use the outhouse as the 'pathshala' for the children. Those houses would act as the shelter themselves for accommodating the villagers during cyclones (**Fig. 12**). They would be located within the walkable limit of each cluster. The incentive for these households to use their houses as multi-purpose cyclone shelters to serve other villagers will be to receive easy financial loans.



Figure 12: (Caption opposite)



Figure 12: Homestead design as a multi-purpose cyclone shelter. Author: Anika Imraana Sohaana

Landscape master plan

A comprehensive landscape master plan was developed, including vegetation, drainage, road network, and emergency evacuation plan. Following the coastal plantation guidelines, three-layered landscapes were planned to achieve maximum protection from cyclonic wind (**Fig. 13**). Large windbreaker trees were suggested on both sides of the embankment to diffuse the wind pressure in the outer layer. The mid-layer plantation between the housing clusters, peripheral roads, and agricultural land would provide additional protection. The inner-layer vegetation with diminutive height would be planted around the homesteads for privacy and economic purposes.

A drainage system around the housing clusters and agricultural land was developed (**Fig. 13**). It was adjacent to the existing Jalkadar canal further connected to the Kutubdia Channel with a sluice gate to prevent the settlement from waterlogging. Besides, peripheral secondary and tertiary roads surrounding the clusters were proposed. As they were connected to the primary community road, they would quickly help access the nearest cyclone shelter during an emergency. A community field was proposed adjacent to the informal school, which would act as the playground and community gathering space for occasions such as sports events, village fairs, and wedding ceremonies. The field would also act as a helipad for emergency relief and rescue after a severe cyclone.



Figure 13: Proposed three-layered landscape master plan with peripheral drainage and roads
Author: Anika Imraana Sohaana

DISCUSSION

Previous researches on cyclone-resilient settlements partially resulted in the juxtaposition of socio-cultural factors and architectural synthesis. Many case studies around the globe also showed similar results. The current practice mostly followed the popular trend of monothetic and one-dimensional approaches in immediate response to disasters and local adaptation policies. As a result, many practical projects and recovery programs eventually failed or did not provide the expected outcome. In Kutubdia Island, Bangladesh, the preventive physical barrier, constructed as a response after the 1991 super cyclone, failed to protect in the long-term, as overflowing surges later resulted in the displacement of the community and change of livelihoods **[41]**. However, the outcomes drastically improved during Cyclone Aila in 2009, as both in-advance structural and non-structural measures were taken to reinforce adaptive capabilities within the vulnerable coastal communities **[41]**. In Taiwan, after Typhoon Morakot in 2009, the government adopted a relocation policy for the indigenous communities, which immediately caused protests and inter-community disputes. Most communities living in the mountains declined to migrate to a new place. The policy ultimately dispersed the communities into different settlements and forced them to change their livelihoods **[42]**. Brazil and

Cameroon also suffered from coastal hazards, as their governments' classical emergency response policies were considered obsolete, insufficient, and inflexible **[43]**. Their top-down approaches and hard-engineering solutions, as an immediate reaction to post-disaster adaptation, lacked community participation and indigenous knowledge.

In these cases, resilient measures adopted a reactive and responsive approach to recovery during the post-disaster period rather than a precautionary approach before the disaster. Besides, traditional coping techniques and lessons were often overlooked during the recovery policy, for instance, in the cases of Cameroon and Taiwan. This research resulted in a comprehensive approach through synthesizing socio-economic factors, and community traditions with architectural innovation. The ultimate result, visualizing the implementation process of the cyclone-resilient village as a non-migratory and collective preparedness and precautionary approach, could be a potential achievement of this research. Although the proposed design is yet to be implemented or tested as a pilot project, the inclusion of participatory site planning and landscape master plan during the architectural synthesis and disaster preparedness would also create a new approach and further scope for research.

CONCLUSION

Climate change has adversely impacted the occurrence and frequency of natural hazards, which is currently a prime global concern, particularly in low-lying countries. Bangladesh's coastal communities were historically and geographically vulnerable due to periodical cyclones. Although the mortality from cyclones had significantly dropped because of an improved disaster forecasting system in recent years, the property wrecks during cyclones were tremendous. Alarmingly, the psychological damages caused by those disasters were immeasurable and it would take a long time to recover from the post-trauma. Even a single disaster could make the entire life of the community miserable. As an immediate initiative for disaster risk reduction, numerous cyclone shelters were constructed in the coastal region of Bangladesh.

Nevertheless, lately, the inhabitants have been reluctant to leave their possessions at risk and transfer themselves to the cyclone shelters. As a consequence, several researchers and professionals insisted on and prioritized the construction of cyclone-resistant homesteads. Unfortunately, their proposed structures, selection of materials, and construction techniques proved expensive for the economically vulnerable inhabitants. Hence, an affordable model of the cyclone-resilient coastal village was proposed at Khudukkhali village, a cyclone-prone remote village located in the south-eastern coastal belt, for the benefit of its inhabitants, where the beneficiaries would adapt to a life with disasters. To encounter the catastrophe, they would have to reshape their lifestyles accordingly.

The architectural synthesis followed a participatory and polythetic approach through integrating technical innovations with community engagement, ecological interventions, and traditional practices. The proposed resilient homesteads would serve the basic functional demands in ordinary times and survive during moderate to regular cyclones. Even if the built forms might get partially damaged during severe to super cyclones, the houses could be repaired rapidly and easily because of lightweight and low-cost materials. Unlike the south-western and central coastal regions, the protection with mangrove forests was absent in the south-eastern coast, making it more vulnerable to high wind and tidal surges. A defensive landscape plan was developed through coastal afforestation with windbreaker trees at a safer distance from the housing clusters to reduce high wind impact. The financially stable households in the community were encouraged to provide shelter during emergencies. As disasters should be encountered collectively, increasing community interactions with shared activities and functions was highly appreciated.

Consequently, through cyclone-resilient built form design, defensive landscape planning, and community development, the coastal communities of south-eastern Bangladesh would be able to reduce vulnerability, enhance their resilient capabilities, and induce self-sustenance. This inclusive design process could also be implemented by similar vulnerable communities in other contexts to adapt to the changing climate and achieve self-sustainability.

Acknowledgments

The authors are grateful to the Department of Architecture, SUST and CARITAS, Bangladesh for their altruistic cooperation.

REFERENCES:

[1] Garschagen, M., Hagenlocher, M., Comes, M., Dubbert, M., Sabelfeld, R., Lee, Y. J., Grunewald, L., Lanzendörfer, M., Mucke, P., Neuschäfer, O., Pott, S., Post, J., Schramm, S., Schumann-Bölsche, D., Vandemeulebroecke, B., Welle, T., Birkmann, J. (2016) “World Risk Report 2016”, United Nations University–Institute for Environment and Human Security, Berlin, Germany, Rep. 5763. Available at: http://collections.unu.edu/eserv/UNU:5763/WorldRiskReport2016_small_meta.pdf [Accessed: 12 March 2021]

[2] Das, P. K. (1972) “Prediction model for storm surges in the Bay of Bengal”, Nature, Volume 239, pp. 211-213. https://doi.org/10.1038/239211a0 [DOI]

[3] Karim, M. F., Mimura, N. (2008) “Impacts of climate change and sea-level rise on cyclonic storm surge floods in Bangladesh”, Global environmental change, Volume 18, issue 3, pp. 490-500. https://doi.org/10.1016/j.gloenvcha.2008.05.002 [DOI]

[4] Quader, M., Khan, A., Kervyn, M. (2017) “Assessing Risks from Cyclones for Human Lives and Livelihoods in the Coastal Region of Bangladesh”, International Journal of Environmental Research and Public Health, Volume 14, issue 8, p. 831. https://doi.org/10.3390/ijerph14080831 [DOI]

[5] Aves, R. (2012) “Bangladesh: Coastal Climate-Resilient Infrastructure Project”, Asian Development Bank and Local Government Engineering Department, People’s Republic of Bangladesh, Dhaka, Bangladesh, Rep. TA 7902-BAN. Available at: https://www.adb.org/sites/default/files/project-documents/45084-001-ban-tacr-a.pdf [Accessed: 12 March 2021]

[6] MoEF (2009) “Bangladesh climate change strategy and action plan 2009”, Ministry of Environment and Forests, Government of the People's Republic of Bangladesh, Dhaka, Bangladesh, Rep. xviii. Available at: https://www.iucn.org/content/bangladesh-climate-change-strategy-and-action-plan-2009 [Accessed: 12 March 2021]
[7] Ahmed, B., Kelman, I., Fehr, H.K., Saha, M. (2016) “Community resilience to cyclone disasters in coastal Bangladesh”, Sustainability, Volume 8, issue 8, pp. 805. https://doi.org/10.3390/su8080805 [DOI]
[8] Paul, B. K. (2009) “Why relatively fewer people died? The case of Bangladesh's Cyclone Sidr”, Natural Hazards, Volume 50, pp. 289-304. https://doi.org/10.1007/s11069-008-9340-5 [DOI]
[9] Mamun, S. B. (2019) “Towards a cyclone resilient settlement form for coastal areas of Bangladesh”, Master's dissertation, Bangladesh University of Engineering and Technology. Available at: http://lib.buet.ac.bd:8080/xmlui/handle/123456789/5506 [Accessed: 12 March 2021]
[10] Uddin, M. N., Islam, A. S., Bala, S. K., Islam, G. T., Adhikary, S., Saha, D., Haque, S., Fahad, M. G. R., Akter, R. (2019) “Mapping of climate vulnerability of the coastal region of Bangladesh using principal component analysis”, Applied Geography, Volume 102, issue 1, pp. 47-57. https://doi.org/10.1016/j.apgeog.2018.12.011 [DOI]
[11] Ahmed, A. U., Haq, S., Nasreen, M., Hassan, A. W. R. (2015) “Climate change and disaster management, 7th Five Year Plan (2016–2021)”, General Economics Division (GED), Dhaka, Bangladesh, Rep. vii-January. Available at: http://nimc.portal.gov.bd/sites/default/files/files/nimc.portal.gov.bd/page/6c53bd88_ad69_4ccf_bbae_d45b70dbc0bf/017%207th%20FYP%20and%202021%20Climate-Change-and-Disaster-Management.pdf [Accessed: 12 March 2021]
[12] Ahmad, H. (2019) “Bangladesh coastal zone management status and future trends”, Journal of Coastal Zone Management, Volume 22, issue 1, pp. 1-7. https://doi.org/10.24105/2473-3350.22.466 [DOI]
[13] Ali, A. (1999) “Climate change impacts and adaptation assessment in Bangladesh”, Climate Research, Volume 12, issue 2-3, pp. 109-116. https://doi.org/10.3354/cr012109 [DOI]
[14] Singh, O. P., Khan, T. M. A., Rahman, S (2000) “The Vulnerability Assessment of the SAARC Coastal Region Due to Sea Level Rise: Bangladesh Case”, SAARC Meteorological Research Centre (SMRC), Dhaka, Bangladesh.
[15] World Bank (2011) “The Cost of Adapting to Extreme Weather Events in a Changing Climate, Bangladesh”, World Bank, Dhaka, Bangladesh, Rep. no. 28. Available at: https://documents1.worldbank.org/curated/en/716231468014361142/pdf/678450NWP0Box3000BDS28ClimateChange.pdf [Accessed: 12 March 2021]
[16] Hossain, I., Mullick, A. R. (2020) “Cyclone and Bangladesh: A Historical and Environmental Overview from 1582 to 2020”, International Medical Journal, Volume 25, issue 6, pp. 2595-2614. [online] Available at: https://www.researchgate.net/publication/344321172_Cyclone_and_Bangladesh_A_Historical_and_Environmental_Overview_from_1582_to_2020 [Accessed: 4 April 2021]
[17] Islam, M. A., Paull, D. J., Griffin, A. L., Murshed, S. (2021) “Spatio-temporal assessment of social resilience to tropical cyclones in coastal Bangladesh”, Geomatics, Natural Hazards and Risk, Volume 12, issue 1, pp. 279-309. https://doi.org/10.1080/19475705.2020.1870169 [DOI]
[18] Centre for Research on Epidemiology of Disasters (2020). “EM-DAT: the international disaster database”, EM-DAT, CRED / UCLouvain, Brussels, Belgium. [online] Available at: https://www.emdat.be/ [Accessed: 28 April 2021]
[19] Eadie, P. (2019) “Typhoon Yolanda and post-disaster resilience: Problems and challenges”, Asia Pacific Viewpoint, Volume 60, pp. 94-107. https://doi.org/10.1111/apv.12215 [DOI]
[20] Sameen, S. (2018) “Process inclusive Infrastructure: Notions towards Cyclone Resilience in Bangladesh”, Procedia Engineering, Volume 212, pp. 30-38. https://doi.org/10.1016/j.proeng.2018.01.005 [DOI]
[21] Seraj, S.M., Ahmed, K.I. (2004) “Building safer houses in rural Bangladesh”, Bangladesh University of Engineering and Technology, Dhaka, Bangladesh. Available at: https://arc456.files.wordpress.com/2015/02/building-safer-houses-in-rural-bangladesh.pdf [Accessed 28 April 2021]
[22] Aquino, D. H., Wilkinson, S. J., Raftery, G., Potangaroa, R., Chang-Richards, A. (2018) “Challenges to building housing resilience: The case of Fiji post-cyclone Winston”, Procedia Engineering, Volume 212, pp. 475-480. https://doi.org/10.1016/j.proeng.2018.01.061 [DOI]
[23] Aquino, D. H., Wilkinson, S. J., Raftery, G., Potangaroa, R. (2019) “Building back towards storm-resilient housing: Lessons from Fiji's Cyclone Winston experience”, International Journal of Disaster Risk Reduction, Volume 33, pp. 355-364. https://doi.org/10.1016/j.ijdrr.2018.10.020 [DOI]
[24] Harwood, S., Carson, D., Wensing, E., Jackson, L. (2014) “Natural Hazard Resilient Communities and Land Use Planning: The Limitations of Planning Governance in Tropical Australia”, Journal of Geography & Natural Disasters, Volume 4, issue 2, pp. 130. https://doi.org/10.4172/2167-0587.1000130 [DOI]
[25] Mowla, Q. A., Zareen, N. (2005) “Ecological Interpretation of Community Structure and Urban Growth”, Asian Studies, Volume 24, pp. 31-42. [online] Available at: https://www.researchgate.net/publication/292143937_Ecological_Interpretation_of_Community_Structure_and_Urban_Growth [Accessed: 10 April 2021]
[26] Mowla, Q. A., Kabir, S. (2012) “Response to Climate Change: Bangladesh Experience”, In National Seminar on Climate Change Impact and Adaptation, DUET, Dhaka, Bangladesh, pp. 62-73. [online] Available at: https://www.researchgate.net/publication/236233100_RESPONSE_TO_CLIMATE_CHANGE_BANGLADESH_EXPERIENCE#fullTextFileContent [Accessed: 10 April 2021]
[27] Tran, T.A. (2015) “Post-disaster housing reconstruction as a significant opportunity to building disaster resilience: a case in Vietnam”, Nat Hazards, Volume 79, pp. 61–79. https://doi.org/10.1007/s11069-015-1826-3 [DOI]
[28] Pasupuleti, R. S. (2013) “Designing culturally responsive built environments in post disaster contexts: Tsunami affected fishing settlements in Tamilnadu, India”, International Journal of Disaster Risk Reduction, Volume 6, pp. 28-39. https://doi.org/10.1016/j.ijdrr.2013.03.008 [DOI]
[29] Jabeen, H. (2019) “Gendered space and climate resilience in informal settlements in Khulna City, Bangladesh”, Environment and Urbanization, Volume 31, issue 1, pp. 115–138. https://doi.org/10.1177/0956247819828274 [DOI]
[30] Islam, M. A., Paull, D. J., Griffin, A. L., Murshed, S., (2020) “Assessing ecosystem resilience to a tropical cyclone based on ecosystem service supply proficiency using geospatial techniques and social responses in coastal Bangladesh”, International Journal of Disaster Risk Reduction, Volume 49, pp. 101667. https://doi.org/10.1016/j.ijdrr.2020.101667 [DOI]
[31] Dasgupta, S., Huq, M., Khan, Z. H., Ahmed, M. M. Z., Mukherjee, N., Khan, M. F., Pandey, K. (2014) “Cyclones in a changing climate: the case of Bangladesh”, Climate and Development, Volume 6, issue 2, pp. 96-110. https://doi.org/10.1080/17565529.2013.868335 [DOI]
[32] Jia, Z. (2012) “Cyclone Shelters and Cyclone Resilient Design in Coastal Areas of Bangladesh”, Master's Dissertation, Department of Urban Studies and Planning, Massachusetts

Institute of Technology, USA. Available at: https://dspace.mit.edu/handle/1721.1/77834 [Accessed: 5 May 2021]
[33] Agarwal, A. (2007) “Cyclone Resistant Building Architecture”, Government of India-United Nations Development Programme (UNDP), New Delhi, India, Rep. Disaster Risk Management Programme. Available at: https://www.preventionweb.net/publication/cyclone-resistant-building-architecture [Accessed: 10 April 2021]
[34] Haq, B., Dutt, P. C. (2007) “Battling the storm: study on cyclone resistant housing”, Bangladesh Red Crescent Society/ German Red Cross, Dhaka, Bangladesh, 2nd edition. Available at: https://www.humanitarianlibrary.org/resource/battling-storm-study-cyclone-resistant-housing-1 [Accessed: 10 April 2021]
[35] Roy, U.K., Hodgson, R.L.P., Seraj, S.M. (2000) “Experimental Study on Wind Effects on Bangladeshi Rural Hut”, In Proceedings of H&H 2000 Conference, Dhaka & Exeter, Bangladesh, pp. 165-174. Available at: https://www.salekseraj.com/C08.pdf [Accessed: 28 April 2021]
[36] Taher, R. (2010) “General Recommendations for Improved Building Practices in Earthquake and Hurricane Prone Areas”, Architecture for Humanity, New Jersey, USA. Available at: https://www.humanitarianlibrary.org/resource/general-recommendations-improved-building-practices-earthquake-and-hurricane-prone-areas-0 [Accessed: 10 April 2021]
[37] HBRI (2018) “Standard Guideline for Rural Housing in Disaster Prone Areas of Bangladesh”, Housing and Building Research Institute, Ministry of Housing and Public Works, Government of Bangladesh, Dhaka. Available at: https://www.sheltercluster.org/sites/default/files/docs/standard_guideline_for_rural_housing_in_disaster_prone_areas_bangladesh1.compressed_0.pdf [Accessed: 10 April 2021]
[38] Mallick, F., Rahman, A. (2013) “Cyclone and tornado risk and reduction approaches in Bangladesh”, In: R. Shaw, F. Mallick, A. Islam (Eds.), Disaster risk reduction approaches in Bangladesh, Springer, Tokyo, pp. 91-102. https://doi.org/10.1007/978-4-431-54252-0 [DOI]
[39] Fien, J., Charlesworth, E., Lee, G., Morris, D., Baker, D., Grice, T. (2008) “Towards a design framework for remote Indigenous housing”, Australian Housing and Urban Research Institute Limited (AHURI), Melbourne, Australia, Rep. No. 114. Available at: https://www.ahuri.edu.au/research/final-reports/114 [Accessed: 5 May 2021]
[40] Tran, T.A. (2016) “Design Framework for Disaster-Resilient Housing”, In: Developing Disaster Resilient Housing in Vietnam: Challenges and Solutions, Springer, Cham, Switzerland, pp. 191-222. https://doi.org/10.1007/978-3-319-26743-2_8 [DOI]
[41] Kaluarachchi, Y. (2018) “Building Community Resilience in the Re-settlement of Displaced Communities”, Procedia Engineering, Volume 212, pp. 443–450. https://doi.org/10.1016/j.proeng.2018.01.057 [DOI]
[42] Taiban, S., Lin, H. N., Ko, C. C. (2020) “Disaster, relocation, and resilience: recovery and adaptation of Karamemedesane in Lily Tribal Community after Typhoon Morakot, Taiwan”, Environmental Hazards, Volume 19, issue 2, pp. 209–222. https://doi.org/10.1080/17477891.2019.1708234 [DOI]
[43] Leal Filho, W., Modesto, F., Nagy, G. J., Saroar, M., YannickToamukum, N., Ha'apio, M. (2018) “Fostering coastal resilience to climate change vulnerability in Bangladesh, Brazil, Cameroon and Uruguay: a cross-country comparison”, Mitigation and Adaptation Strategies for Global Change, Volume 23, issue 4, pp. 579–602. https://doi.org/10.1007/s11027-017-9750-3 [DOI]