SALINE WATER PURIFICATION TECHNOLOGY AT HOUSEHOLD LEVEL AND LOW-COST DURABLE HOUSING TECHNOLOGY FOR COASTAL AREAS OF BANGLADESH

Durable Housing Technology Solutions

KICT

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1. INTRODUCTION

The main objectives of this project for developing affordable and durable housing construction methods in the context of the climate of the coastal areas of Bangladesh are: 1) to survey of climate conditions in the southern part of Bangladesh and analyze the factors that affect the durability of housing, 2) to propose the construction of durable housing using local materials and performance standards, and 3) to propose a pilot model for constructing durable housing.

Firstly, to find the optimal means of building a durable residence for low-income residents in the southern coastal region of Bangladesh, a series of surveys on 1) the local housing context, 2) the status of building materials and production infrastructure, and 3) local building standards and methods was conducted. After these surveys were completed, performance standards and criteria for optimal construction materials in the local residential context were established, along with prototypes for housing.

Table 1 Key steps of this project

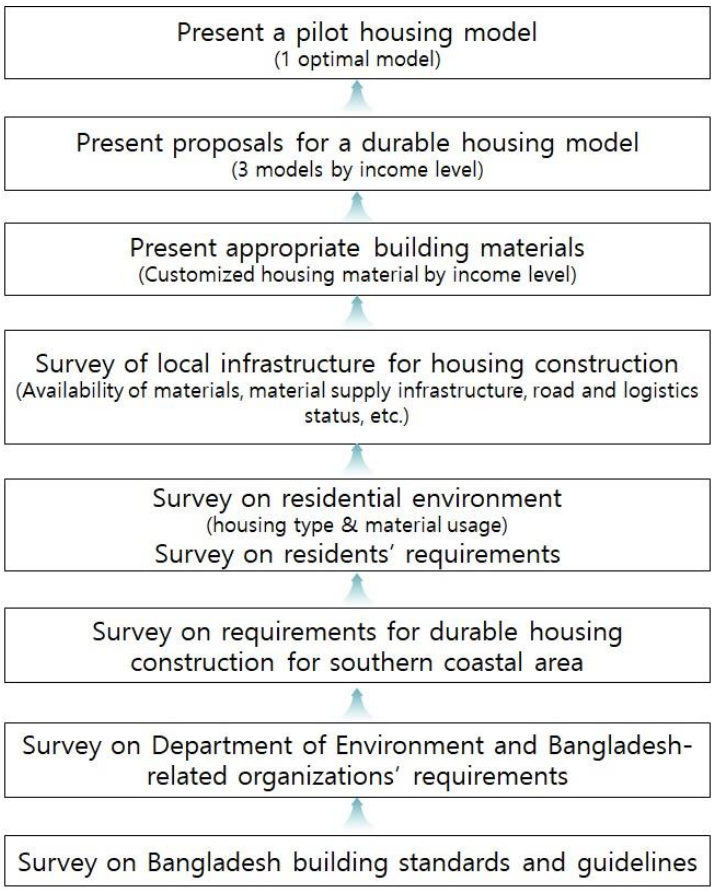

Table 2 Main output contents

Objective	Survey contents	Output contents
Survey of the residential environment in the region	. To investigate the climate conditions of the area and the status of the structures and materials of the present houses	.Review the current residential situation in the southern coastal area of Bangladesh
	. To survey the patterns of building sites and analyze the major materials and structural types of existing houses	.Review the types of building structures and housing materials
	. To investigate the climate characteristics of the target area and data	. Review the defects and deterioration of housing and examples
Survey of the status of materials and infrastructure	. To investigate the current state of building infrastructure in residential construction	.Review the results of residents' requirements
	. To investigate tangible and intangible types of local resources, as well as locally produced materials	. Review the availability of construction materials and supply infrastructure in the southern coastal region
	. To investigate the utilization of construction machinery and the status of construction infrastructure	. Review the accessibility of transportation
	. To investigate building standards and materials	Review appropriate Bangladesh standards and related standards
	. To investigate the utilization of local materials	. Review and suggest durable housing construction materials using local materials
Survey of building standards and system	. To investigate the current state of infrastructure such as housing standards and performance evaluation standards in Bangladesh for housing construction	. Review Bangladesh building law, durable housing construction guidelines, etc. . Review other international organizations' applied standards
Housing proposal for local area	. Housing design and proposal of housing prototype . Proposal of utilization of local building materials and processing plans	. Review standard housing proposals and a pilot housing construction plan
Training workshop	. To provide education related to housing construction plans for low-income households based on local climate environment and infrastructure	. Educate and lecture on outputs
Final presentation	. To present final contents of this project	. Propose optimal housing construction plans for low-income households on the southern coast

During the process of conducting the project, which included literature reviews, field studies, and consultations with stakeholders, its focus changed. Each technology had its own advantages and disadvantages, and it was very hard to overcome certain limitations. As

mentioned in the title of this project, finding the optimal combination of affordability and technology was the most difficult part of this project. During consultations with stakeholders, most of them mentioned and emphasized that the KICT housing team should focus on durability rather than affordability when considering housing solutions for residents of the southern coastal areas of Bangladesh.

2. TECHNOLOGY SOLUTION REVIEW AND IDENTIFICATION

This chapter explains the key points from the literature review,including1)the geo-climatic context of the southern coastal areas of Bangladesh, 2) the local materials in the southern coastal regions of Bangladesh, and3)the cost of local materials, as well as local construction methods, technical skills, construction periods, the availability of materials, and so on.

2.1 GEO-CLIMATIC CONTEXT OF BANGLADESH

Satkhira, and Bagerhat, which make up most of the surveyed area, are classified as strong wind zones. Interestingly, the survey indicates that areas around the river in the northern region are more vulnerable to flooding than the southern coastal region. An alleged reason for this is that, in the southern region, the wetland area blocks flooding at the lower end, making the region relatively stable to flooding. Even if there is a flood, the water will only reach the predictable level, making disaster management relatively easy. Conversely, in the northern region by the river, areas that are not properly equipped with disaster prevention facilities or levees are even more vulnerable to flooding when there is heavy rainfall.

2.1.1 SATKHIRA REGION

Satkhira is a district in South-Western Bangladesh and is part of Khulna Division. It lies along the border with West Bengal, India. Satkhira also has a tropical climate. Satkhira has annual average temperature of 26.2°C and maximum temperature reaches 35.1°C in April, minimum temperature is 12.3 °C in January. There is much less rainfall in winter than in summer. Approximately 1,655 millimeters of precipitation falls annually and 90% of annual rainfall occurs in between May and October.

A. Temperature

The annual average temperature of the Satkhira region is 26.2°C, with a monthly maximum

of 35.1°C in April and monthly minimum of 12.3°C in January.

B. Humidity

Although the humidity of Satkhira area is comparatively high with annual mean of 83%. The maximum monthly relative humidity is 89% in February and the minimum monthly relative humidity 75% in May.

C. Wind speed

The annual mean wind speed is 4.3 m/s. Daily high wind velocity was shown as 7.7m/s during May to July and minimum wind speed of less than1 m/s occurs in July to September.

D. Precipitation

Annual precipitation is 1,655mm. Maximum rainfall of Satkhira is 347mm which occurs during summer in July, and minimum rainfall 6mm occurs in December. The difference in precipitation is 341mm throughout the year.

	January	February	March	April	May	June	July	August	September	October	November	December
Avg. Temperature (°C)	19.1	22	26.8	29.6	30.2	29.5	28.8	28.8	28.9	27.7	23.7	19.8
Min. Temperature (°C)	12.3	15.3	20.3	24.1	25.5	26.1	26	26	25.8	23.7	18.1	13.2
Max. Temperature (°C)	25.9	28.8	33.3	35.1	34.9	33	31.6	31.7	32	31.7	29.4	26.5
Avg. Temperature (°F)	66.4	71.6	80.2	85.3	86.4	85.1	83.8	83.8	84.0	81.9	74.7	67.6
Min. Temperature (°F)	54.1	59.5	68.5	75.4	77.9	79.0	78.8	78.8	78.4	74.7	64.6	55.8
Max. Temperature (°F)	78.6	83.8	91.9	95.2	94.8	91.4	88.9	89.1	89.6	89.1	84.9	79.7
Precipitation / Rainfall (mm)	11	17	28	63	132	296	347	320	271	136	28	6

Figure 1 Satkhira region climate chart

2.1.2 BAGERHAT REGION

Bagerhat District is a district in South-Western Bangladesh, lies East of Khulna, West of Pirojpur. It is a part of the Khulna Division. Bagerhat has annual average temperature of 26.04°C and maximum temperature reaches 34.6°C in May, minimum temperature is 12.4 °C in January. Approximately 1,934 millimeters of precipitation falls annually and 90% of annual rainfall occurs in between May and October.

A. Temperature

The annual average temperature of the Bagerhat region is 26.04°C, with a monthly maximum of 34.6°C in May and monthly minimum of 12.4°C in January.

B. Humidity

Although the humidity of Bagerhat area is comparatively high with annual mean of 74%. The maximum monthly relative humidity is 84% in August and the minimum monthly relative humidity 62% in March.

C. Wind speed

The annual mean wind speed is 3.5 m/s. Daily high wind velocity was shown as 9 m/s during August and minimum wind speed of 1 m/s occurs in October to November.

D. Precipitation

Annual precipitation is 1,934mm. Maximum rainfall of Bagerhat is 404 mm which occurs during summer in July, and minimum rainfall 8 mm occurs in December. The difference in precipitation is 396mm throughout the year.

	January	February	March	April	May	June	July	August	September	October	November	December
Avg. Temperature (°C)	19.1	21.8	26.5	28.9	29.8	28.9	28.4	28.4	28.7	27.7	24.2	20.1
Min. Temperature (°C)	12.4	15.1	20.1	23.7	25.1	25.8	25.8	25.9	25.8	24	19	13.8
Max. Temperature (°C)	25.9	28.6	32.9	34.1	34.6	32.1	31.1	31	31.7	31.5	29.4	26.4
Avg. Temperature (°F)	66.4	71.2	79.7	84.0	85.6	84.0	83.1	83.1	83.7	81.9	75.6	68.2
Min. Temperature (°F)	54.3	59.2	68.2	74.7	77.2	78.4	78.4	78.6	78.4	75.2	66.2	56.8
Max. Temperature (°F)	78.6	83.5	91.2	93.4	94.3	89.8	88.0	87.8	89.1	88.7	84.9	79.5
Precipitation / Rainfall (mm)	12	21	43	90	190	371	404	349	254	158	34	8

Figure 2 Bagerhat region climate chart

2.2 CURRENT BUILDING MATERIALS

During the literature review on material usage in Bangladesh, Mr. Mohammad Sadeque a formal director of HBRI and a relevant stakeholder of this project informed us that HBRI already had a list of more than 20 recommended materials for buildings in coastal areas. Listed

in Table 3, 6 materials were selected by KICT for building durable housing in the coastal areas of Bangladesh, and 4 of them met most of the criteria for this project.

Table 3 Current building materials

Material	Description	cost
Ferrocement Pre-cast	Ferrocement is ideally suited for thin wall structures as the uniform distribution and dispersion of reinforcement provide better crack resistance, higher tensile strength to-weight ratio, ductility and impact resistance Ferrocement pre cast element can be constructed at convenient places (e.g. factory, workshops) and transported to the sites .	135TK/sft
3D panel	3D panel is a prefabricated panel, which consists of a super-insulated core of rigid expanded polystyrene, sandwiched between two sheets of steel welded wire fabric mesh.	182TK /sft
Sandwich Panel	The sandwich panels are consisted of two thin ferrocement layers, reinforced with one layer of iron wire mesh, with core(middle part)made of Expanded Polystyrene Sheet	135TK/sft
Organic/Bamboo mat	Typically in kutcha houses; semi-pucca houses also often have bamboo mat walls. Organic materials (e.g. jute stick, catkin grass) have a lifespan of 2-3 years and bamboo matt 4-5 years.	20TK/sft
CGI sheet	CGI or Corrugated Galvanized Iron is a building material composed of sheets of hot-deep galvanized mild steel, cold-rolled to produce a linear corrugated pattern in them	127TK/sft
Areated concrete block	Autoclaved cellular concrete (ACC) is made with fine aggregate, cement, and an expansion agent that causes the fresh mixture to rise like bread dough	25TK/sft

Based on the literature review, reinforced concrete (RC) and bamboo seemed to be the most appropriate materials for housing construction in the southern coastal areas. RC showed excellent resistance to humidity, CO^2, extreme temperatures, earthquakes, and wind. On the other hand, bamboo showed the best resistance to salt and CO^2. Considering the price of the construction materials, ease of construction methods, technical skills required, duration of construction, supply of local materials, localization issues, and so on, it was determined that the most appropriate materials were bamboo, wood, brick, and reinforced concrete (RC).

2.3 BUILDING STANDARDS AND REGULATIONS

To construct adequate housing, it is necessary to conform to building standards and regulations, especially in the southern coastal areas of Bangladesh. The Housing and Building Research Institute (HBRI) mentions in Chapter 1 of the “Standard Guidelines for Rural Housing in

Disaster-Prone Areas of Bangladesh"[1] that the Bangladeshi building code sets out eight minimum standards for constructing adequate rural housing in Bangladesh. The guidelines are as follows:

Table 4 Eight minimum standards for constructing adequate rural housing in Bangladesh

Standard 1	Security of tenure is guaranteed for a set period of time of at least 30 years
Standard 2	Access to safe water and sanitation solutions are to be provided
Standard 3	All housing is built with materials and techniques that allow easy maintenance, repair and duplication
Standard 4	All housing and sites are adapted to the local hazard profile to resist recurrent disasters over 30 years
Standard 5	All housing offers a comfortable and healthy internal climate
Standard 6	All housing is adapted to special and specific needs of its inhabitants
Standard 7	All housing is functional, culturally appropriate and adaptable
Standard 8	All housing should be situated as close as possible to employment and education opportunities, medical and other social services

In addition, in Bangladesh, Article 4.5.1 of the National Housing Policy states the following: "Suitable construction materials will be made available to rural people. At the same time, measures will be taken to regulate uncontrolled tree-cutting, such as providing fuel for brick kilns, with the goal of conserving nature."

3. FIELD SURVEY

The most important factor that KICT considered during this project was the opinions of regional stakeholders. Regional stakeholders are household-level community members who understand the environmental conditions of the selected sites. Besides considering regional stakeholders' opinions on "durable housing" in Satkhira and Bagerhat districts, understanding of the status of the local housing context was the biggest priority. Through a field survey, KICT analyzed housing status and household composition according to characteristics of the topography of the southern coastal region, dividing it into coastal areas, middle areas, and hilly areas.

[1] Housing and Building Research Institute (HBRI) (2018), *Standard Guideline for rural housing in disaster prone area of Bangladesh*, Bangladesh

3.1 COASTAL AREA OF BANGLADESH

Satkhira and Bagerhat Districts are classified as strong wind zones with high precipitation levels during the rainy season. The precipitation is most intense between June and August, and the monthly precipitation level is around 300 to 3500 mm. The areas around the river in the northern region are more vulnerable to flooding than in the southern coastal region. An alleged reason for this is that, in the southern region, the wetland area blocks flooding at the lower end, making the region relatively safe from flooding. Even in the event of a flood, the water will only reach predicted levels, making disaster management relatively easy. Conversely, in the northern region by the river, areas that are not properly equipped with disaster prevention facilities or levees are especially vulnerable to flooding when there is heavy rainfall. Table 5 profiled 6 selected field survey villages that KICT had visited:

Table 5 Field survey village profile

Village Name	**North Jhapa**	**Durgabati**	**Kamalkathi**	**Hurka**	**Keyabunia**	**Shelabunia**
Ground type	Flat	Coast	Flat	Flat&Hill	Coast	Coast
Union	Padmapukur	Burigualini	Padmapukur	Hurka	Chila	Burirdanga
Upazila	Shyamnagar	Shyamnagar	Shyamnagar	Rampal	Mongla	Mongla
District	Satkhira	Satkhira	Satkhira	Bagerhat	Bagerhat	Bagerhat
GPS_E	89.21326	89.22946	89.21326	89.63467	89.61796	89.57381
GPS_N	22.33638	22.28128	22.33638	22.566	22.4207	22.54982
Households	450	469	420	230	150	153
Population	2600	2700	2450	1060	650	1000
Shelter	Yes	Yes	No	No	No	Yes
Shelter Capacity	500	400				
Mobile Accessibility	No	Yes	No	No	No	No
Mode of easy Accessibility	By Road and water way	By Road and water way	By Road and water way	By Road	By Road and water way	By Road and water way
Distance from main road {in KM}	3	3	2	7	5	3

Road Pavement	Yes	Yes	Yes	Yes	Yes	Yes
Approach road width {in Meter}	3	4	1.8	3.7	1.2	1.8
Average width of main road {in Meter}	9	9	9	8	7	8

3.2 SURVEY RESULTS

From the field survey, KICT gleaned information on the characteristics of households in the southern coastal areas of Bangladesh. As can be seen in Table 6, the average family size was 4.19, with an average yearly household income of 82,556BDT. The average size of a house was around 95m^2, with 1.4 rooms and 1.5 windows.

Table 6 Housing information in southern coast Bangladesh

	Average	**Maximum**	**Minimum**
Number of people per family	4.19	10	1
Number of male child	1.35	7	1
Number of female child	1.45	5	1
Yearly Income (USD)	977 USD	2,130 USD	43 USD
Number of rooms	1.4	5	1
Number of windows	1.5	15	0
Housing area	95.75m^2		
Floor to ceiling height	2.11m		
Ground to floor (plinth of house)	0.64m		

Around 50% of the dwellings have one or two cracks in their roofs and walls, and the rest of the houses have three to fifty cracks. For roofs, 41.3% indicated that decay is the reason for the cracks, 38.7% said salinity, 30.3% said cyclones, and 23.2% said low quality of building materials, etc. On the other hand, 43.4% of the respondents reported that salinity is the major reason for the wall cracks, while 35.5% said decay, 26.8% said low quality building materials, 25.4% said cyclones, 1.3% said tidal surges, and 3.5% said other reasons.

In the survey areas of Satkhira and Bagerhat, the basic structure of a dwelling consists of a

cluster of small shelters or huts around a central courtyard, locally known as an "Uthan." The huts usually consist of a single room, are detached, and are loosely situated around the central courtyard. Usually, kitchens are not attached to houses. From the table 7, we can see that the areas' residents use various types of materials to build the basic structures of their houses, such as golpata leaves, brick, bamboo, wood, mud, asbestos, and concrete. Furthermore, the areas' residents use various types of materials to build the roofs of their houses, such as golpata leaves/straw, brick, bamboo, wood, mud, asbestos, concrete, and corrugated iron sheets. Out of 600 houses, 122 (20.3%) had roofs made of corrugated iron sheets, 118 (18.7%) were made of asbestos, and 107 (17.8%) were made of golpata leaves/straw.

Figure 3 A meter height of plinth with cracks

Figure 4 Temporary ceiling finishing with fabric to avoid the hot temperature

Figure 5 Bamboo wall structure

Figure 6 Indoor floor with mud

From table 7, we can see that 90% of the respondents had houses with floors made of mud, 7.5% were made of concrete, and the remaining 2.5% were made of brick. In addition, the survey respondents reported using various types of materials for the inner walls of their houses. These materials included bamboo, brick, concrete, golpata, mud, brick, tin, and so on. Among these items, wood and tin were the most commonly used materials for the inner walls of houses.

Table 7 Survey result on housing materials

	Materials	Frequency (N)	Percent (%)
Structure	Bamboo	65	10.8
	Brick	39	6.6
	Concrete	76	12.8
	Mud and Golpata	86	14.3
	Wood	334	55.8
Roof	Asbestos	114	19.1
	Bamboo	17	2.8
	Concrete	34	5.8
	Golpata/Straw	170	28.2
	Tile and Tin	135	22.5
	Wood	130	21.7
Floor	Brick	15	2.5
	Concrete	45	7.5
	Mud	540	90
Inner-wall	Bamboo	45	7.5
	Brick	16	2.7
	Concrete	39	6.6
	Golpata	9	1.5
	Mud	176	29.4
	Tin	97	16.2
	Wood	218	36.4

This village survey was conducted in at least six villages, and at least three villages were surveyed in each target region. The selected villages in each region were divided into coastal or riverside areas, isolated (flat) areas, and hilly areas. Riverside villages are more easily accessed via boat than land. Especially in the Bagerhat District, the roads are not in good condition, so transporting materials via the river is considered the most convenient approach. On the other hand, in the Satkhira District, road conditions are decent, and road-based travel by foot and motorcycle is common. Through the survey result, it was found that bamboo, golpata, rice straw, etc. could be supplied as typical local construction materials in the region. In addition to this, cement and bricks are next accessible local material to be use. The results of the local groundwater survey showed that salinity content is very high. Constructing an RC building with saline water may cause corrosion of the reinforcing steel, resulting in poor durability.

In the case of Bagerhat District, the supply of materials can be smoothly provided as it located near Khulna District. Cement brick factories, baked tile factories, and fired brick factories are scattered throughout the region, so if economic conditions are satisfied, these materials can be

utilized as well. The results of the survey of six villages showed that the most effective area for the construction of pilot houses is the Kamal Kathi village in Bagerhat District. This village has good road conditions, and there are construction materials production facilities in neighboring areas. It was also found that the supply of local materials such as bamboo and golpata would be adequate.

4. MATERIAL TECHNOLOGY OPTIONS

The structures can be classified by structural type and materials used. The structural types of houses in the southern coastal region of Bangladesh can be classified into bamboo, masonry, and reinforced concrete buildings. The main constituent materials of the walls are brick, bamboo, soil, wood, stone, and Golpata, while the roofs are mainly composed of SGI sheet, Golpata, slate, and straw.

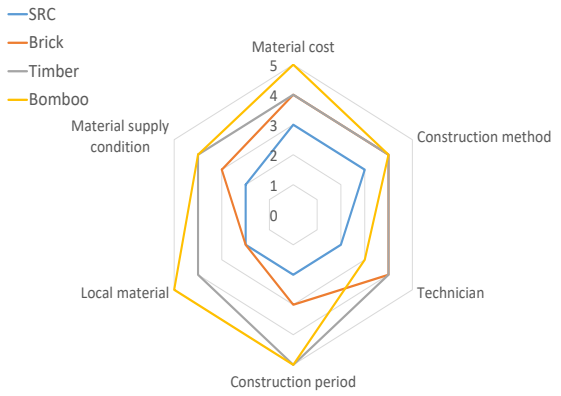

Figure 7 Economic factors of housing construction

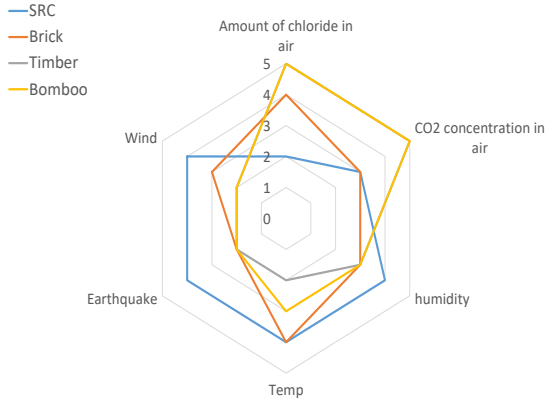

Figure 8 Factors affecting the durability of housing construction

Factors that affect the durability of houses are water, wind, and vibration. If there is salinity in the water or wind, in the case of reinforced concrete structures, durability can be compromised quickly, and the corrosion of metal roofs, such as tiles, can progress rapidly. The main components used in the region are SRC, brick, timber, and bamboo.

Factors that affect durability include salinity in the air or water, CO_2 concentration in the air, high humidity, high temperature, wind, and the physical factor of earthquakes. The influence of each factor can be classified according to a five-level scale. Reinforced concrete structures have strong resistance to wind, earthquake, temperature, and humidity, but are vulnerable to high concentrations of salinity or CO_2 in the air. In particular, the deterioration and peeling of old building surfaces can be vulnerable to weakening of its concrete structure due to neutralization. Therefore, they deteriorate further, affected by expansion due to infiltration of water.

When comparing the economic efficiency of buildings according to the structural type, the economy can be categorized by the price of materials, construction method, construction technology, construction period, availability of materials, supply conditions, transportation conditions, etc.

The materials are composed of reinforced steel and cement concrete for RC structures, forming a relatively expensive structure. From a materials perspective, building RC structures in non-urban areas is inefficient for several reasons. First, cement is sourced by importing clinker from India to be crushed, even though there are many cement companies in Bangladesh. However, due to the lack of infrastructure required to transport cement and the lack of plants for its production, the feasibility of constructing RC buildings in rural areas is considerably low. Moreover, there are many difficulties in supplying rebar.

Timber and bamboo, which are widely used as wall and roof materials in the region, can be obtained locally, and have the advantage of having accumulated technology in accordance with their long history of usage, which leads to shortened construction periods. In particular, using bamboo or timber as roof and wall materials and having an SRC structure can be advantageous in preparing for strong winds and ensuring a pleasant climate space.

Bangladesh has many fired brick factories, and the bricks produced in the country are crushed and used as course aggregate or flood prevention materials. However, its use as a raw material is expected to result in the construction of durable housing. For this, it is necessary to provide infrastructure in the region to enable its transportation, such as roads. Furthermore, it is believed that the use of bricks for the construction of houses in riverside areas will be feasible if the bricks are transported using waterways.

The results of the field survey and HBRI data analysis showed that there are not many inorganic materials that can be used locally. Soils with a high content of organic impurities are disadvantageous in terms of durability. Therefore, bamboo, rice straw, and golpata are the most appropriate local construction materials in the southern coastal region of Bangladesh.

The HBRI produces classic autoclaved lightweight concrete (ALC) blocks using cement and aluminum powder. This proposal outlines the use of a small amount of cement of less than 5%, and proposes instead the construction of aerated blocks using fly ash or clay. ALC is a functional building material, as it maintains a pleasant indoor environment. However, it may cause problems such as mold and contamination during prolonged periods of high humidity due to its low water resistance.

Rice straw is an organic material that has the disadvantage of rotting when it is exposed to moisture. However, when rice straw is used to strengthen inorganic materials, it is possible to use it to produce building materials with high durability because of its high tensile strength. In addition, it enables the use of eco-friendly materials, as it allows humidity control. Once the

rice straw is sufficiently dried, it is possible to produce plates and blocks by applying pressure molding using a binder such as cement.

To secure long-term durability for more than 10 years, the method of partially utilizing vacuum extrusion-molded cement panels was suggested. Moisture is the most important factor that inhibits the durability of buildings. Cement extrusion panels are products that perform vacuum extrusion molding using cement, sand, and reinforcing fiber. In theory, their absorption rate is low because they are completely free of internal voids.

Table 8 Suitable building materials in southern Bangladesh

Aerated Bricks	**Cellulose Brick & Boards**	**Vacuum extrusion panel (Exterior)**
		
- Uses small amount of cement, uses fly ash and clay - Manufactured in room temperature hardening form - Lightweight, processable - Local materials available	- Rice straw is used as main material and adhesive is applied differently depending on the application - The exterior material is cement-bonded and the interior material is resin adhesive. - Utilization of local rich rice straw	- Need to examine the use of exterior materials to ensure durability - High price and poor processability - Optimized product with high density product for 30 years

There are several sintering fired brick factories scattered throughout Khulna, which can produce high-quality cement and perforated bricks. It is common to use cement and fine aggregates for cement bricks, as well as cement, sand, and crushed stone powder instead of fine aggregates.

Figure 9 Cement brick factory in Southern coast area

Figure 10 Cement bricks

Various construction material options had derivate as above throughout the literature review and the field survey trip but these technologies has to be well accepted by the community such as household level local community members in economically and technically. As economic factors can be analyzed according to material price, construction method, technical skills, availability of materials, duration of construction, and localization. Bamboo was evaluated as the most economical construction material, followed by wood and brick. For technical factor, performed and experiment on resistance on salinity, humidity, CO^2, earthquakes, wind, and temperature with steel, masonry, wood, bamboo material, the results came out that bamboo and bricks were excellent in terms of resistance to salinity, and bamboo was excellent in terms of cyclone resistance. Considering both aspects in durability and economic efficiency, it seems to be most effective to apply various combinations of building materials, such as precast RC structures with bamboo or wood walls, and extruded concrete panels for facades with strong wind protection.

5. HOUSING TECHNOLOGY OPTIONS

When comparing methods of constructing durable housing in the southern coastal areas of Bangladesh, technical and economic aspects were the most important considerations.

Since the topic of this project is “technical assistance for low-cost durable housing technology,” construction costs were the most important point to consider. To provide a context for the average cost of housing in Bangladeshi coastal areas, KICT researched other countries’ average yearly incomes and housing prices as well.

Singapore’s average yearly net income (after tax) is 36,570 USD, and the average price per square meter for an apartment outside a city center is 9,824 USD, with a 20-year fixed

mortgage interest rate of 2.51%.[2]In South Korea, the average yearly net income (after tax) is 26,395USD, and the average price per square meter for an apartment outside a city center is 5,803USD, with a 20-year fixed mortgage interest rate of 3.58%.[3]As we can see from the statistics above, people in Singapore and South Korea must make payments for more than 20 years before they own their homes.

In Bangladesh, the average yearly net income (after tax) is 4,341USD, and the average price per square meter to buy an apartment outside a city center is 607USD, with a 20-yearfixed mortgage interest rate of 11.2%.[4] Compared to Singapore and South Korea, Bangladesh's mortgage interest rate is 4.5 times higher, but the ratio between yearly income and the average price of housing in Bangladesh is 0.13, or half as much as Singapore's, so it takes a similar length of time to pay off a mortgage.

From Table 6, we can see that the average yearly income in the selected area is 977 USD, and the average housing area is 95.75m^2. As we can assume that it takes13 years to pay off a mortgage in Bangladesh (without mortgage interests) from the calculation above, we can also calculate that the affordable average housing cost in this region is12,701 USD.

5.1 DESIGN CONSIDERATIONS FOR DURABLE HOUSING

There are four considerations when devising a climate-responsive design: 1) resilience against the impact of the environment, 2) introduction of low-impact building materials and construction technologies, 3) development of standardized and labor-friendly pre-fabricated modes of construction using minimum (economical) building elements, and 4) consideration of contextual issues. Technical options are the most important issue in determining durable housing designs. To achieve greater resistance to natural disasters, the structure, walls, roof, and foundation must be the most important design considerations. Three main options for sustainable materials were suggested for the southern coastal areas of Bangladesh. Table 9 is a brief summary of the structure, wall, roof, and foundation design targets for this project.

[2] Last visited 12/04/2019, Numbeo website, https://www.numbeo.com/property-investment/in/Singapore

[3] Last visited 12/04/2019, Numbeo website, https://www.numbeo.com/property-investment/in/Seoul

[4] Last visited 12/04/2019, Numbeo website, https://www.numbeo.com/property-investment/in/Dhaka

Table 9 Design targets for durable housing

	Design considerations	Main Materials
Structure	- Should be resistant to strong winds and flooding - Should facilitate easy replacement of wall and roof material - Should be economically efficient - Should be connected to a foundation structure	- Steel frame - Wood structure - RC - Precast products using ferro-cement with rebar
Wall (exterior/ interior)	- Use local materials - Use simple materials - Use replaceable materials - Use materials that are dirt and moisture resistant - Use materials that cost less than USD 5/m^2	- Burned products (ensuring durability) - Local straw, golpata - Brick and replaceable panel
Roof	- Should have strong resistance to salt - Should be resilient against strong winds such as cyclones - Should not be corrosive - Should be able to construct a ceiling structure - Should be less than USD 5/m^2	- Use inorganic products or bone fragments for repairs - Fiber-reinforced cement slate or burned tile (CGI sheets are prohibited due to insulation problems)
Foundation	- Should be at least 60 cm above the ground - Should be a durable structure for flooding - Should be able to stabilize the structural frame	- Waterproof surface

5.2 HOUSING PROPOSALS

The main goal is to design several optimum housing prototypes which can be affordable and durable for Southern coastal areas of Bangladesh. Through this project, KICT has outlined 3 different types of housing proposals by income level, building area, resident's living area, price etc. of the residents of Southern Bangladesh. To minimize the maintenance cost of residential living environment, all 3 housing proposals are recommended to apply on the rainwater recycling system and solar system.

In the context of the results mentioned above, housing was designed for residents of the southern coastal areas based on three income levels. The following assumptions were made about the average composition of a household: 1) a family size of four members, 2) a house height of 2.3 m, 3) the presence of at least 2 rooms and at least 1 window per room, 4) a housing area of 50m^2, and 5) a plinth height of 1 m. The three design concepts, separated by income level, are as follows:

Table 10 Summary of 3 housing proposals

	Type A	Type B	Type C
Number of floors	1 floor	1 floor	1 floor
Area	572sft/53㎡	572sft/53㎡	758sft/70.1㎡
Main Material	Light weight foam block/Local brick	Light weight foam block/ Cement brick	Extruded concrete panel
Wall structure	Cement hollow Block	Cement brick	Concrete panel
Roof structure	G.I steel gable roof	G.I steel gable roof	G.I steel gable roof
Division	Room(1,2), Living & Dining, Kitchen, Toilet, Shower	Room(1,2), Living & Dining, Kitchen, Toilet, Shower	Room(1,2), Living & Dining, Kitchen, Toilet, Shower, Verandah, Open terrace
Price / household	USD 10,990	USD 12,570	USD19,770
Price /㎡	USD 207	USD 237	USD 283
Solar system	3KW	3KW	3KW
Rainwater tank	1TON	1TON	1TON

5.2.1 TYPE-A: DURABLE HOUSING DESIGN FOR LOW INCOME CLASS RESIDENTS IN SOUTHERN COASTAL AREA OF BANGLADESH (572SFT/53M^2)

Figure 11 Low-income housing model (Type-A)

Type-A is designed for low-income residents in southern coastal area of Bangladesh. This housing design represents similar to the traditional southern coastal residents living environment, separated toilet and shower area outside of the main building, so that residents can feel comfortable on their own life style. The main building includes two bedrooms with a living & dining room and a kitchen, and an annex building includes toilet and shower area. This housing will utilize with local materials such as golpata, bamboo, and lightweight foam blocks. One-ton of rainwater tank and 3KW solar system will be install. Table 11 shows the Type-A housing room divisions with the sizes.

Table 11 Type-A housing room divisions with the sizes

	Room 1	Room 2	Living & Dining	Kitchen	Shower	Toilet
UNITS	12’-0”X14’-0”	12’-0”X14’-0”	10’-0”X14’-0”	8’-0”X6’-0”	4’-0”X6’-0”	4’-0”X6’-0”
AREA	168sft/15.6m2	168sft/15.6m2	140sft/13m2	48sft/4.4m2	24sft/2.2m2	24sft/2.2m2

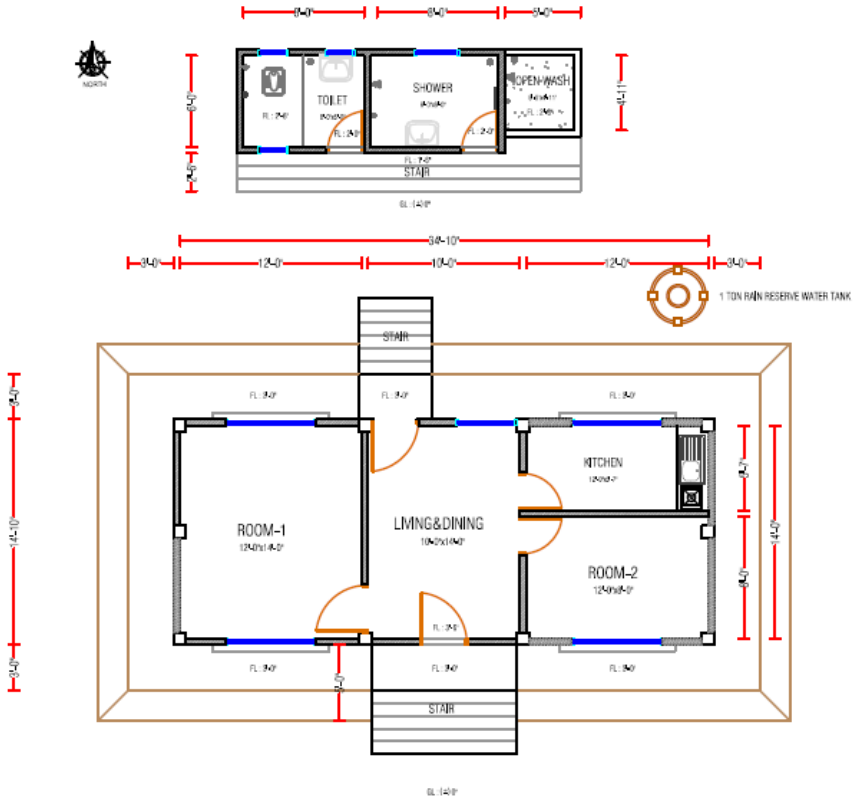

Figure 12 Type-A plan

The basic concept of the proposed design for low-income residents in the southern coastal areas of Bangladesh is to develop a building's walls using local materials that improve durability with existing methods. For the A-type design, we suggest using wall materials that do not exceed a cost of 3 USD/m^2. Table 12 provides a description of Type-A materials.

Table 12 Type-A material description

Raw materials	Additives	Descriptions	Specifications
Straw, soil	Cement, lime, resin	- Local soil is used for main material, and straw is used to enhance reinforcement - Exterior walls are reinforced with resin - For interior materials, use only cement or sodium silicate to improve the humidity - Produce in various brick shapes such as 300 * 300 * 150 mm, 300 * 150 * 150 mm - Intermediate hollow structure to prevent crack breakage - Variable adjustment on length of straw	- Density: 1.0~1.2 g/cm^3 - Compressive strength: 10~15MPa - Additive content: >10% - Resin content: >5%

Forming process: Preparation of soil (sieving after drying as certain powder) → preparation

of straw (cut to a certain length after drying, within 100 mm) → preparation of additive → mixing of binders (soil: total amount of additive = 80:20) → mixing with straw [within 2% of binding material (by weight)] → mixing of water (within 30% of total weight) → casting a mold (pressurizing mold) → natural curing after de-molding

5.2.2 TYPE-B: DURABLE HOUSING DESIGN FOR LOW-MIDDLE INCOME CLASS RESIDENTS IN SOUTHERN COASTAL AREA OF BANGLADESH (572SFT/53M^2)

Figure 13 Middle-income housing model (Type-B)

Type-B is designed for low-middle income residents in southern coastal area of Bangladesh. This design is dedicated to the residents who want to have bathroom inside of the house. As mentioned above on Type-A, most of residents living in a traditional way of separating kitchen, toilet to be separated from the main rooms. In other hand, some of residents in middle of low and middle-income wished to have kitchen and toilet inside the house if there is any kind of flushing and ventilation problems. Type-B is design for53m^{2}same size as Type-A, it is composed with two bedrooms, living & dining room with one-ton size of rainwater tank and 3KW solar system.

Table 13 Type-B housing room divisions with the sizes

	Room 1	Room 2	Living & Dining	Kitchen	Shower	Toilet
UNITS	12’-0”X14’-0”	12’-0”X14’-0”	10’-0”X14’-0”	8’-0”X6’-0”	4’-0”X6’-0”	4’-0”X6’-0”
AREA	168sft/15.6m2	168sft/15.6m2	140sft/13m2	48sft/4.4m2	24sft/2.2m2	24sft/2.2m2

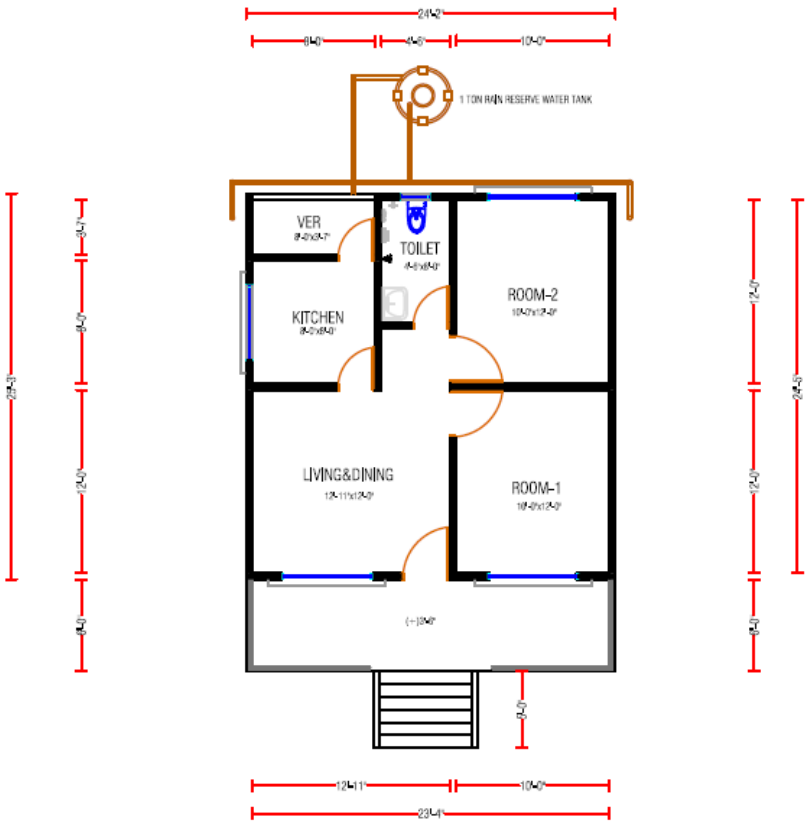

Figure 14 Type-B plan

The basic concept of the design proposal for low- to middle-income residents in the southern coastal areas of Bangladesh is to develop a building's walls using local materials that improve the durability of the existing methods and replace cement brick as a construction material. For a B-type dwelling, we suggest using wall materials that can be processed on site using the molding method. Wall materials should not exceed 5 USD/m^2. Table 14 provides a description of the proposed materials for a Type-B dwelling.

Table 14 Type-B material description

Raw Materials	Additives	Descriptions	Specifications
Ash, clay, bamboo	Cement, sodium silicate, Al powder	- Main materials are fly ash, clay, and cement - form of foam structure to give light weight - Foaming uses Al powder or hydrogen peroxide - Water repellent to improve water resistance for exterior material - Molded up to 500 * 500 * 100 mm - No extra reinforcing fiber - Partially mixed with cement to improve the hardness of the product - The structure of the wall is made by stacking into bamboo molding frame	- Density: < 0.5 g/cm^3 - Compressive strength: < 5MPa - Water absorption: < 15%

- **Forming process:** Preparation of raw materials (fly ash with high concentrations of CaO, clay, and cement) → sieving after drying as certain powder → preparation of foaming agent (Al powder or hydrogen peroxide) → preparation of a mold → mixing of binders (ash : clay : cement = 50 : 30 : 20) → mixing of foaming agent (Al powder is mixed in advance, hydrogen peroxide is mixed with less than 1% water) → insert into a mold → de-molding → insert into a bamboo mold

5.2.3 TYPE-C: DURABLE HOUSING DESIGN FOR MIDDLE INCOME CLASS RESIDENTS IN SOUTHERN COASTAL AREA AND URBAN AREA OF BANGLADESH (758SFT/70.1 ㎡)

Figure 15 Middle-income housing model (Type-C)

Type-C is designed for middle-income residents in southern coastal area of Bangladesh. During the field survey, we found that there are more middle-income class residents than we thought. This Type-C design is dedicated for middle-income class who want to have some big spaces with a toilet inside of the house. Also they wish to have a private area such as enclosed verandah. Type-C is design for 70.1m^2, it is composed with two bedrooms, a living & dining room, a kitchen and a toilet with a small private verandah space. It also designed for one-ton size of rainwater tank and 3KW solar system.

Table 15 Type-C housing room divisions with the sizes

	Room 1	**Room 2**	**Living & Dining**	**Kitchen**	**Toilet**	**Verandah**
UNITS	12’-0”X14’-0”	12’-0”X12’-0”	13’-5”X14’-0”	10’-0”X12’-0”	5’-0”X7’-0”	3’-0”X4’-0” 5’-0”x3”-7”
AREA	168sft/15.6m2	144sft/13.3m2	256sft/23.7m2	120sft/11.1m2	35sft/3.2m2	35sft/3.2m2

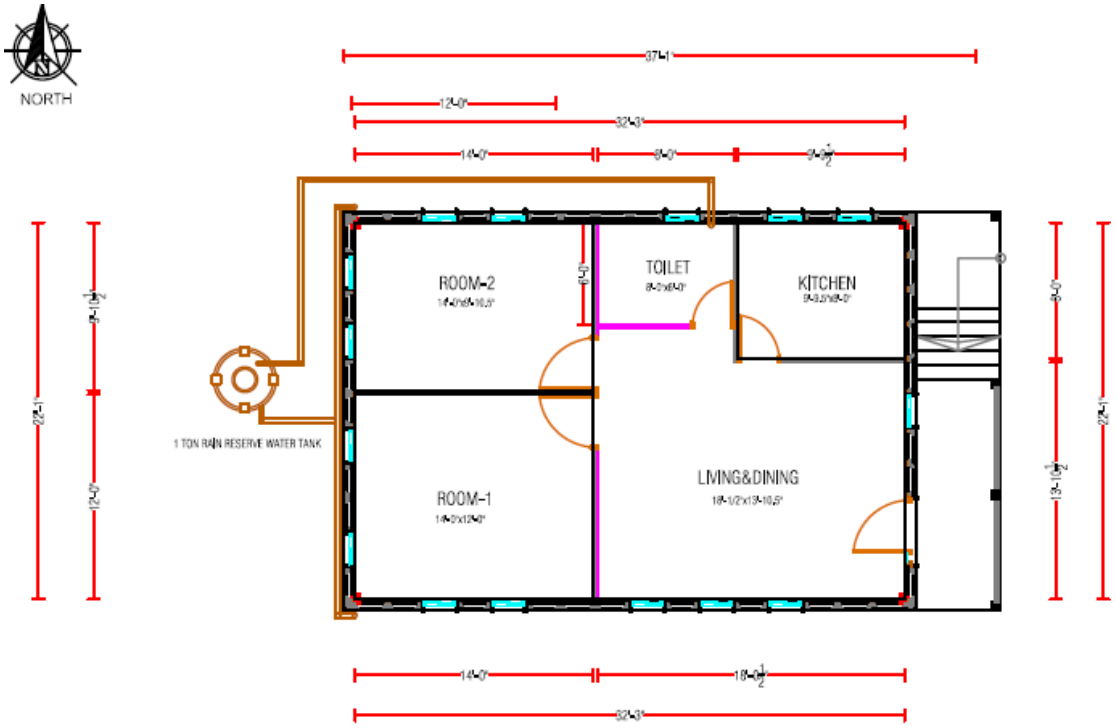

Figure 16 Type-C plan

The basic concept of the design proposal for middle-income residents in the southern coastal areas of Bangladesh is to focus solely on durability. This ideal material would be a durable one with high corrosion resistance to minimize the damage caused by exposure to seawater, and the wall panels should be easy to assemble and should be manufactured on-site. The cost of the wall materials should be 20~30 USD/m^2. Table 16 provides a description of the proposed materials for a Type-C residence.

Table 16 Type-C material description

Raw Materials	Additives	Descriptions	Specifications
Cement, silica powder	Cellulose fiber, methylcellulose powder	- Cement extrusion molding - Using large-scale facilities - Use 40–50% of cement as main raw material (ample cement supply in Bangladesh) - High density and water resistant - Excellent UV resistance - High bending strength and compressive strength - Straw can be used as reinforcing fiber	- Density: > 1.5 g/cm^3 - Flexural strength: > 14MPa -Water absorption: < 15%

Forming process: Preparation of raw materials (cement, silica powder, fiber, additives) →

mixing of binders → extrusion molding → first curing (at 65 ℃ for 8 hours) → second curing (at 180 ℃ for 8 hours) → cutting → construction

5.3 PILOT HOUSING

As we can see from the formulation and assessment of appropriate design strategies shown above, best practices and scientifically sound methods of constructing durable housing must be adopted and implemented within the community through various building strategies. The purpose of this pilot housing construction project is to allow low-income residents of the southern coastal region of Bangladesh to easily assess various technologies, consider them within the local context, and report their best experiences with them. As mentioned in the discussion of the field survey, Kamal Kathi village in Bagerhat District seems to be the optimal area for the construction of pilot housing. This village is in a coastal area and experiences flooding during the wet season. It also has good road conditions, easy access to a supply of local materials like bamboo and golpata, and there are facilities for the production of construction materials in neighboring areas.

As part of this project, KICT decided to construct pilot housing in Kamal Kathi village in Bagerhat. During preparation for the pilot housing construction project, there were a few issues, such as the inaccessibility of the pilot housing site and the necessity of holding meetings with the relevant public, governmental, and non-governmental stakeholders regarding the project. Therefore, KICT decided to construct the pilot housing at an HBRI site in Dhaka that was easily accessible to all the relevant stakeholders and those who might wish to learn from the technologies that KICT has suggested.

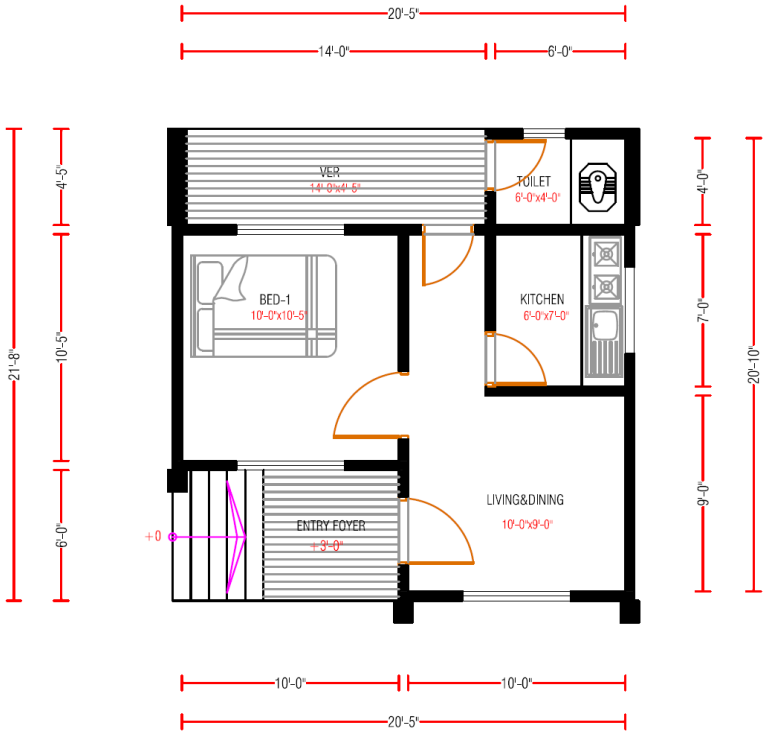

Figure 17 Pilot housing model plan

The most important consideration in constructing the pilot housing is the climate-related issues at the site. To maximize the durability of the pilot housing, we will utilize high-resistance materials that can be supplied locally. The cost of constructing the pilot housing is expected to be 30% higher than the entry-level housing design and will cost less than 15,000 USD/dwelling. The major components of the pilot housing design are as follows: an area of 35~55 m^2 with 1 bedroom, as well as a living room, kitchen area, and bathroom placed outside of the house. The four walls will be constructed from various types of materials like extrusion panels, brick, bamboo, and foam blocks with a brick-like composition. The roof will consist of a slanted sheet panel with a concrete slab, and the main structure of the pilot housing will be comprised of reinforced concrete (RC) or PVC composite columns. Table 17 shows the schedule for the construction of the pilot housing in Dhaka.

Table 17 Schedule plan for pilot housing

Date	Content	Main organization and cooperating organization
2019. 5	Draw basic design	KICT & BOF KOREA
2019. 7	Pilot site selection & document check (land register, building license, etc.)	HBRI
2019. 8	Establishment of material supply plan	KICT & BOF KOREA (HBRI, BUET, etc. for

		consultation)
2019. 9	Construction commencement	BOF KOREA
2019. 11	Construction completion	BOF KOREA

6. CONCLUSION

Throughout this project, the following goals have guided our efforts: 1) identifying technology solutions for low-cost domestic climate-resilient housing, 2) enhancing the technical skills and knowledge of local experts and the building capacities of communities, and 3) developing a final technology solution and planning the construction of pilot housing in Bangladesh, all of which are integral to developing building methods that can improve the resistance to climatic conditions of the vulnerable coastal communities in Bangladesh.

The durable housing technology solutions for the southern coastal area of Bangladesh are as follows:

1) Design for durable housing construction for low-income residents
- Design target for the structural frame, wall, roofing material, and ground material for durable housing construction is presented, and the materials that can meet each performance criterion are presented. For the structural frame, using a ferro-cement frame is recommended in light of its resistance to salt, cyclones, and corrosion. Furthermore, bubble block and plastic brick are recommended for walls because of their durability, as well as CGI sheets for roofs. We do not recommend the use of degraded products.

2) Characteristics of the housing proposals
- We presented three types of housing proposals based on resident income level. The selection of house size and materials was done according to low-income, middle-income, and above middle-income levels.
- To improve Bangladesh's residential culture, each model proposed a system that can use solar panels and a rainwater storage system.

3) Housing construction materials and cost
- Durable housing issues mostly related to the aging of walls and roofing materials rather than main structural parts. Therefore, we proposed a cost-effective method to ensure the durability of the wall materials. We suggest that perforated block using fly ash, or a mixture block of rice straw with soil and a small amount of cement are used for walls. In areas where durability is most required, we suggest using extruded concrete panels.

4) Pilot housing project

- In this study, the Kamal Kathi area, located in Bagerhat District, which has good transport infrastructure with good availability of local materials, is decided for the pilot project. The pilot housing design will differ slightly to what was proposed, but will now also target low-income residents. KICT has proposed a pilot housing construction project beside this CTCN project, which is under process in HBRI site in Dhaka, Bangladesh and expecting to complete this construction by November this year.