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Investigation of bioclimatic design features in vernacular architecture of Northeast India: Case studies of Assam-type houses and stilt houses (Chang Ghar) in Assam, India

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Bioclimatic design features in the buildings are based on surrounding geography and climate to create comfortable and healthy spaces. These features are observed in the vernacular architecture styles across the regions of India. Various bioclimatic design strategies are also observed in Northeast India; however, they are less focused when compared to other regions of India. Therefore, this paper attempts to investigate bioclimatic features in the vernacular architecture of Northeast India, wherein it focuses on two typologies, *i.e*., Assam-type house and Stilt houses (*Chang Ghar*). A qualitative analysis based on the site surveys was done to identify bioclimatic features used in the two selected typologies. The parameters selected to investigate bioclimatic features include the type of construction materials and methods used; the spatial arrangement of spaces; orientation and layout of the building; wall thickness; nearby open spaces; vegetation and water bodies; openings and ventilation; window to wall ratio; plinth height; design and material of shading devices; structure, height, and material of ceiling, any other special features. Overall, the results indicated that Assam-type houses and stilt houses are highly responsive to the local climate, utilizes locally available materials (bamboo, wood, and mud), and reflects the living style, customs, and socio-economic conditions. The outcome of this qualitative study was the identification of multiple bioclimatic features observed in both typologies. The recommendations from this study can act as a reference for designing buildings that shall promote sustainable built environments as per United Nations Sustainable Development Goal number 11 (Sustainable cities and communities).

Keywords: Assam-type house, Bioclimatic design, Northeast India, Stilt house, Vernacular architecture

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Climate has a significant impact on the performance and energy usage in a building. A climate-responsive sustainable building design aims to reduce energy consumption, use natural resources, and provide comfortable, healthier, and sustainable living places[1,2]. Local factors have affected and generated various architectural styles that respond to the climate, materials, socio-cultural setting, and economy of the area[3]. Bioclimatic features effectively use solar radiation to warm up structures in winters while creating a cooling effect during summers. The key factors influencing these features are culture, climatic factors, and human behaviours[4]. Climatic factors, such as solar radiation, wind speed, and its direction significantly impact the buildings[4].

The main features of vernacular architecture are cost-effectiveness, use of locally available materials, effective solutions that are compatible with the climatic conditions of the respective regions[5,6]. These structures though modest, have a higher sense of design sensitivity than modern structures[7]. Previous studies that evaluated various vernacular styles exhibited the predominant use of bioclimatic design features both in the Indian and international context.

It is observed that the bioclimatic features have been the basis of vernacular architecture for centuries across the globe. In the international context, bioclimatic features used in warmer climates include shutters to avoid the saline and humid winds, provision of semi-open spaces to enhance ventilation and cooling, and perforated façades for shading and wind movement[8-10]. Other common bioclimatic features include designing compact structures, use of

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timber, reed, and clay roofs, and other local materials. In colder climatic zones, cave-dwelling houses, courtyards, and balconies oriented to the South direction, terraced front walls for the protection against snow and wooden shutters to avoid the cold winds are commonly observed. Stone façade with wooden interiors are used to mitigate strong winds while wide eaves are used to protect the structure from rains[8,10-12].

Similarly, vernacular architecture in India includes functional structures built using locally available building materials and indigenous techniques to meet the requirements of people in the region[4]. During natural disasters, it has been observed that vernacular houses are the least affected[13]. For decades, indigenous knowledge systems have allowed many communities to live in harmony with their surroundings, and their traditional knowledge systems are vital tools in environmental protection and natural disaster management[14]. The diversity in the design of these vernacular structures corresponds to the diverse climate in India that ranges from hot and dry to cold and cloudy[4].

Some of the most researched vernacular typologies in India include but are not limited to *Kath Kuni* architecture of Himachal Pradesh, *Koti Banal* architecture of Uttarakhand, *Bhunga* houses of Gujarat, *Chuttilu* houses of Andhra Pradesh[15-18]. In hot and humid climatic regions, blocks built around an open courtyard, internal *verandahs*, sloping roofs, *jaalis*, wooden false ceiling, ventilation through thick rubble walls, mud roof, and wider overhangs were built[15,19]. Regions with colder climates mainly use materials with high thermal mass, sunspaces, attics for insulation, sloped roofs, covered verandahs, compact planning, smaller openings[17]. For hot and dry climatic conditions, East-west orientation, use of vegetation in the periphery for shading, courtyards, verandas, thick walls, and roofs are common bioclimatic features[20].

The Northeast region of India is diverse in terms of topography, climate, demographics, and culture. The vernacular architecture in this region directly responds to the local climate, cultural, and social environment[4]. These factors contribute to the diverse architectural styles adopted by the various groups of indigenous people living in this region. Overall, the vernacular architecture of Northeast India represents a purity of form in terms of shape, cohesion, the spatial transition between interior and exterior spaces, materials used, and reciprocity between human needs and environment. The indigenous people have a formidable knowledge of the locally available building materials that can be used for the construction of different building components[21]. The vernacular houses in warm and humid areas of Northeast India have U-shaped or elongated layouts for optimum exposure of surface area to the prevailing wind direction[22]. In cool and humid climates, the houses have long-slanted roofs with an open platform linked to the main structure[23]. To receive the most solar radiation, the majority of the dwellings are east–west oriented and south facing[4]. In cold and cloudy climates, the layouts of vernacular houses are generally rectangular. The houses are compact, follows east-west axis, and built on the southern side of the mountains to receive higher sun radiation[4]. Houses are built without openings in the prevailing wind direction, and verandas are used sparingly. Some of the vernacular typologies of the region include but are not limited to Assam-type house and stilt house or *chang ghar* in Assam, Adi tribe house in Arunachal Pradesh, Naga architecture of Nagaland, *Garo* house in Meghalaya, *Tong ghar* in Tripura[4,21,24,25].

The vernacular architecture in Assam, India, includes Assam-type houses and Stilt houses. The Assam-type houses are commonly one or two-storied high and predominantly designed for dwellings or institutional buildings. The uniqueness lies in its simple form, economical and easy to build, light-weight structure, maximizing the use of locally available material, sloping roof, and proper ventilation[26]. Stilt houses are traditional structures built to get protection from floodwater and wild creatures. The tribal population of the region constructs their architecture with locally available natural materials, following their respective tradition[27].

The various methods used by researchers to identify and study the bioclimatic features of vernacular typologies and related aspects include but are not limited to the study of meteorological data[26], climate station sampling[9], field surveys and observations[4,20-22,28], and measurement of environmental parameters[29]. Other methods include case studies and literature studies[8,16,18,29-31], interviews[32], the study of bioclimatic charts and psychrometrics charts[30], Architectural Evaluation System (AES)[9]. Most of the earlier research on Northeastern vernacular architecture includes the

study of climatic zones, resilient structures, ethno-cultural influences, and other technical aspects. However, a detailed study has not been conducted to investigate the bioclimatic features of the Assam-type houses and stilt houses.

Therefore, this study attempts to investigate the bioclimatic features commonly used in the Assam-type houses and stilt houses and recommend suggestions for the inclusion of bioclimatic design features in modern buildings to promote sustainable built environments.

Study area

The northeast is classified into three climatic zones, *i.e.*, warm and humid, cool and humid, and cold and cloudy[26]. The northeastern region lies between 21° N to 30° N latitude and 89° E to 97° E longitudes with an approximate area of about 254,438 sq. km. This region is characterized by uneven topography and varying climatic conditions. This study is based on Assam-type houses and Stilt houses found in the state of Assam. The location of selected case studies is shown in Figure 1.

The state of Assam extends from 24° N to 28° N latitude and 89° E to 96° E longitude between the foothills of the Eastern Himalayas and the Patkai and Naga Hill Ranges[33]. The southwest tropical monsoon, active from April to October brings occasional winter showers, and has the greatest influence on Assam. The annual average rainfall in the state varies between 1600 mm and 4300 mm, depending on location. The state receives an average annual rainfall of around 2900 mm, mostly during the months of June and July. The average temperature ranges between 4°C to 19°C in the winter and 26°C to 37°C in the summer, all of which are accompanied by considerable humidity[33].

Method and Data Sources

The methodology adopted in this study is exhibited in Figure 2. The primary data for this study were

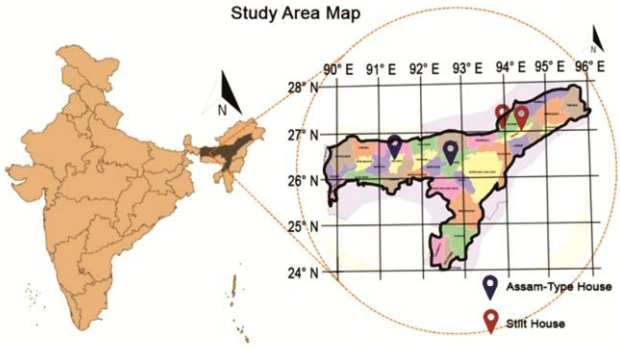

Fig. 1 — Case study locations

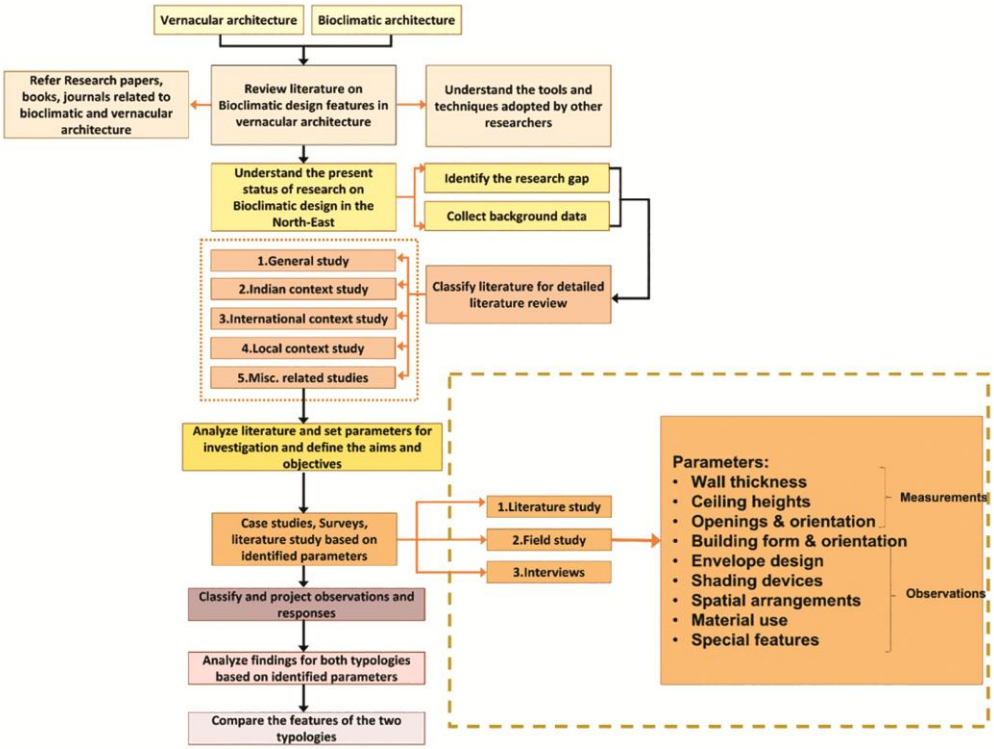

Fig. 2 — Methodology chart

collected from case studies, interviews of the residents while secondary data were based on the literature study. A literature review was done to understand the various tools and techniques adopted by the researchers to investigate bioclimatic features. Further, this study investigated the selected vernacular typologies based on the parameters identified through the literature review[34-37]. The ten parameters selected for this study include:

- Construction materials and methods
- Spatial arrangement, Orientation, and Layout
- Wall thickness
- Open spaces, Vegetation and Water Bodies
- Openings and Ventilation
- Window to wall ratio
- Plinth height
- Roofing and Shading (structure, material)
- Ceiling (structure, height, and material)
- Special Features

The selected case studies for Assam-type houses included only those houses which are at least 40 years old, while houses older than 35 years were considered for stilt houses.

Results

Bioclimatic design features in Assam-type houses

Construction materials and methods

Wattle and daub construction (weaved bamboo plastered with processed mud) was used to construct the houses to minimize indoor heat gain. Since the material and labor are locally available, the embodied energy (energy associated with processing, manufacturing, transportation, and assembly) is low. The light structures supported with horizontal and vertical wooden battens make these structures flexible, thus making it earthquake resistance.

The plastering on the wall was generally done using red soil mixed with lime. In houses that were constructed around 100 years back, Sal wood columns could be seen in their natural form instead of rectangular columns (Fig. 3).

Spatial arrangement, orientation and layout

Most rooms in these houses were arranged along the *verandahs*, allowing cross ventilation. Washrooms were built away from the main house to reduce moisture content in the houses and maintain a hygienic condition inside the houses. These houses commonly had an L-shaped or rectangular layout (Fig. 4). The L-shaped layout creates spaces that can

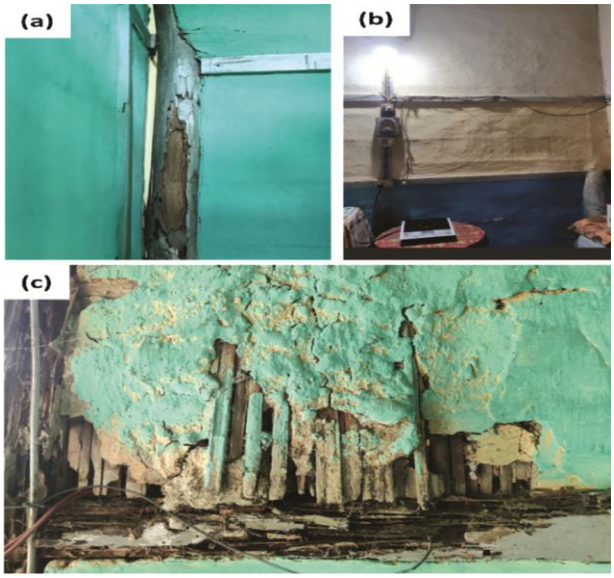

Fig. 3 — (a) Sal wood column (b) interior wattle and daub wall (c) exposed part of wall

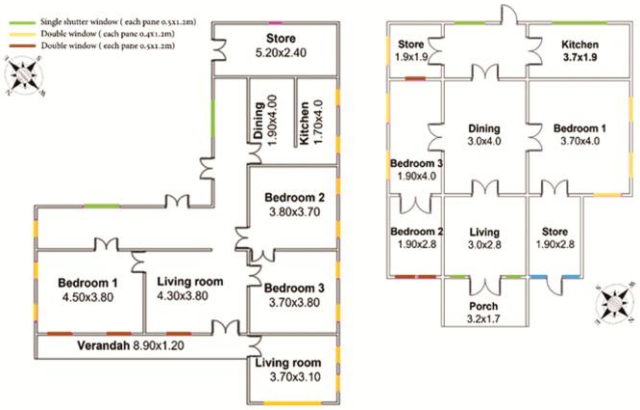

Fig. 4 — Example of spatial layouts in Assam-type houses (Dimensions in meter)

be used as courtyards adding to the openness and helping in better air circulation. Also, this layout maximizes the surface area exposed to the prevailing wind direction that helps in better air circulation contributing to the overall heat loss. Although some houses have a compact rectangular layout, most rooms are naturally ventilated due to the specific arrangements or location of windows and ventilators.

Wall thickness

The walls were made of brick (about 15 cm thick) up to about 80-90 cm from the plinth level above which mud-plastered bamboo walls (wattle and daub) of about 5 cm thickness is used (Fig. 5a). Such a technique would avoid the contact of bamboo with the moisture coming from the ground and further improve the lifespan of the building.

Fig. 5 — (a) Plinth and brick wall below wattle and daub (b) open space in front of house (c) ventilators at around 3 m height (d) net over lintel for lighting and ventilation

Open spaces, vegetation and water bodies

The *verandahs* and courtyard facilitate overall air circulation and allow maximum sunlight (Fig. 5b). The vegetation surrounding most houses helps shade the openings as some houses do not have shading devices above the openings. No water bodies were observed around these houses.

Openings and ventilation

Predominantly the openings are oriented in the prevailing wind direction, and the ventilators on all sides allow for the release of warm air in the houses (Fig. 5c). The majority of these openings were seen on the South-West and North-West façades, which allow ample sunlight inside the house. The centrally located rooms were lit and ventilated using ventilators placed at heights above the ceiling height of surrounding spaces or through nets placed over lintel heights (Fig. 5d). Few openings were observed on the northeast façade. The doors and windows were placed in opposite directions, and some would open to the *verandah* or the exterior spaces to allow for cross ventilation.

Window to wall ratio

The observed window to wall ratio was approximately 0.15-0.17.

Plinth height

The plinth height of the houses was around 45 cm. Higher plinths were not observed in the locations with no history of floods but were observed in houses of flood-prone areas.

Fig. 6 — Sloping roofs with GI sheet coverings

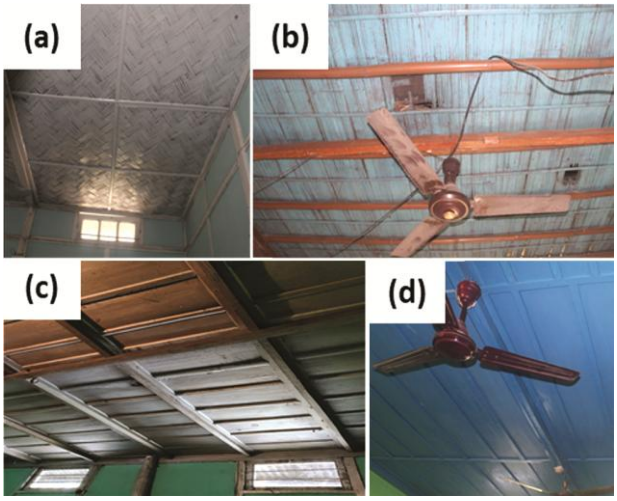

Fig. 7— (a) & (b) woven bamboo ceiling (c) & (d) timber ceiling

Roofing and shading

Sloping roofs were used in Assam-type houses due to heavy rainfall in the region (Fig. 6). The roof frame was made of Sal wood due to its easy availability and resistance of matured Sal to moisture and termite. The roof covering was made of Galvanized Iron (GI) sheets. It is used due to its property of wind and water resistivity. The sunshades or *chajjas* observed in a few houses designed for shading and were made of timber, covered with GI sheets.

Ceiling

A bamboo (Fig. 7a & b) or wooden (Fig. 7c & d) false ceiling separates the living volume from the attic in Assam-type houses. In addition, it reduces summer heat gain and winter heat loss. The higher ceiling heights in the living area allow more natural light and ventilation. Ceiling heights for these houses varied from 240 cm to 350 cm. The use of Sal wood ceilings has also been observed for exterior areas like verandahs.

Special features

Attics were observed in all the houses to control the inside temperatures by providing a large mass of slow-moving air (Fig. 8a & b). The void between the roof and wall helps in the movement of warm air (Fig. 8c & d). These voids were covered with perforated bamboo or wooden screens that allow natural light inside. Along with this, a special shading device made of bamboo was observed in some houses for shading ventilators (Fig. 8e & f).

Bioclimatic design strategies in stilt houses

Construction materials and methods

The walls and floors of these houses are made of bamboo, while roofs were made of thatch. The vertical and horizontal supports were made of timber or bamboo. The bamboo walls and floors were perforated to promote ventilation (Fig. 9).

Spatial arrangement, orientation and layout:

Houses were rectangular in layout, with no internal partitions. The centrally located fireplaces used for cooking also keep the dwelling warm in winters. *Mishing* houses are generally built on riverbanks, perpendicular to the mainstream which is a mitigation strategy for erosion.

Wall thickness

The walls were usually made of bamboo mats, one or two layers thick and not more than 1-2 cm thick.

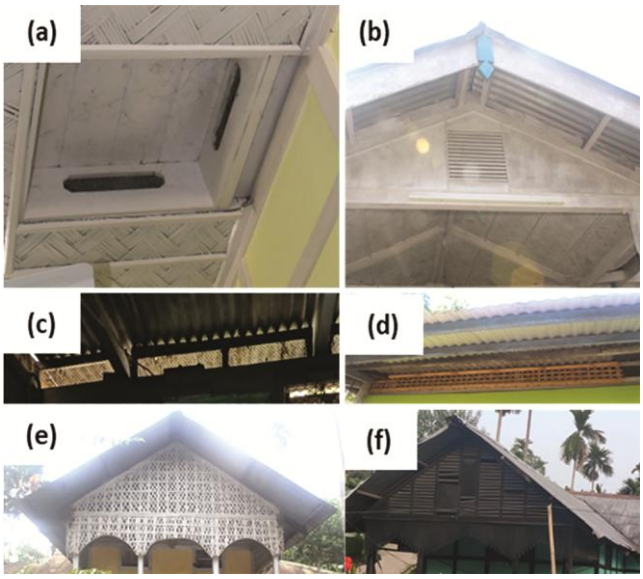

Fig. 8 — (a) Interior opening of attic (b) exterior opening of attic (c) & (d) gap between roof and wall (e) & (f) bamboo shading device

Open spaces, vegetation and water bodies

Stilt houses were observed in groups on the same plot of land with a shared front courtyard and back courtyard. The adjacent water bodies are used for water supply for daily activities (Fig. 10a). Also, the water body keeps the surroundings cool due to evaporative cooling.

Openings and ventilation

These houses do not have windows or ventilators and mainly depend on the perforated envelope for lighting and ventilation. Since there are no internal partitions, cross ventilation can occur freely through the perforated walls.

Window to wall ratio

These houses do not have windows; hence window to wall ratio is not applicable in this typology.

Plinth height

These houses were built on an elevated platform, '*Chang*,' or stilts 130– 160 cm or higher than the

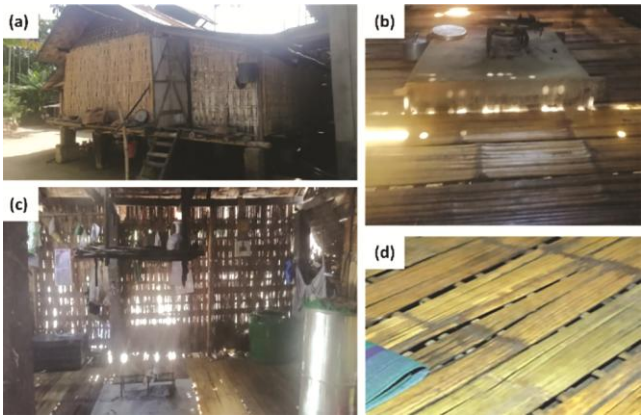

Fig. 9 — (a) Structure made of bamboo (b) fireplace used for cooking and heating (c) perforated bamboo walls (d) bamboo flooring

Fig. 10 — (a) Stilted structure built near river bank (b) thatch roof used in older houses19 (c) GI sheet sloping roof used currently

ground level. It is mostly done to protect the houses from floodwater and animals/ insects/ reptiles. The space underneath is either utilized for storage or as poultry sheds.

Roofing and shading

Stilt houses have sloping roofs which are made of bamboo or wood framing and covered with thatch (Fig. 10b). For newer houses, Galvanized Iron (GI) sheets or asbestos is also used (Fig. 10c). Thatch roofs are natural insulators and useful for both summers and winters. Extended roofs are used as shading devices.

Ceiling

A separate layer within the houses as a ceiling is not observed. Beneath the roof, a bamboo mat is placed that acts as the ceiling. Bamboo is used due to its easy availability and easy construction.

Special features

The void between the roof and walls is covered by a perforated weaved bamboo panel that helps in lighting and ventilation.

Discussion

In Assam-type houses, walls were made of wattle and daub technique (bamboo mixed with mud), roofs, columns, windows, and door frames were made of Sal or Teak wood. Bamboo is the primary material for most building components in stilt houses. These materials are used due to easy availability (Sal wood, bamboo, mud) and resistance to climate (matured Sal wood can last more than 100 years in this climate, bamboo is resistant to water). The use of lightweight materials also makes both the typologies earthquake resistant[4,38]. In Assam-type houses, wattle and daub walls of about 5 cm thickness with a 15 cm brick wall as a plinth layer (80-90 cm high) were observed. This brick wall helps in resist moisture from coming in contact with the wattle and daub part and bamboo helps to maintain comfortable temperature inside the house. Similar features were observed by other researchers in their studies[4,39]. In Stilt houses, 1-2 cm thick woven bamboo wall was observed[38]. The perforations created due to the weaved bamboo material helped in air circulation.

In Assam-type houses, different spatial layouts like U or L-shaped or rectangular layouts are used. The U and L-shaped layouts maximize the surface area towards prevailing wind direction[4]. It also creates spaces for courtyards that help in air circulation, and most spaces in the houses are arranged along open spaces that allow for cross ventilation. Washrooms were planned away from the main house to reduce moisture content and due to hygiene issues[4,39]. Stilt houses were rectangular in layout, with no internal partitions, and the fireplaces were used for cooking and also keeps the dwellings warm in winters[21]. The lack of internal partition helps in unrestricted airflow, and houses are oriented perpendicular to the nearby rivers as an erosion mitigation strategy.

In Assam-type houses, the open spaces were planned in the front and back to allow maximum sunlight to enter and promote air circulation[28]. The surrounding vegetation shades the openings. As already documented in previous studies, it was observed that multiple stilt houses had shared open spaces in front of the houses, which were used mainly during winters for harvesting activities and sunlight[21]. These houses were built near the water bodies, mainly rivers or lakes because it acts as the major water source and keeps the surrounding cool due to evaporation.

Most openings are oriented in the prevailing wind directions in Assam-type houses with a window to wall ratio of <20%, and ventilators are also present to release the warm air[22]. The stilt houses do not have openings except doors, and no glazing is used, but wall perforations promote cross ventilation. The absence of openings helps in keeping indoor temperatures low.

The plinth height was around 45 cm in the Assam-type houses. Depending on location and flooding, plinth heights tend to be higher. Stilts are the main bioclimatic feature in the stilt houses to protect from floodwater[40]. Since these houses are located near riverbanks and prone to flooding, stilts of around 130-160 cm or more are used. The space below the floor helps in air circulation through the perforated bamboo floors.

Sloping roofs were found in both typologies due to the heavy annual rainfall in this region. In Assam-type houses, roofs were made of timber framing is covered with GI sheets or asbestos. In stilt houses, sloping roofs with bamboo or wooden framing were observed and traditionally covered with thatch, while recent houses use GI sheets as roof coverings[38]. Thatch roofs act as natural insulators and have proven helpful during summers and winters. Extended roofs were used as shading devices.

Wooden or bamboo false ceilings seen in Assam-type houses minimize heat gain during summer and

heat loss during winter. The higher ceiling heights in the living area allow for entry of natural light and ventilation. The height within the houses varies from around 240 cm to 350 cm and is made of Sal or Teak wood. False ceiling is not observed in stilt houses; however, the interior side of the roof is sometimes layered with weaved bamboo mats.

Assam-type houses use attics that controls temperatures by providing a large mass of slow-moving air. These voids were observed between roof and wall in both typologies for the movement of warm air. These voids are covered with perforated bamboo or timber screens that allow natural light inside. Similar interventions for improved lighting and ventilation were observed in other vernacular typologies[41].

Recommendations

Following are a few recommendations based on the inferences derived from this study to integrate bioclimatic design in modern buildings that shall promote Sustainable Development Goal number 11 (Sustainable cities and communities)[42]

- Locally available materials can be adapted for building components, such as bamboo to construct walls, roofing, flooring. It reduces the embodied energy of buildings which relates directly to the sustainability of the built environment.
- Perforated bamboo lattice between wall and roof can promote natural light and ventilation in warm and humid climates.
- Attics can be designed in structures that have sloping roofs. It promotes ventilation and can be utilized as storage space.
- Stilt housing as a typology can be adopted in flood-prone regions. These structures can use innovative materials and techniques, such as bamboo reinforced columns, bamboo footings encased in concrete, waterproof bamboo columns with rubberized coating.
- Bamboo lattice structures can be integrated as shading devices in places where bamboo is locally available or can be easily sourced. These can act as effective shading devices for hot and humid and even hot and dry climates or shading of southern façades.
- Perforated bamboo walls can be used in hot and humid climates as a sustainable intervention towards promoting natural light and ventilation.
- The wooden or bamboo false ceiling can be used to enhance the energy efficiency of buildings. By lowering the height of the roof, the volume of air that needs to be heated or cooled is reduced. In addition, the air space that forms below the ceiling provides thermal and acoustic insulation for the room.

Conclusion

The Assam-type houses and stilt houses are highly responsive to the local environment (hot and humid climate) of the region, utilizes locally available materials (bamboo, wood, and mud), and reflect the living style, customs, and socio-economic conditions. Multiple approaches were observed from the case studies to solve similar climatic restrictions. As observed in both the typologies, the climatic conditions are similar, but a different approach was adopted to build the houses. The primary feature of both typologies is the utilization of locally available materials such as mud and bamboo for wattle and daub construction, bamboo, and Sal wood for multiple building components like walls, floors, ceiling, and doors. Overall, these materials promote a sustainable building strategy by minimizing the use of energy-intensive materials, such as steel, concrete, aluminum, burnt clay bricks. Due to high humidity in this region, the design incorporates multiple bioclimatic features to enhance the air circulations, such as openings in the prevailing wind directions, perforated structures, voids between wall and roof, and attics. The use of stilts and lightweight materials make the buildings resistant to earthquakes and floods.

This research showcased the significant presence of bioclimatic design features in the selected vernacular typologies, *i.e.,* Assam-type houses and stilt houses. The factors which influenced bioclimatic design features are climate, topography, availability of materials, socio- cultural and economic factors, and the construction techniques adopted in the particular region. Overall, the local climatic conditions significantly influenced the design decisions in both the vernacular typologies. Despite the advantages from the vernacular typologies, they are being rapidly replaced by modern buildings based on new construction materials and techniques primarily due to unavailability of the local building materials in and around the urban areas, increase in the cost of procuring local materials, and reduction in the number of skilled masons.

The limitations of this study are: 1) other vernacular typologies of the northeast and variations of the two typologies found in other Indian states were not considered; 2) the case studies were limited to particular regions of Assam and did not cover the whole extent of the state. Studying the bioclimatic features of other vernacular architecture typologies can be the future scope of this research. Understanding the merits and demerits of these vernacular architecture typologies can help architects and designers integrate them with advanced construction materials and techniques. Such techniques can alleviate the drawbacks and maximize the value of the modern construction industry to promote sustainable built environment.

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Conflict of Interest

The authors declare no conflict of interest.

Authors' Contributions

ASDC: Conceptualized and conducted field survey, collected and analyzed data, and prepared the draft manuscript; VC: Conceptualized and supervised the research work, analyzed, prepared, edited and finalized the manuscript.

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