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Assessment of Vernacular Architecture as a Framework for Sustainable Built Form: The Case of Assam, India

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Abstract Buildings consume a significant amount of energy, and this trend is anticipated to continue as living standards rise. Due to their energy efficiency and sustainability, vernacular structures have gained popularity among architects and designers in recent years, helping to mitigate the planet's ongoing ecological problems. Solar passive design has been a part of global vernacular architecture since ancient times. One effective way to lower energy usage is to add suitable solar passive elements to climate-responsive buildings. Assam's rich history is attested to by its diverse population, long-standing customs, way of life, and architectural typologies (vernacular architecture). To maximize building energy efficiency, this architectural technique combines microclimate, architecture, and human thermal comfort levels. Vernacular architecture is incredibly practical and climate-sensitive. These buildings were mostly constructed by the locals without any professional construction instruction, and they developed over time. Despite its advantages, modern architecture that employs cutting-edge construction materials and techniques is quickly replacing vernacular typologies. This is mostly because local building materials are harder to come by in and around urban areas, they are more expensive to acquire, and fewer skilled masons are working in these areas. This research aims to describe vernacular architecture in the context of Assam, India, by examining it from many perspectives connected to bioclimatism, including sustainability and culture. Many studies from primary sources are compiled to create a research database. Because a qualitative methodology was used to address the majority of the themes, this study had certain limitations. To produce more precise scientific data for Assam-type houses that architects may utilize for sustainable building design in the region, more research is required, including quantitative evaluations. The paper also examines the similarities between climate-sensitive design as a means of community definition and Assamese sustainability as a way of life.

Keywords: *vernacular architecture, bioclimatic design, climatic design, solar passive design, sustainability, Assam, India*

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1. Introduction

Sustainability has always been a significant topic in human history. Numerous civilizations have developed and endured over time by integrating with their surroundings and depending on the protection of the natural world. The key elements that have a significant impact on building architecture and sustainability are the climate, sociocultural setup, economy, availability of resources, and technology. Due to regional variations in climate, vernacular architecture refers to advantageous architectural solutions for the built environment that are peculiar to a given region. Building locally in response to the cultural, social, and microclimatic conditions of a place has historically been done through vernacular architecture [1]. People's needs and sociocultural values are frequently reflected in the vernacular architecture they create [2]. However, through a consistent path of straight revivalism, the functionally focused contributions to vernacular architecture only revealed a narrow fundamentalist viewpoint. There is yet much more amazing potential for vernacular constructions to be taken into account. One of the criteria that could be renewed is employing environmental energy to respond to needs [1].

A key element of vernacular architecture is sustainability, which has developed over time by leveraging regional resources and innovations to foster a happy coexistence of humans and their environment. Since vernacular architecture embodies the idea of the indivisibility of culture and its manifestation through architecture, buildings built with materials that are readily available in the area also demonstrate a greater respect for the surrounding environment and the limitations imposed by the climate [3]. The result of traditional knowledge derived from a trial-and-error methodology is the design of vernacular buildings. This kind of building maximizes

flexibility and adaptation while addressing the limitations imposed by the local climate. As a marker of a specific community or cultural setting, this gives these vernacular structures their distinctiveness [4]. Vernacular design employs bioclimatic principles and is a determining factor in modern architecture's pursuit of sustainability [5,6,7]. The microclimate and architecture are integrated with human thermal comfort conditions through bioclimatism [8,9].

Vernacular architecture offers a critique and substitute for modernist methods that elevate creations devoid of regional identity [10]. Even in areas with similar geography and climate, societies have used the same construction material in a variety of ways, as demonstrated by the numerous styles of vernacular architecture [11,12,13]. Many ancient civilizations have created distinctive conventional architectural forms that are tailored to the specific environment in which they were found. Assam is a source of pride for its people and delight for visitors due to its rich heritage. Assam's unique vernacular architecture has evolved and is a fundamental component of the region's cultural heritage. The vernacular buildings, constructed by the locals themselves from locally accessible materials, are resilient, long-lasting, and sensitive to microclimatic conditions and natural disasters, including earthquakes, to which the Northeast region is vulnerable [14]. The concept of climate-oriented design is embodied in the Assamese vernacular houses [8]. These structures follow conventional ways of life and have natural ventilation. The impression of thermal comfort among inhabitants is significantly influenced by their socioeconomic status and conventional lifestyles. Over time, the shape and form of these buildings have changed to accommodate daily needs and sociocultural norms [5,15]. The local populace continues to prefer these structures, which are still being built in large quantities.

Through adaptability, this bioclimatic notion gives vernacular buildings an advantage over the local climate limits. These days, as lifestyles change, so do comfort levels and energy requirements. As a result, considering the climate while designing a building is now required rather than optional in modern times. Environment and tradition are not only prerequisites for sustainable practices but also necessary for their success [16,17].

2. Research Methodology

The relationship between Assamese vernacular architecture and socio-cultural background is examined in this research. It offers a paradigm that combines sustainable construction practices with the essence of location as experienced through embodied awareness and reflection. The planned study's objective is to monitor and assess the development of uneven geographic and climatic distribution while undertaking a qualitative literature review on the main concerns, which include identity, culture, vernacular architecture, climate change, and sustainability. The current study adheres to qualitative research paradigms by using a descriptive, non-experimental methodology. By synthesizing information from past studies and research initiatives on the topic, the reading method was utilized to create the theoretical foundation for the study. Reading books, documents, and theoretical underpinnings were used to collect data. The procedure involved in the research process includes selecting a topic, finding sources, and conducting analytical, interpretive, and historical research to draw conclusions.

The findings interpret how closely characteristics like bioclimatism, sociocultural diversity, accessibility of local building materials, thermal comfort, and adaptability are adhered to by vernacular architecture. The results also look into the relationship between building architectural style and social and cultural values. Ultimately, this will provide a comprehensive blueprint for sustainable practices that utilize bioclimatic building design to achieve sustainability for the region and demonstrate how comfort is improved by vernacular architecture.

3. Vernacular Architecture and Sustainability: Natural and Built Environment

Sustainability is the cornerstone of vernacular architecture, and it connects to more ecologically friendly constructions. Vernacular architecture is defined as unassuming, straightforward, native, traditional buildings made of local materials and according to tried-and-true forms and sorts [18]. The built environment—the city, the buildings, and the interior spaces—that was produced to satisfy the needs of civilization is known as vernacular architecture. To meet people's physical, economic, social, and cultural demands, it is built in line with the natural environment (geography, topography, site, climate, local building materials, labour experience, and construction techniques) [19]. Because it may be used as a practical answer to severe weather conditions and as an analogy for regional shelter, vernacular architecture has considerable promise for modernism [20]. People in the late 20th century are becoming more regionalist as they realize the shortcomings of conventional cultures [21]. The sociocultural milieu and architectural design of the city are greatly influenced by the variety of sustainability movements. Scholars outline the phenomenological prism that unveils the connection that emerges between individuals and locations, as evidenced by territorial expressions and cultural customs like celebrations or traditions. Since vernacular architecture has an inherent inventiveness in how it interacts with the environmental, cultural, technological, and historical context, phenomenology allows us to analyse the traditional village and its social construct through its spatial organization, including its dwellings and exterior spaces [22]. It necessitates a long-term commitment to the region's identity through a sustainable strategy, as well as a deep grasp of materials and their interactions, experience in construction, artisan techniques, qualified professionals, and available resources.

For ages, traditional communities have farmed food, changed their ways of living, and coexisted with the natural world. Acknowledging the significance of preserving equilibrium with the environment, they

constructed buildings utilizing indigenous materials and methods. Iterative acts of doing and making develop into vernacular architecture. Its highly ordered socio-cultural order, which establishes its architectural syntax, facilitates its design process [23]. This type of research is required due to the lack of sufficient literature on creative architectural vernacular architecture and the close relationship that exists between the built and unbuilt. High praise is given to the architecture's eco-friendliness, climate sensitivity, natural setting, and use of locally sourced building materials. A never-ending supply of valuable ecological built environment solutions that meet social needs can be found by re-evaluating vernacular architecture [24]. Their value is further increased by the fact that they can serve as models for newly constructed buildings. Architects and designers must use approaches to long-term development that respect the environment and the ecological balance of nature to ensure society's long-term survival.

Each civilization that has constructed architecture has also evolved unique forms, including apparel, customs, language, and mythology. Up until the dissolution of cultural boundaries in the twentieth century, unique regional forms and features were a natural result of the materials, technological advances, environment, and people's culture in architecture [25]. Though it is founded on the idea of regionalism, sustainable architecture promotes responsible, long-term use of technology and design rather than urging designers and architects to return to earlier times [26]. Optimal interactions between people and their environment are the goal of sustainable building design. The opportunity and responsibility to preserve a region's character, people, and spirit fall on architects and designers.

Sustainability advocates argue that sustainable living should be guided by notions and aspirations found in traditional cultures and philosophies [27]. In contrast to the notion that buildings should be constructed and designed uniformly everywhere, the sustainable design concept values regional features. Architecture should respond to place in fundamental ways [26]. Instead of a thorough analysis of regional identity and vernacular architecture, regionalism in architecture was generally understood to be a sentimental image of a legacy through specific forms, architectural qualities, or materials.

4. The State of Assam: Place, Climate, Culture, and Settlement Pattern

Situated in the Brahmaputra and Barak River valleys, north-eastern India's Assam state spans 78,438 km2 (30,285 sq. mi) and is situated south of the eastern Himalayas (Figure 1). Assam is the largest state in terms of population and the second largest state by area in north-eastern India; it is bordered by Arunachal Pradesh, Bhutan, Manipur, Meghalaya, Mizoram, Nagaland, Tripura, Bangladesh, and West Bengal. Bengali, Assamese, Boro, and Meitei are among the official languages.

The state is spared the typical hot, humid, and rainy season in India [28,29]. In August, the average high temperature in Assam is in the upper 90s F, or roughly 36°C, while in January, the average low temperature is in the mid-40s F, or around 7°C. Fog and light rain are characteristic of the cool season, which typically lasts from October to February. Assam's climate is cold and rainy for most of the month due to the Brahmaputra's flow. Arunachal Pradesh's river, which has deep ravines and rapids, flows into Assam, where it braids and occasionally widens to 10 mi/16 km. Its tributaries form the Brahmaputra Valley flood plain, which is 600 mi/1000 km long and 50–60 mi/80–100 km wide [28]. While there is considerable precipitation from March to May, the southwest monsoon, which begins in June and continues through September, brings the most powerful downpours and frequently results in extensive and damaging floods. Assam has some of the highest yearly rainfall in the globe as well as one of the highest in the nation; the average annual rainfall ranges from over 70 inches (1,800 mm) in the west to over 120 inches (3,000 mm) in the east [30]. In Assam, flooding from rivers like the Brahmaputra and Barak rivers results in overflowing banks, destruction of dwellings, animals, bridges, roads, railway tracks, communication failures, and fatalities in numerous regions of the state [31,32].

Figure 1. Map of India showing the location of the state of Assam.

With its abundance of tropical rainforests, deciduous forests, riverine grasslands, bamboo orchards, and various wetland ecosystems, Assam is one of the world's most biodiverse regions [33,34,35]. There are many wildlife sanctuaries in Assam, but two UNESCO World Heritage sites stand out in particular: Manas Wildlife Sanctuary, which is close to the Bhutanese border, and Kaziranga National Park, which is located on the bank of the Brahmaputra River [36]. Assam is a significant global location for the white-winged wood duck, which is the state bird [37]. With about 820 species and as many as 946 subspecies, the state has the greatest bird variety in all of India [38,39]. The state flower of Assam is the foxtail orchid, and the region is very rich in orchid species [40].

The ethnic groupings of Tai, Tibeto-Burman, Indo-Aryan, and Austroasiatic are blended into Assamese culture. Consequently, it is possible to find both local elements and local elements in sanskritized forms [41]. Several kingdoms, including Kamarupa, Chutia, Ahom, Koch, and Kachari, have assimilated it and allowed it to evolve [42]. Assamese culture was profoundly influenced by the Neo-Vaishanavite Movement, which brought about

a newfound Hinduization and the creation of Vaishnav monasteries and other social organizations. British and post-British events have shaped modern culture, which is still a vibrant and evolving system.

The Assamese natural environment, which integrates the interaction between the terrain that supports and preserves it, is the foundation for the region's character and the way people live there. Rural areas are home to the vast majority of people in Assam. Several small towns with linear settlement patterns surround Dispur, the capital of Assam, which is situated along the Brahmaputra plain. Along the sides of rivers and roads are settlements [30]. But because of the mountainous topography, the abundance of rivers and forests, the limited amount of arable land, and the absence of industry, the population is distributed unevenly. Relatively randomly arranged but incredibly intuitively positioned, the houses have been inhabited for generations and make careful use of the available space as they are arranged along the street. Each house has a minimum retaining walls since part of it is built on stilts and the rest is constructed from the ground up. The majority of individuals in this plain's urban regions work in manufacturing and services. However, primary activities, particularly agriculture, are the main source of income for the rural areas' settlements. Relatively dense habitation is supported by the agricultural zone of the Barak River valley [30]. A significant amount of the plain's general economic development scenario can be inferred from the percentage of the population that is employed and the worker's occupational composition.

The development projects were carried out after independence and the flood of refugees from what was then East Pakistan into suburban neighbourhoods, business districts, train stations, intersections, etc. Guwahati, one of the top 100 cities in the world for quickest growth, is one of the urban hubs [43]. The second-most populous city in Assam and a major hub for business is Silchar, which is located in the Barak Valley. Dibrugarh, an industrial hub for natural gas and oil, is one of the other major cities [44]. Nalbari (2.41%), Morigaon (4.91%), Darrang (4.91%), Kokrajhar (6.84%), and Dhemaji (6.91%) are the Assamese districts with the least amount of urbanization. Approximately 500,000 workers, families, and supervisors are employed in Assam's more than 850 tea gardens. The outcome is a controlled estate village known as a latifundia settlement, which consists of a tea processing facility, office, warehouse, primary school, dispensary, bungalows, residential quarters, and huts.

5. Vernacular Architecture of Assam

Assam is located at 26.2006° N latitude and 92.9376°E longitude. With the exception of a few areas in middle Assam, the whole of Assam typically experiences warm, humid weather [8]. Ikra houses are typical in Northeast India and are sometimes referred to as "Assam type houses." For domestic use, the majority of these houses are used [45]. Typical functional building diagram is shown in Figure 2.

For optimal surface area exposure to the direction of the prevailing wind, the building forms of warm, humid vernacular architecture have elongated or U-shaped layouts [5]. The majority of houses in this region are built specifically to accommodate the region's climate [8]. The construction of the Assamese vernacular building envelopes is massive. The houses are shaped in a way that exposes the majority of their surface area to the direction of the predominant wind. This aids in the building's increased natural ventilation, which is one of the key needs to combat excessive humidity and excess heat loss for thermal comfort [46]. To meet their social and cultural demands, every house is equipped with the essential necessities. Common building layout for Assam-type house is shown in Figure 3.

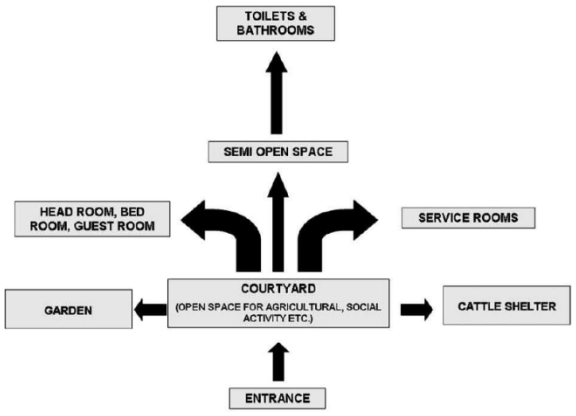

Figure 2. Functional building diagram for Assam-type house

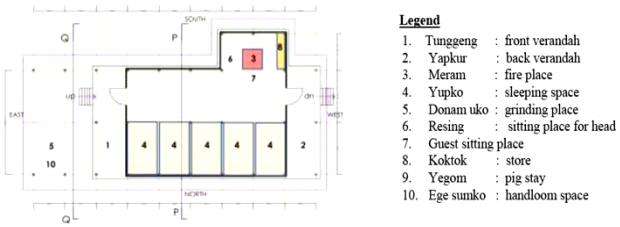

Figure 3. Common building layout for Assam-type house

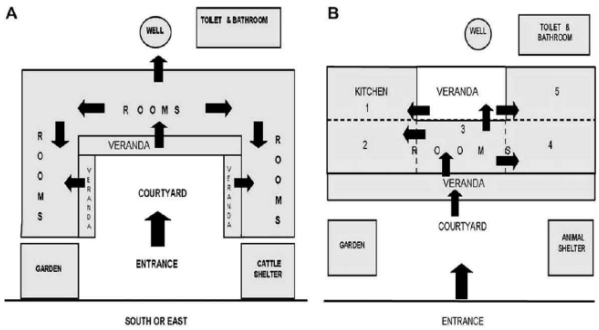

Figure 4. Common building layout for Stilt house

Local climate, resources, technology, architectural principles, lifestyles, customs, and socioeconomic circumstances are all balanced in vernacular architecture. In Assam, India, stilt houses and Assam-type dwellings are examples of the region's vernacular architecture [47]. Typically rectangular in shape, stilt houses lack interior walls and rely on fireplaces for cooking as well as warmth during the winter season (Figure 4). Because of its simplicity, ease of building, affordability, light structure, use of locally accessible materials, slanting roof, and adequate ventilation, Assamese-style architecture is

popular in the northeast [48]. Unlike their urban counterparts, rural house has courtyards as essential components of their architectural designs. In addition to offering shade and allowing for natural ventilation, rural houses often feature courtyards [5,49]. In areas with agriculture, they are frequently employed for post-harvest tasks. Verandas and hallways are examples of transitional areas that serve as buffers to enable seasonal adaptation. Rural houses are different from urban ones because of their distinctive characteristics and cultural significance. Conventionally, stilt houses are constructed so people can get shelter from flooding and wild animals. Following their own traditions, the tribal population of the area builds their construction using materials that are naturally occurring and readily available in the region [50].

5.1. Climatic Condition and Spatial Layout

There are extremely few two-story houses, and the majority are single-story. Because of their permeable structure, vernacular houses are highly susceptible to infiltration. Vernacular houses in Assam (warm and humid zones) are typically built in three patterns: without false ceiling, with ceiling and attic space, and with individual attic space above each room [51]. With a courtyard, houses are open buildings [52]. In addition to offering shade during the day, the courtyard accumulates cool air at night. Along with supporting the tenants' daily activities, it also meets socio-cultural demands. In order to minimize solar radiation in the courtyard and on external surfaces, minimize heat gain, and take advantage of shade from vegetation, the residences are oriented east-west and south [8]. Apart from kitchens, toilets, and verandas, residences usually include three to four rooms, while some have as many as seven or eight. Family size and socio-cultural requirements determine how many rooms are needed. The size of a room can vary from 3.05 by 4.27 meters to 4.27 by 4.27 meters. Building layouts strive to provide each family member with privacy and a comfortable place [5]. Bathrooms and toilets are kept apart from the main building design to ensure a comfortable living space and because of hygienic concerns [8,53].

Open areas were incorporated into the front and rear of Assam-type house to increase natural light and encourage ventilation [54]. The interior temperature of these houses is controlled by natural ventilation and air exchange. The locations of windows, doors, and ventilators, as well as the directions of the local winds, are crucial factors in achieving this. It is challenging for the design to efficiently use natural ventilation and air exchange because of the year-round high humidity. To regulate airflow and prevent sunlight from entering the interior of a house, many doors and windows are fitted with louvres or venetian blinds (Figure 5). In order to provide improved ventilation, windows and ventilators makeup roughly 50% of the floor space [8]. This is a result of the majority of houses lacking glazing in their windows and ventilators [55]. While a larger opening on the leeward side can produce a plume effect, smaller holes on the windward side can aid in natural ventilation. Since direct sunlight is not ideal for thermal reasons, external overhangs shade these openings, and higher-level outlets exhaust heated air as shown in Figure 6.

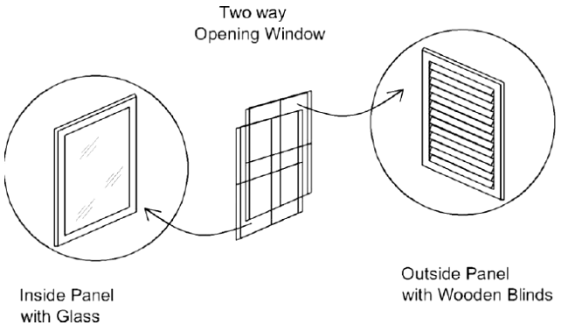

Figure 5. Windows construction techniques featuring louvres and venetian blinds

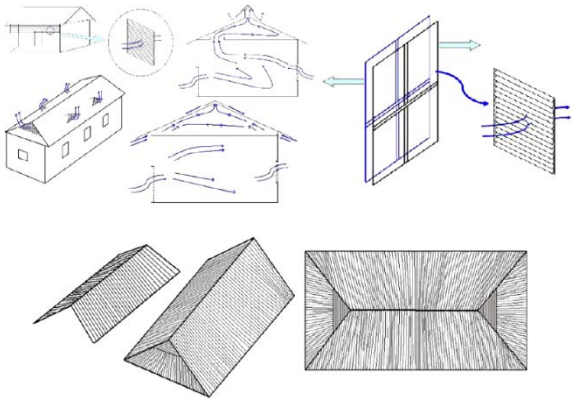

Figure 6. Shading, ventilation strategies with common roof patterns

5.2. Building Construction Techniques

Sustaining appropriate climatic conditions is enhanced by the use of traditional building materials and construction techniques. The primary building materials of a typical Assamese house are baked bricks, wood, cane, mud, lime, and bamboo, which are utilized in various amounts to achieve effective and efficient construction. Bricks in pukka constructions are fixed with urchin, a mixture of lime, brick powder, sand, and jaggery, among other ingredients [8]. Sal or teak wood was used to make the door frames, windows, roofs, columns, and walls of Assam-type houses using the wattle and daub technique (bamboo mixed with mud) [56]. For the most part, stilt house construction components are made of bamboo. Because they are readily available and climate-resistant (matured Sal wood can survive over 100 years in this region, and bamboo is water-resistant), these materials are used. Both typologies are earthquake-resistant due to the use of lightweight materials [52,57]. Two-story houses are free of wet and damp ground because the base floor is composed of brick masonry and the first floor is raised with wood. In certain houses, the outer half of the walls are made of wood, while the interior is composed of brick. Every building material needed to make the traditional houses is accessible in the area [8]. This gives us an advantage on the environmental front because less energy is used in processing and transportation, resulting in a minimum environmental impact.

In Assam, a solar passive house or structure is intended to maximize the use of solar radiation for heating purposes in the winter and to block out solar radiation in the summer. This technique also improves internal lighting conditions through natural lighting [58]. The interaction

between architectural textures, human behaviours, culture, and climatic elements must be thoroughly understood in order to build solar passive houses and structures [8,59,60,61]. The warm and humid bioclimatic zone described by bioclimatic zones indicates that high humidity and heavy precipitation are the main elements influencing the comfort level inside built environments [8,62]. The construction of dwellings is also affected by solar radiation and the direction and speed of the wind. The vernacular architecture of a typical Assam-type house reflects the effects of all these variables. The house entrances are drawn inward due to the excessive rainfall in this area. The mud dwellings' walls are built on an elevated platform to prevent side walls from collapsing from rainwater draining off the roof, hence reducing damage from flooding [63]. Massive walls have lightweight roofs and are constructed from either mud or bricks with backing. The capacitance effect is the ability of a massive wall to both store and radiate heat [64]. These walls can be used to efficiently control the interior temperature if they have the right thickness and tightness. Mud architecture, which consists of wattle and daub walls that are around 5 cm thick with a 15 cm brick plinth layer (80–90 cm high), is rather widespread in rural areas with typical Assam-type dwellings. A soil combination combining clay, water, and lime is used to prepare Adobe. The addition of lime keeps fungi and mould from growing on walls. To build the walls, the mud bricks are prepared on the spot and stacked one on top of the other. The partition walls of the rooms are constructed by sandwiching layers of mud between bamboo that have been weaved. Every monsoon, these houses require some maintenance. The walls are frequently cleaned or painted in soft pastel colours [63]. It was noted that the woven bamboo walls of stilt dwellings were 1-2 cm thick [57]. The primary bioclimatic element of stilt buildings that provides floodwater protection is their stilts [65]. Air circulation was aided by the perforations made by the bamboo material's weaving. Surkhi is used for plastering and brick repairs in pukka buildings.

All of the traditional Assam-type houses feature slanting roofs that face two or four directions in order to overcome the climate constraint. To shield the wall from precipitation and bright sunlight, roofs are typically extended to serve as an overhang [56]. In order to facilitate natural airflow and better ventilation, roofs have vents and chimneys that let warm air from attic spaces escape [5]. Since timber frames have a low thermal mass and quickly transfer heat into interior spaces during the day and vice versa at night, they are typically used for roofing in conjunction with asbestos cement sheeting or galvanized tin sheeting. Stilt houses, however, are more likely to have thatched roofs with bamboo or wood frames [57].

To keep living areas apart and reduce heat gain in the summer and heat loss in the winter, vernacular houses utilize ceilings composed of materials such as plywood, asbestos sheets, hardwood planks, and woven bamboo mats [8]. Between 4.57 and 5.49 meters is the height of these ceilings, with apertures at the very end. Warm air can exit through rooftop vents and chimneys due to these solar passive features, which also provide a natural draft (Figure 6). For better insulation, some houses incorporate air gaps and multi-layered ceilings [5]. In order to keep warm air indoors during the winter and let it escape during the summer, openings are controlled (Figure 7).

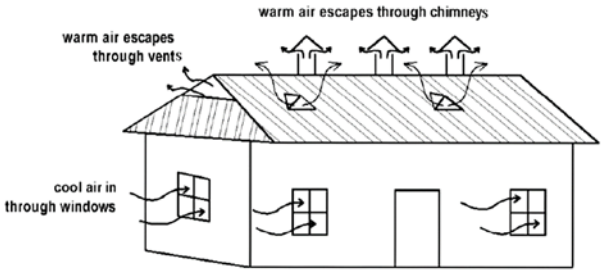

Figure 7. Warm air exhaust through vents and chimneys

Shading has a significant impact on how the building regulates its heat intake. In addition to having roofs that extend outward to function as overhangs, vernacular houses have overhangs (Chajja) on their windows (Figure 8). Furthermore, it is noted that the vegetation serves as shading quite well.

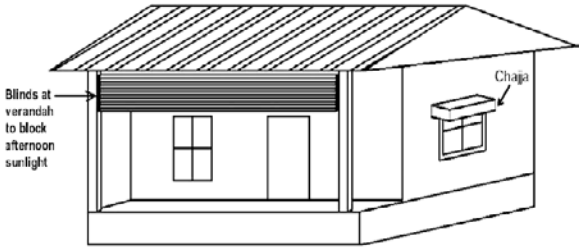

Figure 8. Shading devices (chajja) and veranda blinds used to reduce afternoon solar radiation

6. Bioclimatism as a Sustainable Practice in Vernacular Architecture of Assam

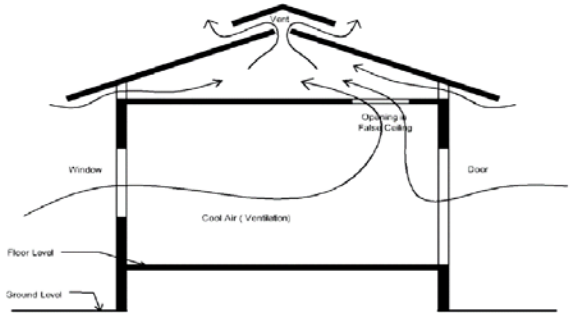

Figure 9. Airflow patterns in warm humid climates

The ideal architectural solutions for the built environment are also region-specific because climates differ from place to place. A combination on of local climate, solar heat gain or loss, and human thermal comfort has been used to build the scientific foundation for bioclimatic design [66]. Assamese vernacular architecture is extensively constructed, naturally ventilated, and features a broad roof line (Figure 9). The key elements that have a significant impact on building architecture and sustainability are the climate, sociocultural setup, economy, building materials, and technological availability. However, abstract problems in the social, economic, and environmental spheres affect sustainability. The definition and characteristics of a

sustainable city, as well as the types of urban structures that may be more sustainable, have been the subject of extensive research [67].

When it comes to the design of buildings and habitats, sustainability has multiple implications. A development that minimizes its negative effects on the environment while optimizing its positive effects on the economy, society, and environment is termed sustainable development. A building or habitat that is socially acceptable, environmentally benign, and economically feasible is considered sustainable [68]. The relationship between the climate, daily activities, and the dispersion of humans and other living things is known as bioclimatic [69]. The architecture practiced by the Assamese people is already entirely vernacular and centered around bioclimatism. The north-eastern bioclimatic climate has a significant impact on the socioeconomic standing and cultural context of Assamese vernacular buildings. In addition to the other forms, this kind of spontaneous activity creates a distinct architectural style known as "Assam-type" by the locals. This Assam-type house is incredibly inexpensive, straightforward, and adept at meeting cultural and social requirements—not to mention the demands of the climate, which it does brilliantly [8]. Solar passive features that regulate temperature and encourage natural ventilation are a common feature of these houses [5]. Various locally accessible materials, such as baked bricks, wood, cane, mud, lime, bamboo, and others, serve as outstanding examples of sustainable building design in this regard [8]. Since these houses are made to use as little energy and other natural resources as possible, the environment will benefit. In contrast, the majority of buildings that are planned and used today are neither sustainable nor environmentally friendly. Originally, buildings were made to be shelters from harsh weather, with materials chosen to maximize comfort and awareness of the surrounding environment [19,20,70]. According to different research, the built environment is essential to sustainable development, and its sustainability needs to be carefully investigated. The harmony between human behaviour, architecture, and environment is best exemplified by vernacular architecture, which is frequently disregarded in modern times. We as architects can take a cue from our ancestors, who recognized the interdependence of people, structures, and the physical environment, even in light of our superior technological skills and cultural background [71].

Compared to modern rural or urban dwelling structures, Assamese vernacular architecture is very distinct. Contrary to urban housing, which is collective because of physical restrictions imposed by nature, rural housing is composed of scattered settlements designed to accommodate the daily needs of residents. In addition to indicating additional socio-cultural traits, the constructed form's morphology and the cluster dwelling unit's spatial arrangement also emphasize utility [72]. These structures change over time to take on the characteristics of their surrounding historical, cultural, and environmental contexts. The construction knowledge used in these types of architecture is frequently passed down through the generations and is therefore primarily reliant on knowledge acquired through trial and error [73].

Various research conducted on vernacular architecture has demonstrated that bioclimatism is an essential factor in attaining sustainability in contemporary architecture [4,59,74,75]. Due to its representation of solutions that exhibit maximum flexibility and adaptability, as well as its setting an example for sustainability, this design is extremely valuable to modern architecture. Building materials like steel, cement, and bricks require a lot of energy in the modern world. According to several studies, designing climate-responsive buildings can drastically lower both the embodied energy cost and operating costs [7]. To save energy and reduce carbon emissions, climate-responsive architecture design has become essential rather than voluntary [75]. This idea enhances the artificial energy efficiency of buildings and the thermal comfort of the built environment by considering solar passive approaches and microclimatic variables in building design. Therefore, it is important for us as designers and architects to recognise the value of vernacular architecture. Instead, it necessitates thorough and methodical scientific comprehension.

7. Discussion and Analysis

There are several different ethnic groups in north-eastern India, and each has its own unique social and cultural structure. Since tribal settlements differ greatly from urban forms in terms of scale, magnitude, and character, it would be unfair to compare and analyze them. However, socio-cultural issues and climate take precedence in warm, humid climate regions, particularly in the case of Assam. Assamese vernacular architecture is a great illustration of bioclimatic building design. The local builders always look for better methods to use the resources that are already available, having learned their trade from earlier generations. [76] Research on the vernacular architecture of Assam indicates that a typical Assam-type house includes several noticeable solar passive characteristics, including greater ventilation, temperature control, air circulation, and shading. The majority of Assamese vernacular houses have an internal temperature swing of 10°C, which is fairly reasonable for free-standing structures, according to the temperature profile of these buildings. Advanced solar passive features such as a double-layered false ceiling, an air gap in the ceiling, movable blinds for effective shading, and a chimney arrangement for better air circulation are also illustrated in some of these houses. Numerous doors and windows are included to allow for proper airflow and cross-ventilation. Concerning that, there is a strong correlation between social and cultural values and the design and functionality of buildings. Therefore, while evaluating the sustainability and comfort of buildings, these variables need to be given the appropriate weight.

This research examines Assamese vernacular architecture in comparison to contemporary rural and urban homes. The building is porous, exposing the majority of its surfaces to the direction of the wind for natural ventilation, and it makes use of locally accessible materials to reduce inside temperature swings. As overhangs, slanted roofs block heat gain and shield walls from precipitation. Different materials are used to construct ceilings to divide a room's volume from the attic.

To provide natural ventilation, windows and ventilators are positioned above doors and windows. However, windows without glazing let in very little natural light. Windows with overhangs is a typical feature. Because they fulfil a variety of functions, such as controlling the environment, providing for daily needs, and satisfying social and cultural requirements, courtyards are essential to vernacular architectural designs. Because of hygienic concerns and religious convictions, restrooms and toilets are kept apart from the main building plan. This kind of design is simple, cost-effective, serves cultural and social needs, and, most importantly, cleverly adapts to the local climate.

The ability of a building to give its occupants thermal comfort determines whether a built environment succeeds or fails. Natural ventilation is one of the main features of vernacular architecture. The construction and operation of buildings are the main areas of attention for sustainability in the construction and building industry. According to a study, the cost of operating a building is far more than the cost of construction, since the availability of energy has made it easier to use mechanical methods to extend a structure's thermal comfort. This occurs because the needs of the occupants, who decide how the buildings should operate, and the local climate were not given due consideration during the development of the structures. However, by taking into account all of the variables that influence building design well in advance of the construction phase, sustainable bioclimatic building design offers a comprehensive approach. To considerably reduce the building's operational energy costs and use of energy-intensive building materials, this model must be considered throughout the building's development process.

It is noteworthy to observe that the region's climatic restrictions are effectively addressed by this vernacular architecture. In this sense, there are benefits to using building materials that are readily available locally. Because they originate from the same climate, for instance, the materials are more affordable, flexible, and long-lasting. Also, these buildings in the region were constructed by various individuals in various places and at different times; they embody the spirit of individuality. The concepts of bioclimatic architecture and sustainability are linked disciplines of research. When discussing architecture and the built environment, designers and architects must take into account more than just the locations influenced by structures. We also need to take into account how people alter their surroundings to suit their requirements, way of life, traditions, and cultural standards. This could be related to the relationship between architecture and sustainability. To sum up, the sustainable design concept honours regional traits, customs, and philosophies.

7.1. SWOT Analysis

As a foundation for sustainable practices, the critical evaluation of Assamese vernacular architecture highlights both the strengths and weaknesses of using traditional construction techniques. The Assam-type houses show sustainability by using local materials and flexibility in regional conditions, but they also have challenges, like the requirement for modern amenities. For Assamese vernacular architecture to be preserved and promoted, threats like urbanization and the loss of traditional knowledge must be addressed. Nevertheless, there is potential for incorporating contemporary technologies and encouraging cultural tourism. Table 1 presents the SWOT analysis for the vernacular architecture of Assam, India.

Table 1. SWOT Analysis for the Vernacular Architecture of Assam

Strength	Weakness	Opportunity	Threat
Assamese vernacular architecture features locally developed construction methods and building materials that have been handed down through the years, reflecting the region's rich cultural legacy and customs.	Identifying and conserving indigenous building methods is difficult due to a lack of research and documentation on Assamese vernacular architecture.	Modern technology can be incorporated into vernacular homes to improve their resilience and sustainability. For instance it can include solar panels, rainwater collection systems, and energy-efficient insulating materials.	Vernacular architecture is being dispersed and deteriorated as a result of the pressure that industrialization and rapid urbanization are placing on land resources and traditional settlement patterns.
Natural ventilation, thermal insulation, and shading systems for local climate adaptation are some of the bioclimatic approaches used in Assam-type houses and stilt houses to improve thermal comfort and energy efficiency.	The continuation of Assamese vernacular architecture practices is threatened by the state's rapid urbanization and the use of contemporary construction methods.	In addition to boosting the local economy, Assamese vernacular architecture offers a chance for cultural tourism by drawing tourists eager to experience traditional ways of living, firsthand construction techniques, and eco-tourism.	The impacts of climate change, such as extreme weather and rising temperatures, may have an impact on the durability and applicability of indigenous building materials and construction techniques.
Assam-type houses and stilt houses have flexible, adaptable floor plans that accommodate changing occupant needs and serve as useful areas for a range of activities.	The lack of contemporary amenities and technology in traditional Assamese-style homes and stilt houses, such as electricity, plumbing, and adequate sanitary facilities, can be problematic for the comfort and convenience of their occupants.	Educational programs and workshops can raise awareness and develop skills among architects and engineers, collaboration between academia and communities can increase knowledge exchange and capacity building in the preservation and promotion of vernacular architecture.	Traditional construction methods and the Assamese architectural legacy are being lost as a result of shifting socioeconomic conditions and cultural choices.
Assamese vernacular houses are built with locally produced, renewable resources like bamboo, thatch, and mud, which reduces construction's negative environmental effects and encourages	The preservation and promotion of vernacular architecture is hampered by the reduction in skilled artisans and craftsmen who are	Assamese vernacular architecture can be encouraged by policy interventions that support the preservation of indigenous building methods and heritage	The survival of Assamese vernacular architecture is threatened by commercial interests and market forces that favor contemporary building materials

sustainability.	knowledgeable in traditional building techniques.	conservation.	and methods.
The study emphasizes how crucial community involvement is to the preservation and promotion of vernacular architecture, as it helps to create a sense of cultural continuity and ownership.			The integrity and value of vernacular buildings may be compromised by the careless demolition or alteration of such structures as a result of inadequate enforcement of zoning restrictions and heritage protection laws.

8. Conclusions

This paper demonstrated how prevalent bioclimatic design elements are in the Assamese vernacular housing typology (Assam-type house). Because Assam-type houses are constructed using materials that are readily available in the area, such as bamboo, wood, and mud, they are particularly vulnerable to the warm, humid climate. They also represent the manner of life, social status, and customs of the community. All things considered, the use of less energy-intensive materials like steel, concrete, aluminium, and bricks made of burned clay supports a sustainable building strategy. Overall, these materials support environmentally friendly building practices by reducing the usage of energy-intensive materials, including burnt clay bricks, concrete, steel, and aluminum [77].

In conclusion, the concept of energy efficiency in architecture can only be fulfilled through the integration of vernacular solutions. Over time, vernacular practices have endured. Because of the excessive humidity in Assam, the design includes several bioclimatic features to improve ventilation. These features include openings that face the direction of the predominant winds, attics, perforated buildings, and the gaps between walls and roofs. Because of this, these houses don't require mechanical ventilation. As a result, the overall energy consumption is greatly reduced. The buildings are also earthquake and flood-resistant due to the use of lightweight materials and stilts. Overall, the regional climate had a significant impact on the vernacular typologies' design choices. Given that vernacular typology reflects location, time, and culture, it serves as a "mirror" of nations and a predictor of long-term survival [78]. It is an architecture designed by humans that has developed throughout time to satisfy the needs of civilization while maintaining environmental harmony. To make an impact on a world that is constantly changing, not just in terms of architecture but in all facets of existence, bioclimatism is essential to the development of a new culture.

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