



Proceedings of The 2nd International Conference on Smart Villages and Rural Development COSVARD 2019

2-4 December 2019
Assam Administrative Staff College
Guwahati, Assam, India

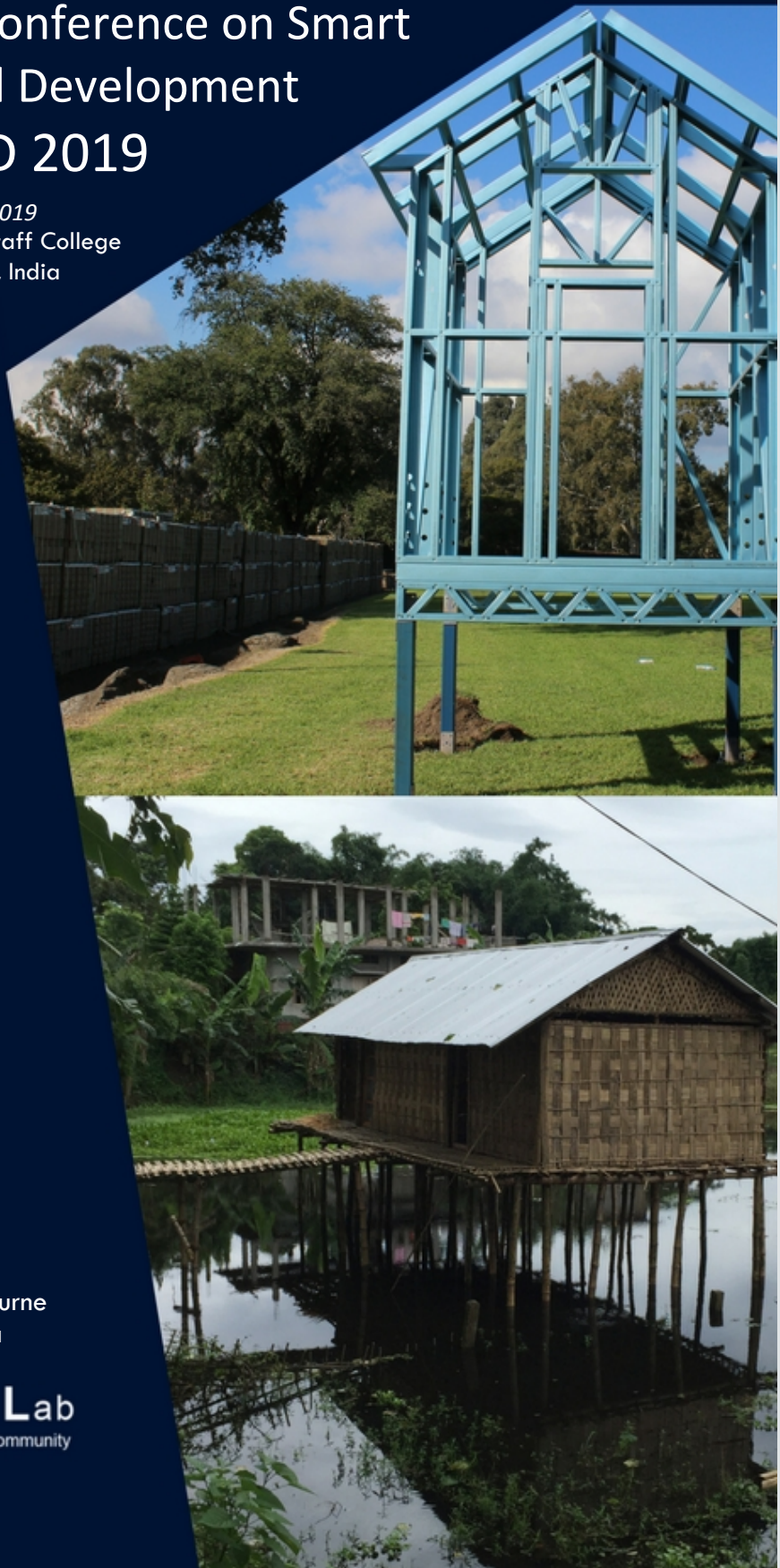
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Smart Villages Lab
Culture • Construction • Capacity • Community



2nd International Conference on Smart Villages and Rural Development (COSVARD 2019) hosted by the Smart Villages Lab (SVL) of the Faculty of Architecture, Building and Planning of the University of Melbourne.

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Preface

A very warm welcome from the conference Convenor and the Chair to all the attendees and stakeholders of COSVARD 2019 conference.

I am pleased to state that 2019 is truly a remarkable year as we have been able to showcase the existence of the International Conference on Smart Villages and Rural Development (COSVARD) as an established global forum for the second time. The 2nd International Conference on Smart Villages and Rural Development (COSVARD 2019) was hosted by the Smart Villages Lab (SVL) of the Faculty of Architecture, Building and Planning in the beautiful city of Guwahati of the North East Indian state of Assam.

With over 40% of the world's population now living in rural areas, there is a global interest in research associated with the creation of "Smart Villages" to address the ever growing urban-rural divide. Smart Villages research being undertaken in the Faculty of Architecture, Building and Planning at the University of Melbourne is exploring rural community development, practices and relevant policies with a focus on community-centric planning of affordable housing, infrastructure, sustainable development and growth, community empowerment and other issues related to the creation of Smart Villages. Leveraging the effort on Smart Villages research and for growing the knowledge in this area of critical need internationally, COSVARD conference was first held in 2018. Like the previous year, the conference was held again in the same premier venue of Assam Administrative Staff College, Khanapara on 02-04 December 2019. Assam Engineering College being the local partner for COSVARD 2019 had shown the real leadership across numerous fronts associated a seamless conduct of the conference.

The aim of the COSVARD 2019 conference is to provide a global platform to bring together researchers, policy makers and industry professionals to share relevant knowledge and examples of new forms of rural development that can help to better define the notion of a Smart Village. Notably, the sponsorship and support received from the TEQIP – III program of the institution towards COSVARD 2019 was truly incredible. TEQIP – III being one of the key sponsors, the organising committee is truly grateful for the TEQIP – III coordinators for kindly agreeing to and making necessary provisions within their program and extending the support for successful conduct of the COSVARD 2019. The assistance received from TEQIP – III includes accommodation for international and national experts, local travel for the experts, catering, stationary including the conference packs for the participants. In addition, the in-kind support provided by a large group of TEQIP – III volunteers under the leadership of the coordinators over an extended period including pre- and post-conference activities is highly commendable.

Having successfully conducted COSVARD 2019, we hope that COSVARD becomes a gateway for imparting intellectual discourse among the communities of practitioners, academia, policy-makers and students facilitated by the Smart Villages Lab (SVL) at the University of Melbourne. The research and development initiatives at SVL aim to narrow the gap between urban and rural communities. It is our intention that the conference becomes a regular occurrence for creating necessary awareness of this area of critical need among the broader international community, expanding engagements with potential future partnerships from other parts of the world, especially developing economies and harnessing funding opportunities for conducting sustained research and expanding disciplinary knowledge.

The scope of COSVARD 2019 conference was within five broad themes, 'Rural Housing', 'Rural Infrastructure', 'Rural Economy', 'Sustainability' and 'Smart Governance'. A "Smart Villages Poster Competition" was also incorporated in COSVARD 2019 to promote emerging design ideas in Smart Villages.

Under the Rural Housing theme, the key focus was on housing affordability, low-cost housing, materials selection, energy and water solutions, sanitation, reusability and recycling of waste, skill development, environmental design, disaster resilience and other relevant topics.

The focus of the Rural Infrastructure was on construction and maintenance of roads and other forms of infrastructure, access to education and health care, provision of services, including energy, potable water, waste and sewage management, creation of public spaces, ICT applications and operations, and other related topics.

Rural Economy section was to deal with the building social capital, micro and community-led finance, income generation, farming support, crop selection and improvement, market access, pricing, various forms of tourism and other related topics.

Sustainability theme focused on Environmental, Social, and Economic sustainability of all aspect of rural development.

Finally, Smart Governance section comprised the research and development associated with the Information Communication and Technology (ICT) and data-driven solutions, machine learning applications, alternative forms of governance and other relevant topics.

The research papers received from broad audience across all five themes were accepted for COSVARD 2019 following the double-blind review process. The scientific committee of the conference comprised over 30 experts from diverse disciplinary background recruited globally. A total of 21 final papers and three posters were included in the conference proceedings. Five selected keynotes were presented by five distinguished academics in the field. The keynotes presenters were Prof Atul Bora, Principal Assam Engineering College; Prof K C Iyer from Indian Institute of Technology Delhi, Ms Shasanka Ala, Deputy Commissioner, Lawngtlai, Mizoram, Prof Nagesh Kolagani from Centurion University Odisha, India and Mr Akshay Modak from VoltaGreen Hyderabad, India.

Last but not least, I sincerely appreciate the support, dedication and commitment of every single member of the scientific committee and a few other distinguished colleagues in reviewing the papers for the conference. Without their selfless support and good wishes, COSVARD 2019 would not have been possible.

With warm regards

Hemanta Doloi

Dr Hemanta Doloi,
Convenor and Chair
Director (Smart Villages Lab)

Message from Co-Chair

At the outset, I wish to thank everyone involved in organising COSVARD-2019 in a grand manner.

Assam Engineering College, being the local organising partner, involved in collaboration with University of Melbourne for organising this 2nd International Conference on Smart Villages and Rural Development (COSVARD 2019). COSVARD conference is one of the most significant outcomes of the ongoing collaborative research project between the University of Melbourne and Assam Engineering College with a focus of upgradation of skills in construction sector of the state. The construction sector has a strong multiplier effect on all other sectors of economy and therefore attempt has been made to engage all stakeholders to make the collaborative venture a grand success.

This conference is organized with a vision for sharing intellectual knowledge and wisdom of experts committed for upgradation of skills in the construction sector of the places of high need such as the state of Assam, and states in India and abroad and to disseminate the information to all stakeholders involved in construction sector with a focus to facilitate creation of smart and sustainable villages and cities.

As Skills in Construction, Information Communication and Technology (ICT), Smart and Sustainable Village and Cities, Sustainable human settlements are embedded to each other, the theme of this annual conference is chosen to continue a healthy debate among the participating experts and stakeholders of diverge background.

Our message is clear. 'Smart Village' will never happen without 'Sustainable Construction Practices'. Therefore, improvement of capacity in this sector is taken up to create smart and sustainable villages, cities and towns in the state as well as in the world.

I wish the COSVARD will become a truly international event with the above stated mission in years to come.

With warm regards to all the delegates participated in COSVARD 2019.



Dr Atul Bora
Conference Co-Chair
Principal, Assam Engineering College

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COSVARD 2019 – 2nd International Conference on Smart Villages and Rural Development

Venue: Assam Administrative Staff College, Khanapara, Guwahati
Date: 2-4 December 2019

Program Schedule

2nd International Conference in Smart Villages and Rural Development (COSVARD 2019) Agenda for Opening Ceremony and Inauguration Monday 2 December 2019 Assam Administrative Staff College	
10.00-10.10 am:	Swaraswati Bandana by students/staff of AEC
10.10-10.15 am:	Felicitation of Guests
10.15-10.20 am:	Welcome Speech [context and purpose] Dr Atul Bora [Principal, Assam Engineering College]
10.20-10.45 am:	Introductory Remarks, COSVARD 2019 [Associate Professor Hemanta Doloi, The University of Melbourne]
10:45-11.20 am:	Opening Address [International Conference in Smart Villages and Rural Development] Sri Siddhartha Bhattacharya Hon'able Minister, Education, GDD, Law & Justice Government of Assam
11.20-11.30am:	General Insights [Manindar Singh IAS, Additional Chief Secretary, Education]
11.30-11.40 am:	Project Insights [Prof Mark Burry, The University of Melbourne]
11.40-11.50 am:	Project Insights [Ms Shasanka Ala IAS, Deputy Comm, Lawngtlai Mizoram]
11.50-12.00 pm:	Closing remark [Assoc. Prof Robert Crawford, The University of Melbourne]
12:00 -12.10 pm:	Vote of Thanks [Dr Sally Donovan, The University of Melbourne]
12:15 pm:	High Tea
High Tea and Lunch at 12:00pm – 1:20pm	
Technical Session starts at 1:30pm	

COSVARD 2019 – 2nd International Conference on Smart Villages and Rural Development

2-4th December, 2019, Assam Administrative Staff College, Khanapara, Guwahati

Time	Day 1 - Monday 2 nd December
1:30pm	Keynote 1: Prof KC Iyer, IIT Delhi (<i>Rural Development, construction and project finance</i>)
2.00 pm	Session 1: Housing – Resilience Chair: Prof Mark Burry
01	<i>Exploring vernacular design for informing housing requirements in rural villages</i> V. Katharpi & H. Doloi, The University of Melbourne, Australia
02	<i>Technical intervention on khona's maxims to design an amphibian house</i> Md. O. Haque, Premier University, Chittagong, Bangladesh; N. N. Rahman, Brac University, Dhaka, Bangladesh; T. Zaman, Urban Sketch, Dhaka, Bangladesh
03	<i>Seismic performance of vernacular structures: A review</i> M. Pyngrope & S. Unnikrishnan, Christ University, Bangalore, India
3.00pm	Afternoon Tea
3.30 pm	Session 2: Housing – Thermal Performance Chair: Dr Robert Crawford
04	<i>Comparative analysis of indoor comfort between wooden and composite house in the coastal region, Bangladesh</i> R. Islam, S. Chowdhury, M. T. Mou, R. A. Rubai, M. Aritro & F. Nasir, Chittagong University of Engineering & Technology, Bangladesh
05	<i>Improving the thermal performance of non- airconditioned low income housing in different Indian climatic zones: A numerical study</i> S. Chithiravel & G. Pal, Shiv Nadar University, Greater Noida, India
06	<i>Exploring environmental adaptability of traditional mud house, Chittagong, Bangladesh</i> S. Chowdhury, R. Islam, N. Jannat, S. Paul & P. Paul, Chittagong University of Engineering and Technology, Bangladesh
5.00 pm	End of day
7:00pm	A low-key cultural event may be hosted in the evening by the local organisers

Time	Day 2 - Tuesday 3 rd December
9.30 am	Keynote 2: Prof Nagesh Kolagani (Centurion University Odisha) (<i>Developing and deploying mobile and web based public participatory GIS (PP-GIS), participatory modelling (PM), and AI/ML solutions for use by farmers (including women, youth and school children in villages)</i>)
10.00 am	Session 3: Housing – Design Chair: Dr Sally Donovan
07	<i>Computer aided analysis to select optimal rural housing technique for rural areas of Assam</i> M. Bhuyan & S. K. Deb, AEC; H. Doloi, University of Melbourne
08	<i>Composites in Housing and Infrastructure - A Review</i> M. K. Buragohain, Advanced Systems Laboratory, DRDO, Hyderabad, India
09	<i>Embodied emissions analysis of emerging construction technologies for mass housing in India</i> R. Crawford, The University of Melbourne
11.00 am	Morning Tea
11.30 am	Keynote 3: Shashanka Ala (Deputy Commissioner, Lawngtlai, Mizoram) (<i>Empowering rural community, sustainable growth and development</i>)
12.00 pm	Session 4: Culture Chair: Dr Hemanta Doloi
10	<i>English language development in village schools: A case study in Assam</i> B. Mali, Jawaharlal Nehru University, Delhi, India

11	<i>Eco-Village: Sustainable development for spiritual gatherings in the Indian context</i> S. K. Singh, IIT Delhi; A. Ghosh, Deakin University, Australia; B. Bhattacharjee, IIT Delhi
12	<i>Accessible responsive community simulations for Smart Villages in Assam</i> G. Kimm & M. Burry, Swinburne University of Technology, Australia
1.00 pm	Lunch
2.00 pm	Keynote 4: Prof Atul Bora, Principal (AEC) and Director (Technical Education) <i>(A roadmap for multi-skilling, employability and sustainability)</i>
2.30 pm	Session 5: Building Materials Chair: Prof KC Iyer
13	<i>Utilization of waste plastic in concrete</i> M. Duttabaruah, & N. Chetia, Jorhat Engineering College, Assam, India
14	<i>Bamboo reinforced concrete- A solution for affordable rural housing</i> N. Chetia, JEC; B. Mishra & P. Sarmah, The Assam Kaziranga University, Jorhat, Assam, India
15	<i>Cold formed steel buildings: An affordable housing solution for rural India</i> N. Mokkaiayan & V. Y. Palagala, IIT Tirupati, India
3.30 pm	Afternoon Tea
4.00 pm	Session 6: Infrastructure Chair: Prof Jayanta Pathak
16	<i>Effect of sustainable material incorporation along with RAP in Bituminous Pavement</i> V. Dhurai & R. Padmakumar, College of Trivandrum, Thiruvananthapuram, India
17	<i>Domestic wastewater treatment for recycling it safely to environment</i> B. Mali, Sant Longowal Institute of Engineering & Technology, Longowal, India & A. M. Kingshuk Mali, North Eastern Hill University, Shillong, India
18	<i>Energy initiatives for empowering Smart Villages</i> D. Dahiya, T. Guite & L. B. Singh, IIT Guwahati, India
19	<i>Housing System for Flood Mitigation in Rural Assam: A Case Study</i> A M Kingshuk Mali and Ar. Rameez R. Gazi North-Eastern Hill University, Shillong, India
5.00 pm	End of day
7:15 pm	Al Fresco Grand dinner cruise on the Brahmaputra River with traditional Assamese folk dancing and live music (Optional activity)

Time	Day 3 – 4 th December Wednesday
9.30 am	Keynote 5: Akshay Modak, Volta Green Hyderabad <i>(Low cost housing solutions for Rural Assam – Practical Insights)</i>
10.30 am	Final Session Chair: Prof S. K. Deb
20	<i>Income generation, food security and growth in local industry – a new approach for rural empowerment</i> H. Doloi, University of Melbourne
21	<i>Flood and Erosion induced displacements: Deployment of flood resilient housing in Assam</i> J. Pathak, AEC, H. Doloi University of Melbourne, A. Bora, AEC
22	<i>A roadmap for multi-skilling, employability and sustainability (available separately)</i> A. Bora, Assam Engineering college, Jalukbari, Guwahati, Assam, India
11:00 am	Morning Tea
11.30 am	Results of the poster competition from finalists: 1. <i>Developing framework for a Smart Future</i> , M. Rezwan & S. A. Islam, Daffodil International University (1 st Prize) 2. <i>Rural learning centre</i> , S. Nengvanglian, T. Guite & B. L. Singh, IIT Guwahati (2 nd Prize) 3. <i>Cultural habitat in a digital ecosystem</i> A. Bangia, Bangia & Associates, A. Patowary, Macquarie University, N. Das, University of Technology, Sydney (3 rd Prize)
1.00 pm	Closing remarks and end of conference

Keynotes Speakers and topics

1. Prof K C Iyer, Indian Institute of Technology Delhi, India
 - *Rural Development, construction and project finance*
2. Prof Nagesh Kolagani (Centurion University Odisha)
 - *Developing and deploying mobile and web based public participatory GIS (PP-GIS), participatory modelling (PM), and AI/ML solutions for use by farmers (including women, youth and school children in villages*
3. Shashanka Ala (Deputy Commissioner, Lawngtlai, Mizoram)
 - *Empowering rural community, sustainable growth and development)*
4. Prof Atul Bora, Principal, Assam Engineering College, Guwahati, India
 - *Roadmap for multi-skilling, employability and sustainability*
5. Mr Akshay Modak, Volta Green Hyderabad, India
 - *Low cost housing solutions for Rural Assam – Practical Insights*

Exploring vernacular design for informing housing requirements in rural villages

Velyne Katharpi¹ and Hemanta Doloi²

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Abstract: The vernacular design in rural housing is characterized by unique perceptions of spaces, function, form, material and construction of the houses among the community. Based on a field study conducted as part of a PhD research, this paper highlights some of the key findings critical to vernacular design of rural houses in an Indian context. This paper compares the data collected from cultural mapping of the four village cases in the sixth schedule areas of Assam. The method includes transect mapping to develop a map based on the walk-through observation of the researcher; and a focus group discussion to collect data based on its history, socio-economic, socio-cultural, socio-environmental context, and the vernacular architecture of the village cases. The intent of the data collection is to indicate the relation between vernacular design and the vernacular context within the regional context of the village cases. This is accomplished by conducting a within case content analysis of the villages and the vernacular design, followed by a cross case analysis to highlight the similarities and differences in vernacular design within a regional context. The village is analyzed based on the information from the transect map and the focus group discussion. In conducting the cross-case analysis, the relations between the vernacular design and its history, socio-economic, socio-cultural, socio-environmental context is indicated. This paper aids in establishing the elements and factors that are considered within the regional context and the village case by the community when building a vernacular house for shelter. This contributes in understanding the design of a self-built house within a specific context. The distinction in the vernacular design is based on the similarities and differences provided by the specific context of each village case.

Keywords: Cultural ecology, rural housing, sixth schedule areas, vernacular design.

1 Introduction

The necessity of providing rural housing is among the developmental goals recognized by the United Nations Development Program along with the Indian national government and a few state governments (IIT Delhi, CBRI, & UNDP India, 2016). However, in the case of Assam, the efforts have demonstrated financial and engineering concerns while overlooking the ethnic diversity present in the state. This was demonstrated by the suggestion of six samples of rural housing for the five topographically diverse area of the state. This result fell short of responding to the cultural context of the 117 ethnicities recognized by the state government (Doloi, 2019).

To provide a wholesome housing solution to the rural communities, the research aims to understand the culture of the communities that guide the design of vernacular housing that they build for themselves. As part of the current PhD research, the authors aimed to investigate the design of rural housing from the community perspective. For such, the research methodology required a two-phase multi-case study in four villages within the state. Based on the comprehensive literature review carried out in the research, the factors such as culture, value, history, place, origin of the community have found to be highly significant in conceptualizing vernacular design of houses in specific community. This paper focuses on the preliminary results of the data collection conducted for the research and discusses links between the context of the cases and the design of traditional houses of the cases studies.

2 Background

In this research, four communities were studied within a four-month fieldwork period that are located within the sixth schedule areas in Assam under the constitution of India. The sixth schedule of the constitution of India allows provisions for the states of Meghalaya, Mizoram, Tripura and certain areas of Assam to behave as an autonomous body for the protection of the customary practices and laws of the tribespeople of the afore-mentioned regions ("Sixth schedule," 1950). Therefore, providing a unique socio-political context along with the fact that the cases were all located in hilly terrain.

In case of Assam, the district councils of Karbi Anglong (East and West), Dima Hasao (previously known as North Cachar Hills) and Bodoland are established under the Sixth schedule of the constitution and as such are referred to as the sixth scheduled areas of Assam. During the data collection for this research, the inclusion of Bodoland was not yet confirmed and hence, only Karbi Anglong and Dima Hasao were considered.

3 Research Methodology

A thorough multi-case study was conducted for each village case selected for the data collection based on the theory of cultural ecology, which is the intersection of people, place and use (Pillai, 2013; Steward, 1972); and cultural mapping, which is the technique of mapping a place with from the cultural perspective of the community (Field, 2010; Pillai, 2013; UNESCO Bangkok, 2017). The data relevant for the research was collected by conducting a transect walk to observe the spatial context of the village, a focus group discussion with the elders or village council representatives to learn about the village history, socio-economy and socio-

cultural context, and aided by a projective floorplan technique, to illustrate the result of vernacular practices in their traditional house (Anon., n.y; Gaver, Dunne, & Pacenti, 1999; Patton, 2002; Zubin, Eron, & Schumer, 1965). The data collection was followed by within-case content analyses and cross-case analyses of the data collected from the village cases (Krippendorff, 2004; Miles & Huberman, 1994).

This methodology was followed to demonstrate the link between the regional context and the layout of the village, and the village context and the architectural design of houses in their respective villages. The analyses of the elements observed in the study indicated that the similarities in the design were due to the regional context of the villages, however the differences in the design were due to the value system of the individual communities. However, the focus of this paper is to demonstrate the influence of context and vernacular practices that inform housing design. The next section analyzes the design of the traditional houses that were described by each focus group discussion to demonstrate the influence of context by showing the cultural differences and environmental similarities.

4 Traditional House

As described by the methodology, each focus group discussion ended with the illustrations of the traditional houses aided by their description to understand the vernacular practice of housing according to the needs of the community as shown in Figure 2, Figure 3,

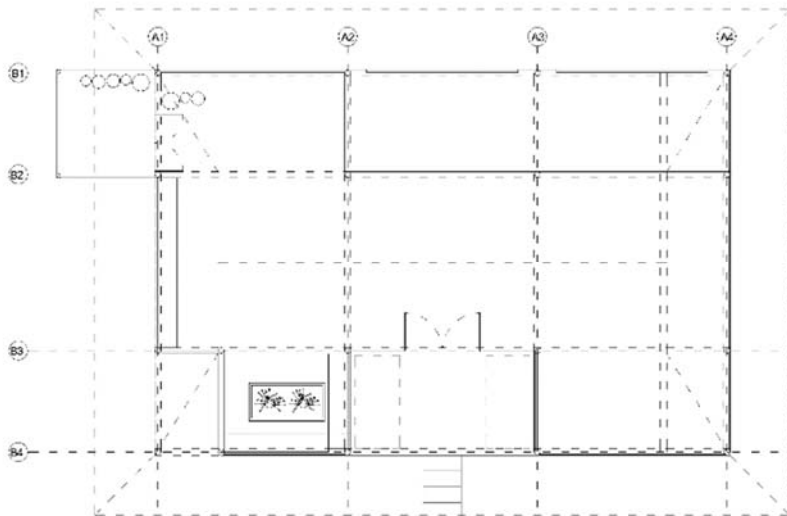


Figure 1 and Figure 4. Each case described a vernacular house which may appear like one another due to its use of local construction materials such as bamboo, wood and thatch, however, the difference in the houses stood out in the layout of the spaces and functions

within.

Figure

2,

Figure

3,

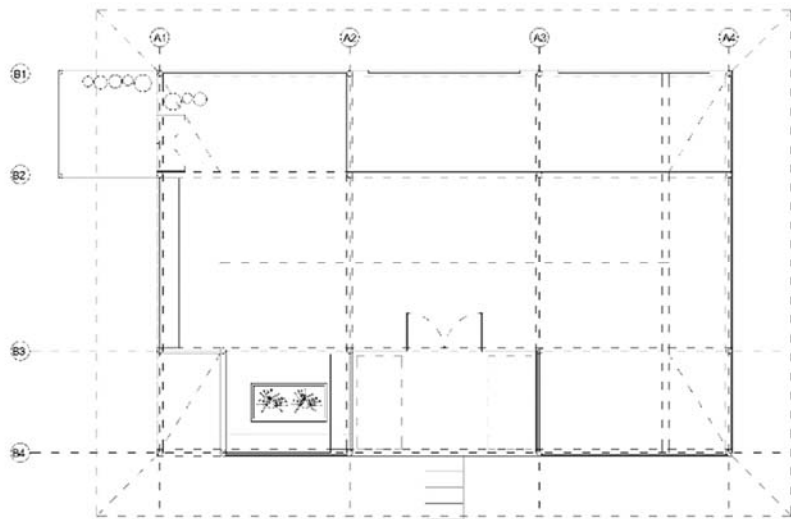


Figure 1 and Figure 4 show the diverse layouts of the four cases that were studied through the research methodology. The following sections discuss few basic architectural elements that indicate the differences among the four layouts.

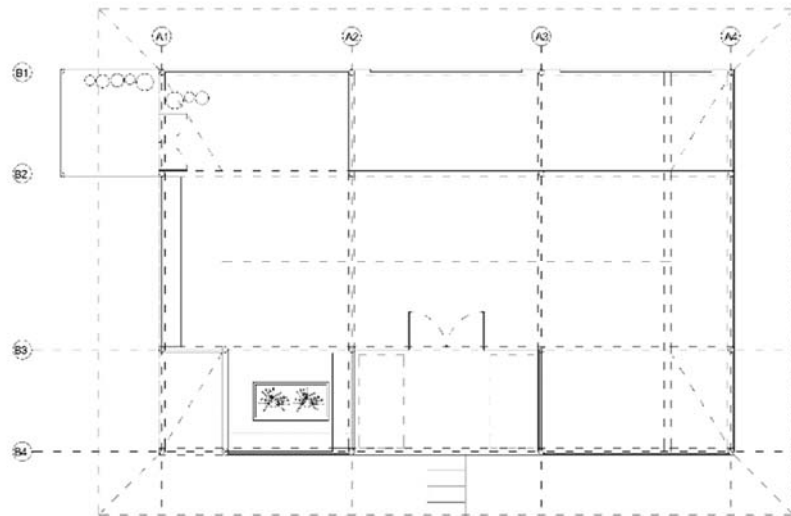


Figure 1: Kuki House Layout

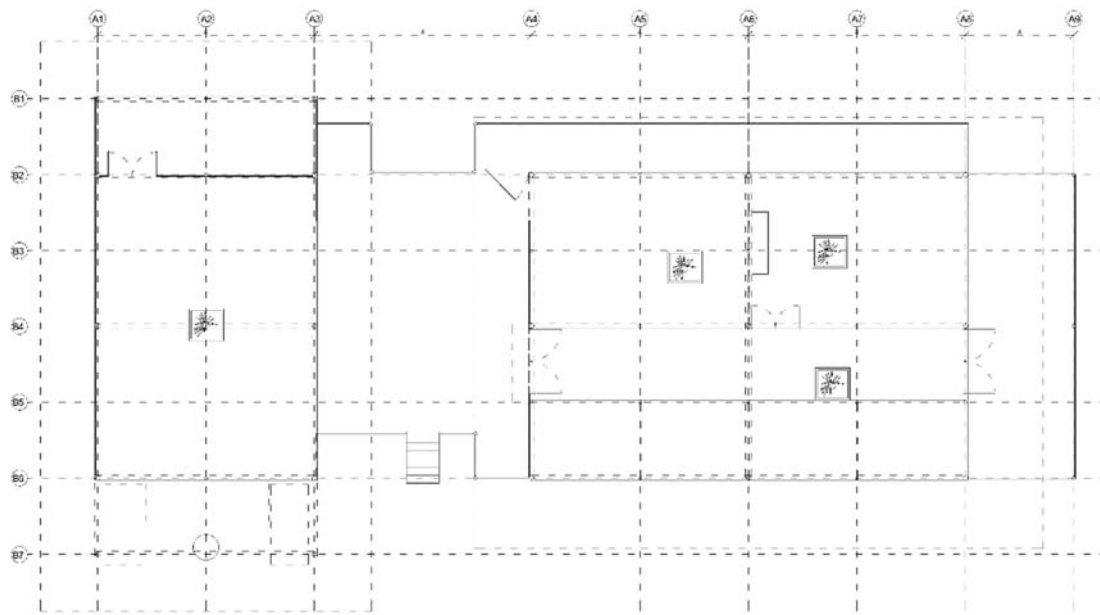


Figure 2: Karbi house Layout

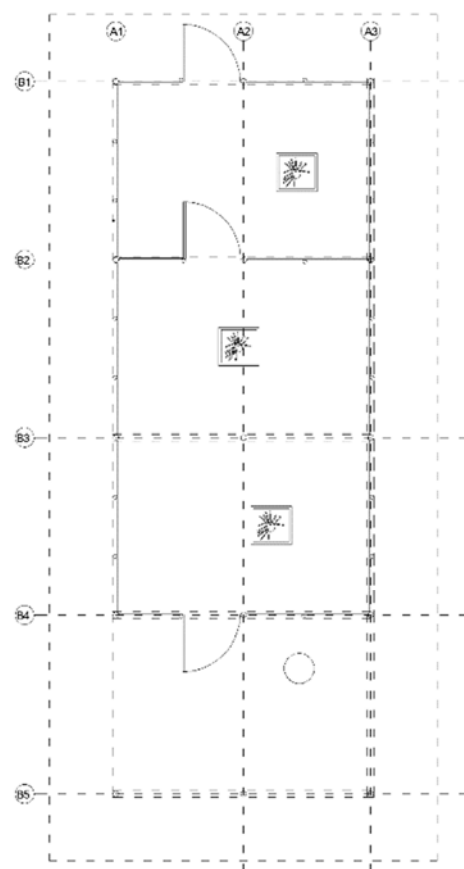


Figure 3: Dimasa House Layout

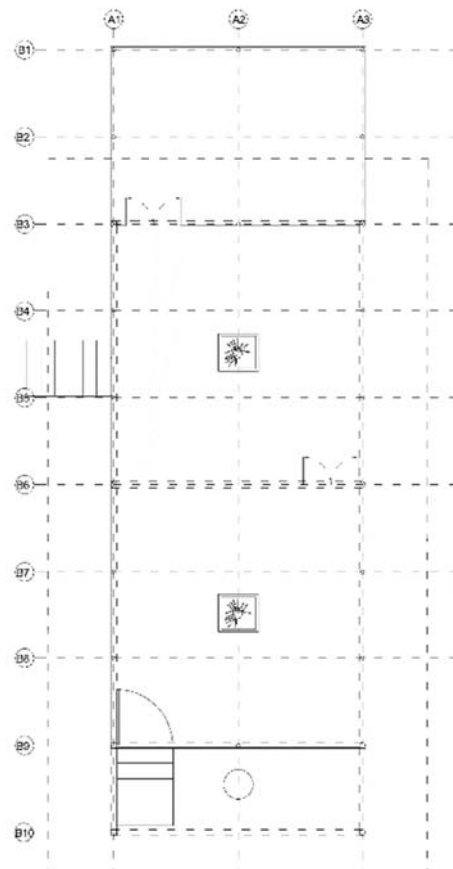


Figure 4: Labang House Layout

4.1 Orientation

The Kuki and Karbi case houses are oriented with the long side of the house facing the street while the Dimasa and Labang houses are oriented with the short side facing the street. Entrance to the houses were directly from the street in front of the house, meaning that the Kuki and Karbi house entrance was on the long side, while the Dimasa and Labang were on the short side. Figure 5 demonstrates the orientation of the house with regards to the street and the topography of the village.

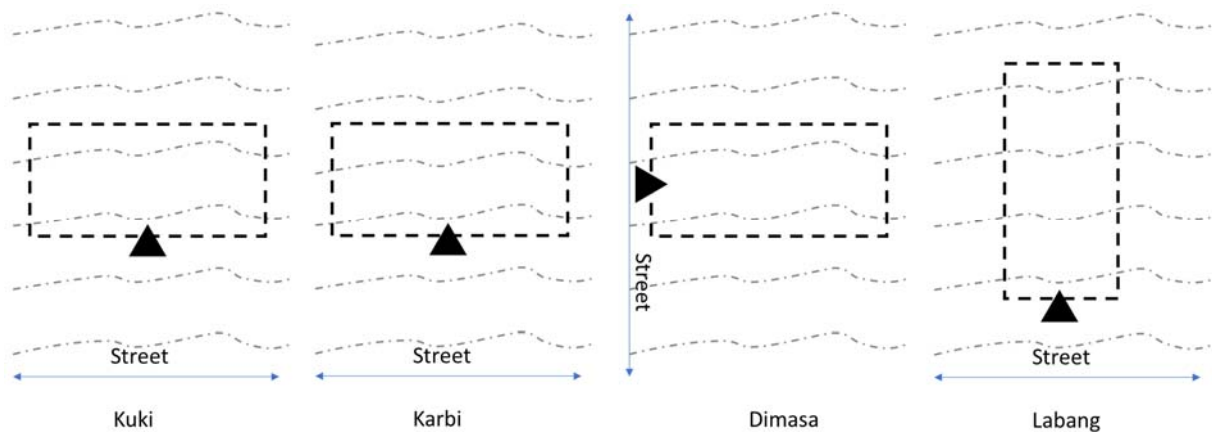


Figure 5: Orientation to street and contours

With regards to the topography, the orientation of the Karbi, Kuki and Labang houses are mostly from higher altitude to lower altitude, that is, the entrance to the house would be closer to the ground while the utility spaces which are generally placed away from the entrance would be in a higher altitude from the ground. In other words, the house would be oriented so that the house is situated on a downward slope. However, in the case of the Dimasa house, the house was oriented along the topography of the hill. The slope would be leveled by infilling the lower slope to form a platform for building the house.

4.2 Form

The houses are not squared or cuboidal in volume but rather oblong in shape. The houses are built in either a 2 x 4 or 3 x 4 ratio. As shown in Figure 6, the Karbi, Kuki and Labang houses are generally built elevated maintaining their plinth level at 1m to 1.5 m above ground on stilts while the Dimasa house is built directly on the ground. The plinth of the house is made of the earth which is raised from ground level by 150-200mm. However, the utility area of the Dimasa house may still be elevated from the ground. The local materials used in constructing the house is lesser in the case of the Dimasa house since it does not require wood or bamboo for flooring. All the houses maintained sloped roofs.

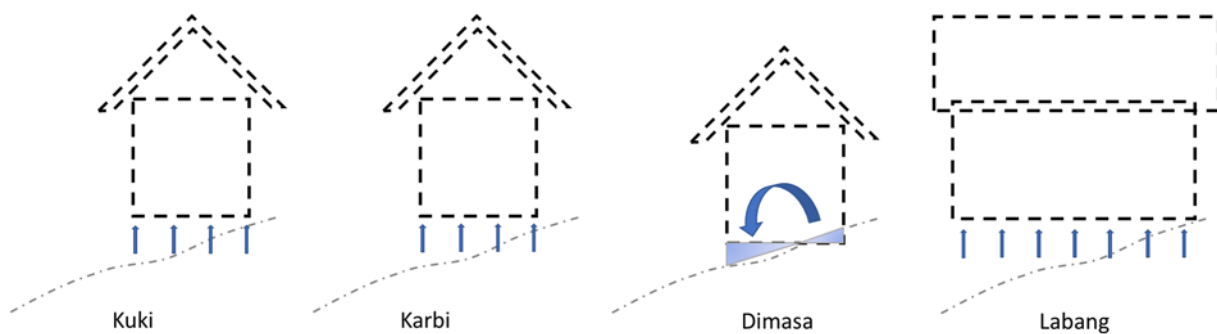


Figure 6: Roofing and Plinth

4.3 Spatial segregation

Figure 7 demonstrates the segregation of spaces based on the accessibility of family and non-family members of the household. As shown, on entering the house would be split based on

access of non-family members, so the Labang and Dimasa houses have a front room and a back room. The front room is meant for receiving guests, eating, sleeping or storage while the back room is meant for preparing food, eating, sleeping and storage. In the case of Kuki house, which has no partitions, the raised platforms indicate the spatial differences within the house. The Karbi house is divided into the openly accessible spaces that is meant for the non-family members, while the rest of the house is separated by a wall clearly indicating the boundary between family members and non-family members. While the Kuki, Dimasa and Labang houses have simplified the layout of their houses through segregation based on spatial and functional details, the Karbi house has developed a complexity in the layout by creating segregation based on age, gender, familiarity and marital status.

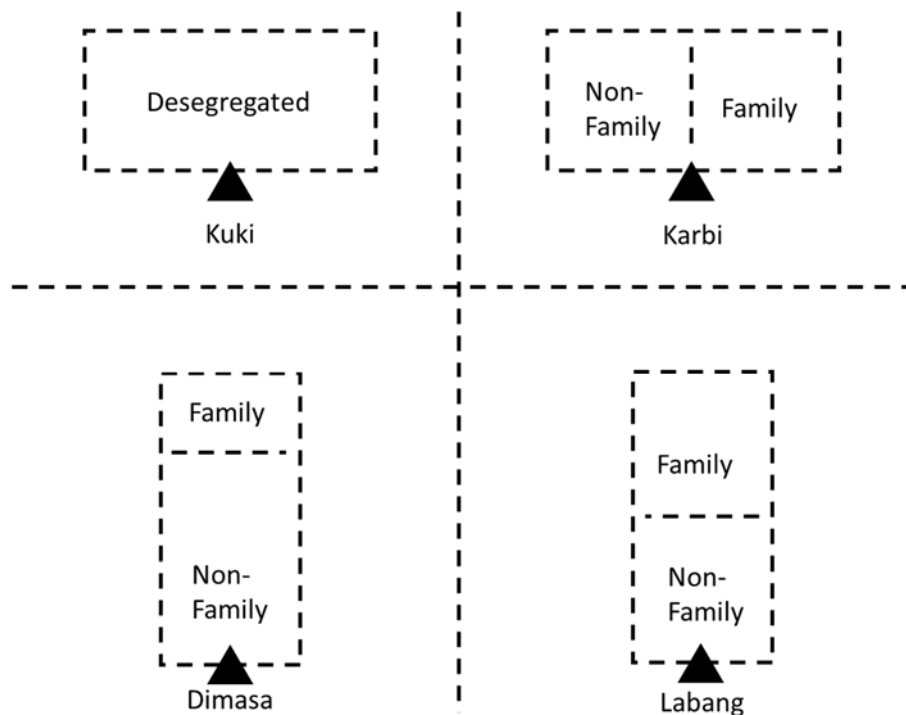


Figure 7 Segregation

As shown in Figure 8, with regards to the requirements of the house based on changing family dynamics, the Kuki, Karbi and Dimasa houses tend to go through changes within the same house by adding partition walls or by adding or enlarging rooms in the house while the Labang house does not change as much. The Kuki house can extend its volume in either adjacent sides or towards the front but is restricted from moving its walls back as it is believed that this brings bad luck. The Karbi and Dimasa house respond to changing family dynamics by adding wall partitions as the first solution before extending the house on either side. In the Karbi house, while extending towards the back is an option, it is only from the non-familiar side of the house. In the Dimasa house, if the spaces are not adequate despite the partitions, the kitchen is moved out of the house built at the back before any extensions are added into the house from either side. The adjacent extensions to the Dimasa house are mainly for storage purposes or for maintaining a mill or workshop, the sleeping area is maintained within the original walls of the house.

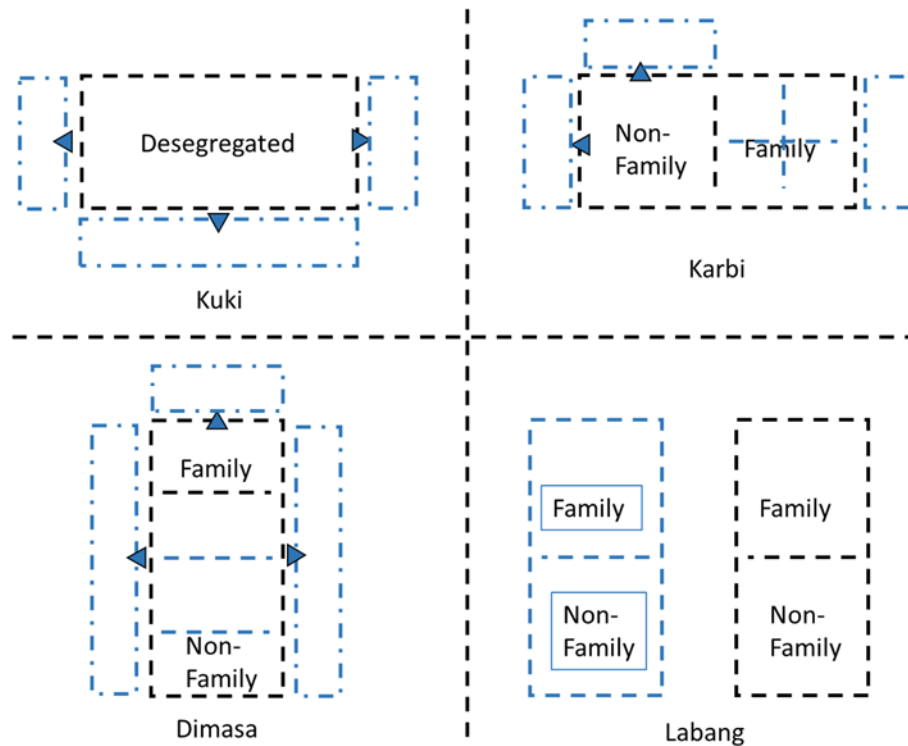


Figure 8 Reconstruction of house based on family dynamics

In the case of the Labang house, a completely new house is constructed according to the traditional style of two rooms on stilts with a fireplace, utility area, storage area etc. It is due to the social practice of constructing a completely new house for their children once they are of 15 -16 years of age. It is more common among families with more than one daughter in the house, where the youngest one stays in the ancestral home while the older ones move to their own quarters within the family land and closely located. Unless the daughters are married and move to a different plot of land within the village or to another village, they would continue to function as one family by farming together, cooking together, eating together etc. The sons are also expected to move out to their siblings' quarter or their in-law's. This practice of constructing a completely new house for the elder daughters is almost akin to encouraging self-dependence in children by giving them their own room and possessions to manage their livelihood while giving them privacy in their life.

4.4 Layout

As illustrated in Figure 9, in the case of Dimasa and Labang, the houses have at least two doors; one that is meant for entry by the guests, and the other which is a back entry/exit from the kitchen. However, the Karbi and Kuki house have successfully maintained a single door for entry and exit of the house. In the case of Kuki, the community itself is a very transparent and close-knit community that is demonstrated by the open layout that it does not segregate between family and non-family member. In the case of Karbi, the entry to the house is from one door leads to an open space which is akin to a foyer which leads to either the family space or the non-family space.

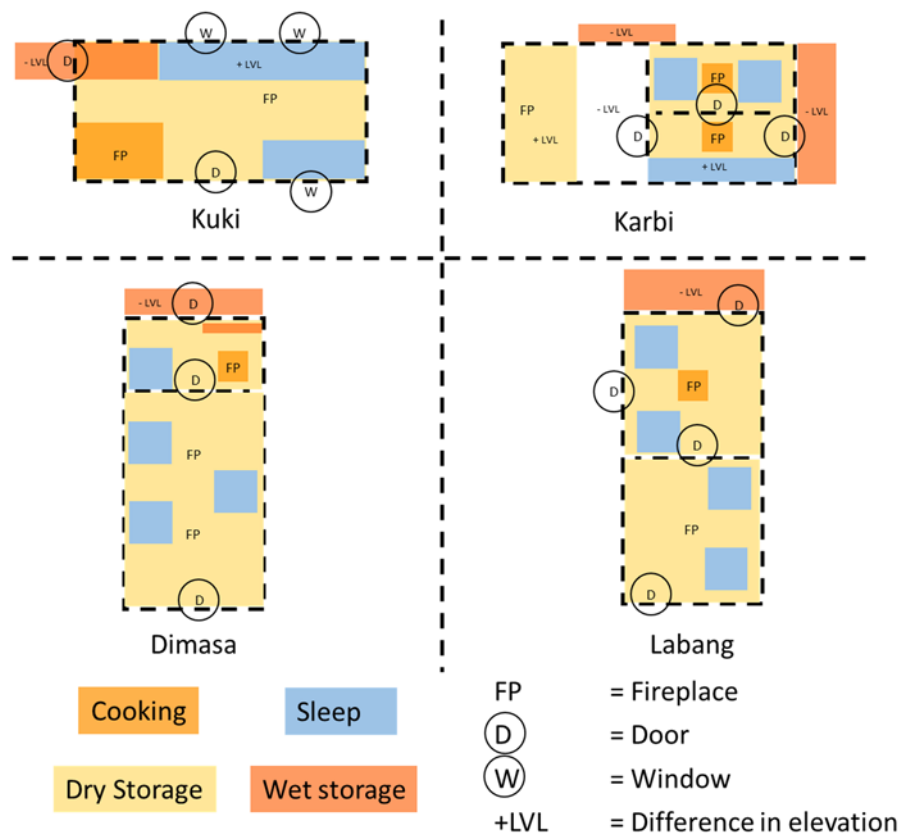


Figure 9: Layout

The similarity in the layout of the houses was that each house is designed around the basic purposes of storage, cooking, and sleeping. Though the toilet and bathing are not part of the main house, the houses had designated locations for storing water that would be used for cooking, cleaning and freshening up in the morning. As indicated, the space in the Kuki house is not segregated and un-partitioned, however, the house had elevated parts of the floors that served as seating or a bed. The cooking area would be around a fireplace that would have a shelf suspended from the ceiling for drying fish, chili or rice grains. The rest of the layout is multipurpose having minimal furniture other than the presence of a cane/bamboo woven baskets or trunks for storing possessions which are usually placed on the loft space created by the gabled roofs. This is done to maintain as much free space as possible for the storage of the harvested goods or for sleeping if there were guests.

In the Kuki, Dimasa and Labang houses, the animals are housed separate from the house, while in the case of the Karbi house, the chicken and goats were housed within the house, excluding the pigs which were housed under it. The reason for doing so was explained as a preference. The Kuki, Dimasa and Labang preferred to provide sheds for the chicken and goats separate from the house and each other on the side of the house, while the pigs were housed towards the back of the house or within the forest area. The disposal of garbage and refuse are towards the back of the house which is generally in the direction of the forest.

Any outdoor activity such as threshing, or carpentry were done in the shaded verandah of the house. Traditional handloom which is still practiced by the women of communities is woven in the shaded multipurpose areas of the houses. The traditional apparatus which is made by

using the walls to steady the apparatus to weave their clothes in the multipurpose areas of their houses. In the Kuki and Labang houses, the weaving was done indoors, while the Karbi and Dimasa did their weaving either in the verandah.

The cross-analysis of the traditional houses indicate the considerations that the community accommodate to build a house according to vernacular practices. However, these vernacular practices are adapted according to the changing context. The following section discusses the elements in the context that ultimately influence the design of traditional houses in the multi-case study.

5 Discussion:

From the above discussion, the cross-analysis of the traditional houses indicate that the architecture of the house is shaped by orientation, form, spatial segregation and layout. And these are shaped according to the characteristics of the physical environment of the village and the cultural practices of the community. Figure 10 below is a schematic diagram of the link of the context to the principles of design and subsequently to the design itself.

Orientation	Topography
	Street layout
	External functions
Form	Space and function
	Materials and construction
	Rain
	Ventilation
Spatial segregation	Functions
	Family/non-family
	Age
	Gender
Layout	Accessibility:
	Family/non-family
	Utility vs storage
	Circulation

Figure 10: Development of vernacular architecture

While orientation and form are primarily influenced by the physical context and surroundings of the house, such as topography, street layout, climate and local materials; and the spatial segregation and layout of the house is primarily dictated by the socio-cultural practice and values of the occupants of the house, such as family size, familiarity, age and gender etc.

Hence re-affirming the fact that traditional house design of a community is dependent on the context of the community, which is the region, village and culture of the community.

6 Conclusion

This study was conducted to demonstrate the influence of context on choices made in building of a vernacular house within a vernacular setting by a citizen of a rural community. This paper signifies the importance of understanding the social, economic, environmental and cultural aspects of a village and its residing community.

The analyses and discussion of the traditional houses and the village context has demonstrated that the orientation of the house is influenced by the topography and the street to ensure that the back of the house which is meant for disposal of garbage is away from the front of the house. Following the same logic, the utility areas are placed far from the entrance. The segregation of spaces is dominantly governed by the family composition, while the socio-economic culture decides the degree of change to space. The extensions to the house are both economically and socially decided by the family to respond to their needs.

This paper has demonstrated that the historical, social, economic, environmental and cultural context of the village has been instrumental in developing different kinds of vernacular architecture within the sixth schedule areas of Assam. This preliminary analyses and discussion of the multi-case study research has established the integral role of culture in designing a house for a rural community. Further analyses of the house designs that are in response to the regional, village and household context will inform the understanding and development of vernacular design for proposing effective rural housing solutions.

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TECHNICAL INTERVENTION ON KHONA'S MAXIMS TO DESIGN AN AMPHIBIAN HOUSE

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Abstract: Reports and researches show about 7.6% of area in Bangladesh is under inland water-bodies and of the remaining land, 80% is accounted for floodplains, where flooding is a key problem. Majority of the population of Bangladesh lives in rural areas and development of smart villages may vastly contribute in the progress of the nation. Studies show numerous rural-development programs in Bangladesh focus on social, economic, education and health issues. There is potential scope to include resilient rural-housing and sustainability from the viewpoint of architecture and technical intervention to make villages smarter. This study focuses on designing a sample smart house, termed 'amphibian house', by investigating such a village settlement – Chakaria, Cox's Bazar – to provide a practical solution to the flood-affected rural-dwellers.

The approach of this research focuses on two major aspects. Firstly, interpreting the maxims of 'Khona' and comparing them to vernacular architecture, i.e., through thoughtful observation of nature and human behavior; leading to holistic living and maximizing natural advantages for meaningful interaction with environment. Secondly, the contextual needs and strength which generates the idea of an amphibian house – floating on water during flood and upright on ground otherwise – to provide residents a healthy, productive, cost-effective and accessible solution to accommodation problems through technical intervention. Use of local materials, minimum-effort construction, low energy-consumption and maintenance needs aid in sustainability and may eradicate some current dwelling problems of the flash-flood affected areas country-wide. These approaches echo the concept of sustainability and have been translated into design principles.

It is expected that this study has the potential to become a significant part in the overall rural landscape and contribute to the vast research on smart villages. Incorporating age-old traditional wisdom and translating them into solving dwelling problems of today could be one way to address ever-growing environmental problems.

Keywords: Flood, village, maxims of Khona, sample amphibian house, sustainability

1 Introduction

Concepts of smart rural developments are emerging all over the world as the difference between urban and rural comfort and convenience gets wider as the world delves deeper into the technological era. This paper is purposed to contribute to this wing of study by addressing the problems of the flood affected people of Chakaria village in Bangladesh by attempting to advance the understanding of traditional wisdom derived from the legendary maxims of Khona – a wise woman of ancient times, often considered mythical (Chowdhury 2017) – integrated in the culture of the region and intervene technical aspects of addressing flood issues, in order to deliver an architectural solution to accommodation needs in flood-prone areas by designing a sample amphibian house that resonates smart village living ideas.

Due to the geographical position, Bangladesh is almost entirely a low-lying flat land barely above sea-level (EJF 2018:2). Floods are yearly occurrences and about a million people get struck by them each year (Islam et al. 2019:11). This problem is critical in the rural areas as 76.7% of people live in villages (Bhattacharjee et al. 2015:11). Although numerous studies are found on flood resistance and resilience, few applications provide long-term resolutions. This study attempts to address this issue by merging cultural practices with technical knowledge to provide a smart architectural design solution – a sample amphibian house – which can be accepted and applied by the intended users easily and efficiently. As Jon Hawkes continually emphasizes the need of cultural sustainability in the process of preserving the rest of the sustainability factors – environmental, social and economic (Hawkes, 2019), it becomes more relevant to this study to analyze that aspect.

1.1 Aim and objectives:

This research aims to create awareness about positive effects of environmental treatments of thousand years of practice in order to rethink adapting and including local strength in the context of Bangladesh. The objectives of the study are:

Table 1: Specific Objectives of the study

#	Description	Method(s)
1	To understand sustainability aspects from the maxims of Khona	Literature Review
2	To outline the needs of flood prone context	Literature Review and Case study
3	To establish a sample house design by merging cultural wisdom with technical intervention	Analysis of Site, Problem and Literature, Design Proposal
4	To align the findings with the concept of smart villages	Literature Review, Analysis, Design features and Discussion

1.2 Scope and Limitation of the study:

The paper is primarily based on case study and literature review and the solution can be applied to similar flood affected areas, in which case the design may vary according to needs. However, the study is limited to the climatic conditions and traditional practices of the region.

1.3 Organization of the study:

This paper is organized in three major parts. Firstly, background-study through literature review to realize the problem and how best to address them. This includes case study

analysis to recognize the needs of the flood-affected population of Chakaria and efforts to solve them in the following part, which consists of the process this research was carried out and the sample floating house design it delivered. The learning from the previous studies and the idea of the researchers are incorporated to solve the problem at hand. The technique this was done by is integrating traditional wisdom, which is easily applicable and understood by the locals, with technical intervention to resolve flood-related problems. Finally, discussion and conclusion aids to conclude the study.

2 Literature Review

2.1 Sustainable development

Mankind can make reasonable improvement to guarantee that it meets the necessities of the present without trading-off the capacity of future to meet their needs and that is sustainable development (Brundtland 1987). Since years, the idea of sustainability was only limited to its environmental or ecological aspect (Hawkes 2019). Although it can be concurred that ecological crisis is the result, it would be an error to think it is the reason too. What has led to environmental catastrophe are economic crunch and social calamity. Rapid globalization and the internet era have their fair share of benefits but have also prompted all social orders to be scattered far and wide while continuously importing other region and society's model (Bacchetta and Jansen 2011).

The concept of sustainability evolved to an extent through years of study as seen in Figure1. The new, imported and collective urban-behaviors have not just been breaking traditional structures but also social relations between people. Europe, and now Asia, are duplicating Anglo-Saxon social-model and eradicating their social and character highlights, magnifying the ecological effect of these over notable regions. This has brought a higher collective use of assets just as, thusly, an expansion of waste. Addressing the ecological issue has to do with the recreation of cultural tissues (Hawkes, 2019). This is where the concept of triple bottom line (Figure1a) transforms into the idea of the four pillars of sustainability (Hawkes 2001). Culture can be defined as “the set of distinct, transcendent, substantial, cerebral and responsive features of a society or a social-group” (UNESCO 2001). When outlining the crucial elements of sustainable human development, it is an acute concern, rooting in local authenticities and competencies (UNESCO 2013). The four pillars of sustainability, which is now being widely practiced, as depicted in Figure1b.

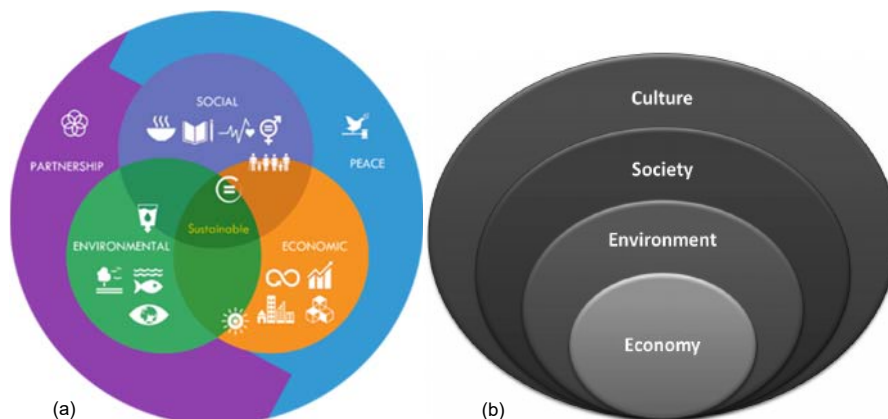


Figure 1: Sustainability affecting factors (Sow 2016) and four pillars of sustainability (Makrakis et al. 2012)

2.2 History of Khona:

Khona's maxims are in Bangla language in the form of short, rhyming poems and are resonated from medieval times in Bangladesh; existing through verbally-passed wisdom from generation to generation. They are called "Khonar Bachan" in Bangla. The sayings remain the reason of her fame. The name Khona survives as a clandestine in folklores and traditional wisdom in the east part of Indian-subcontinent (Ahmed and Ahmed 2015:1-19:1-19). According to legends, Khona is considered a sage-like woman, who existed around 800 to 1200 AD (Chowdhury 2017). She was a poet, an astrologer and a vehement observer of nature and human behaviour (Nath 2016). There are many versions of her legends as there are no solid evidences. The reason behind the interest in Khona for this particular study however does not lie in her legend, but in her maxims. The impact of these sayings over vernacular architecture is discussed in the following.

2.3 Architectural Directions from Khona's Maxims

a. পূবে হাঁস, পশ্চিমে বাঁশ, উত্তরে বেড়ে (কলা), দক্ষিণে ছেড়ে, ঘর কর গো পোতা জুড়ে

As seen in Figure2a, this translates into: Duck in east – meaning a pond dug in the east of dwellings allows the wind from east to cool down (Ahmed and Ahmed 2015:1-19). Bamboo in west – means cluster of bamboo trees on the west can block the glare of the sun. Banana in north – Profitable trees like banana could be planted in north as the height is short and do not obstruct the wind-flow. Left empty in south with vegetable patch – meant to not hinder the south wind-flow, define this cardinal as entry and to put in use of the empty space by harvesting vegetables.

b. দখিন দুয়ারী ঘরের রাজা, পূব দুয়ারী তাহার প্রজা, পশ্চিম দুয়ারীর মুখে ছাই, উত্তর দুয়ারীর খাজনা নাই

Literally, this rhyme depicts an overall orientation system – south-oriented room is the best, east-oriented room is comfortable, north-oriented room is worse during winter and west-oriented room is the worst as it suffers from overheating (Figure2b).

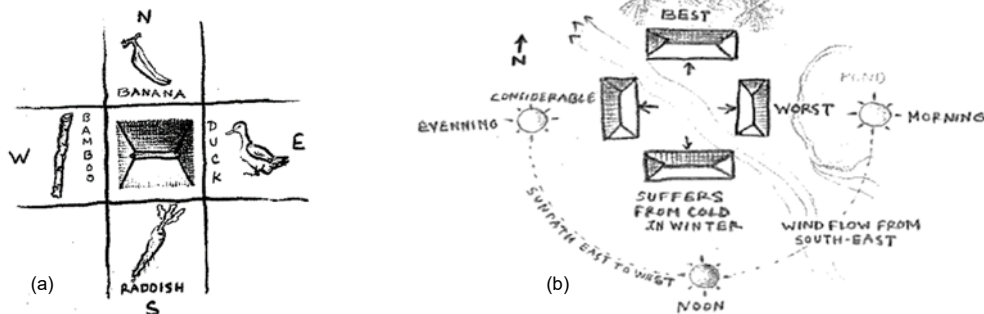


Figure 2: Khona's direction on landscape (a) and house orientation (b) (Ahmed and Ahmed 2015:1-19)

c. উত্তরের ঘরেরা দুধে ভাতে, দক্ষিণের ঘরেরা মরে শীতে, পশ্চিমের ঘরেরা খায় ভাত, পূবের ঘরেরা ফেলে পাত

This is based on environmental design and it means dwellers of northern rooms having door in south enjoy the best condition, dwellers of southern rooms having entrance in north suffer from cold wind during winter, dwellers of western rooms with door in east are comfortable but dwellers of eastern rooms having entrance in west are unfortunate for presence of heat and absence of wind.

d. পিড়ে উঁচু মেঝে খাল, তার দুঃখ সর্বকাল

It means, if the surrounding of plinth is higher; the resident might suffer for life. The message is a lower plinth cannot be kept cleaned; the floor may remain wet and create unhygienic circumstances to effect residents by diseases throughout their life. This is relevant to the flood-problem studied here and appropriate height is shown in Figure3b.

e. আলো-হাওয়া বেঁধ না, রোগে ভুগে মর না

This implies that natural ventilation and light should not be blocked in order to lead a physically and mentally healthy life and resonates with Figure3a.

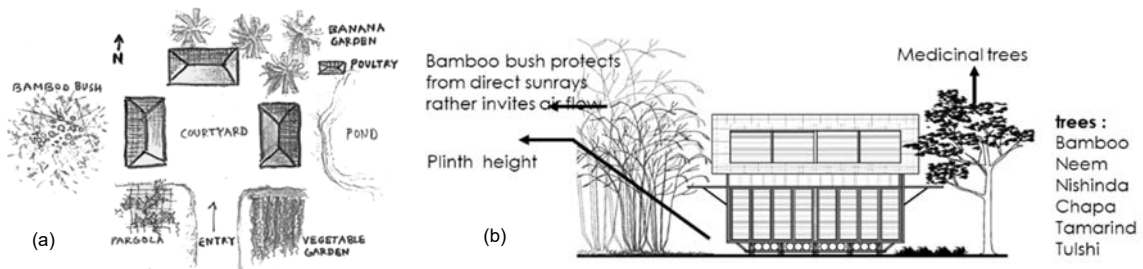


Figure 3: Ideal residential zoning (a) and Foliage consideration (b) from Khona's Maxims (Ahmed and Ahmed 2015:1-19)

f. নিম নিসিন্দা যথা, মানুষ কি মরে তথা?

It means where there are medicinal trees, like Neem (Figure6), man remains healthier. This is a scientific truth that such trees emit fragrances and purify winds from bad odor and of well-known reputations for herbal medicine (Ahmed and Ahmed 2015:1-19).

g. ঘিরিলে বাড়ি, সাজায়েলে তিরী

It means, if residents have surrounded the house with trees, then they have organized their world. The message is plantation around a house brings happiness and healthiness to mind. It is collected from Chittagong region (Ahmed and Ahmed 2015:1-19).

h. গৃহপাশে থিলে তাল, অল্প দিনে পুরে কাল; শকুনপক্ষী বসিতা 'পরে, নানা ব্যাধি জাত করে।

Meaning, palm tree (Figure4) is a shelter for corpse-scavenger birds, like vultures. They spread germs of communicable-diseases. As a result, the inhabitants get short life span.



Figure 4: Khona's direction on wrong foliage (Ahmed and Ahmed 2015:1-19)

2.4 Vernacular Architecture and Khona's Directions

Vernacular architecture in Bangladesh (Figure5) is user-oriented, zoning based and locally sourced. It has unique features and echoes traditional wisdom of Khona.



Figure 5: Kucha, Bamboo house, Mud house – Vernacular Houses of Bangladesh

Stated below is a comparative analysis relating Khona's Maxims to Vernacular Architecture of Bangladesh.

Table 2: Comparative analysis of Khona's directions and vernacular architecture

Characters	Khona's Directions	Vernacular architecture
Orientation	North-south	North-south
Access	From South side	Usually from South
Openings	Door and window. Entry door is located in south. East and west are more solid than north-south	Door and window. Entry door is located in south. East and west are more solid than north-south
Roofing	Pitch roof (Chala)	Pitch roof (dochala/chouchala)
Plinth	Indicates to provide a plinth height higher than surroundings	Plinth exists
Materials	Mostly bamboo, mud, thatch	Bamboo, mud, thatch, brick, tin
South features	Open or low height vegetation for welcoming the summer wind and the entry purpose as well	Open. no obstacles to the south breeze
North features	Banana trees	Locally common trees including banana
East features	Pond for the cooler air and farming fish, rearing chicken, duck	Pond (if possible) or vegetation and trees
West features	Bamboo trees for shading purpose.	Usually bamboo trees or tress which protects the house from harsh west sun.



Figure 6: Different parts of vernacular house in Bangladesh (Guy, 2000)

2.5 Case Study

According to the HCTT Joint Needs Assessment (JNA) report on flash floods in Bangladesh, Chakaria, a sub-district in Cox's Bazar, suffers from major floods almost every year (JNA 2015). As per the report, one-third of the population has to relocate during the flood due to their houses becoming uninhabitable for water damage. On the other hand, another one-third of the population cannot even relocate as they do not have the option due to extreme poverty. Every year the deaths caused by floods are consisted of 70% by drowning, 25% by snake bites and diseases and 5% of miscellaneous causes (JNA 2015). These alarming figures caused Chakaria to be selected as case study for this research. The situation is depicted in Figure 7.



Figure 7: After-flood affect in Chakaria (a) Typical Rural house in Chakaria (b) Drinking-water contamination (c) Lack of basic resources (d) Damaged roads (e) Damaged houses (f) forcing relocation

From the physical case study conducted by the students of Department of Architecture, Premier University, under supervision of Haque, M.O (2017), and the JNA report (2015) the following needs were found of the flood affected people:

- Settlement needs – no desire to relocate
- Economic needs – self-sufficiency during flood
- Climatic needs – adapting to changing weather conditions like raining and flooding
- Basic survival needs – emergency medical, food and fresh drinking water supply, sanitation and hygiene needs
- Social needs – adequate privacy for females in a family

The sample population has further needs too, but this study focuses on the above and chooses to address housing needs first while incorporating into the solution other needs as much as possible.

2.6 Amphibian Housing

It appears that in the approach of rising ocean levels because of environmental change, there is a prominent requirement for flood security at the size of private structures. Regardless of the endeavors of raising the structure on a plinth or stilts, assurance from floods stays flighty because of a point of confinement in height. A house raised high over the ground disturbs the association of the occupants to the community and causes regular troubles. The historical backdrop of the Bangladeshi individuals is firmly attached to the earth. Agriculture is a significant occupation among the common people (Prosun, 2011). Thus, solid association with the ground is a stable idea with these people and hence the inkling of a flood-adaptive amphibian house.

Amphibious design is a feasible flood-alleviation technique that enables a structure to float on the top of rising flood-water as opposed to capitulate to immersion. A buoyant base is that on which an edifice is retrofitted to permit it to coast as high as necessary during flood while enduring on ground in typical circumstances. The framework comprises of three essential components: buoyancy-blocks beneath the structure that deliver buoyancy, a means of tethering that avert the structure from drifting away, and an auxiliary sub-outline that bonds everything together. A structure that can be raised like this can become amphibious (buoyantfoundation.org 2019).

The idea of amphibian houses has already been studied in local context, termed 'Beltola Lily' and perceived as a flexible and economical solution for accommodation as it is manufactured by low-priced native materials, needs least work in assembly and upkeep and consumes low-energy (Aman, Rahman and Zahir 2016). The knowledge from this project was the understanding of context, the floating mechanism, and materials for thermal comfort, wind movement and design pattern.

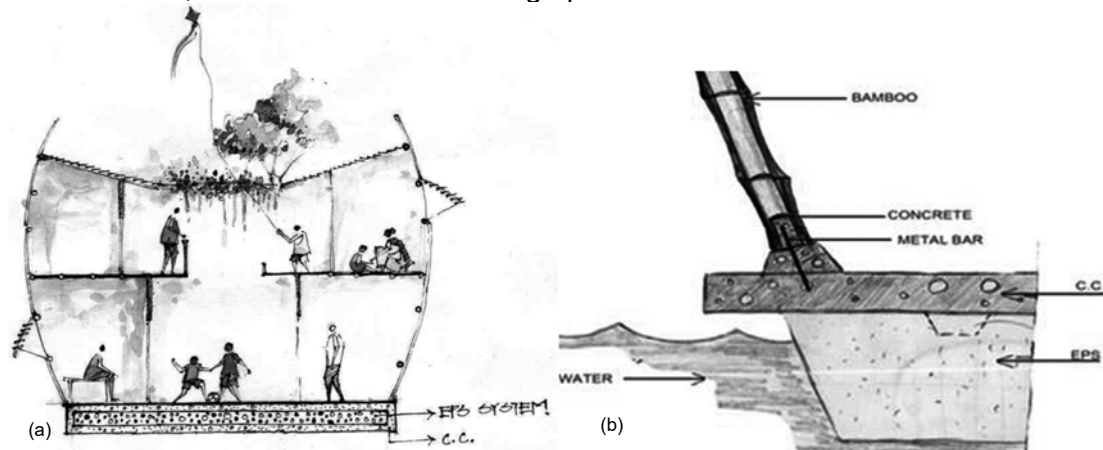


Figure 8: Contextual amphibian house (Aman, Rahman and Zahir 2016)

In other regions there has been a wide application in amphibian houses like the Floating Wooden Exbury Egg Shelter in England (Turner 2014). The understanding from this project was through direct experience of knowing ecological patterns and procedures, and the connection between the surrounding and human-activity narratives in the seasonal life calendar dictates how efficiently housing needs can be addressed, and how floating houses can work through tethering mechanism. This project resonates with the observation of nature by Khona and can be translated partially in this study.



Figure 9: Floating Wooden Exbury Egg Shelter (Turner 2014)

3 Methodology

The methodology of this study can be considered as mixed. It included site survey, literature and contextual study, experts' and users' interviews in addition to the researchers' understanding. The method is shown through flow of work in Figure10.

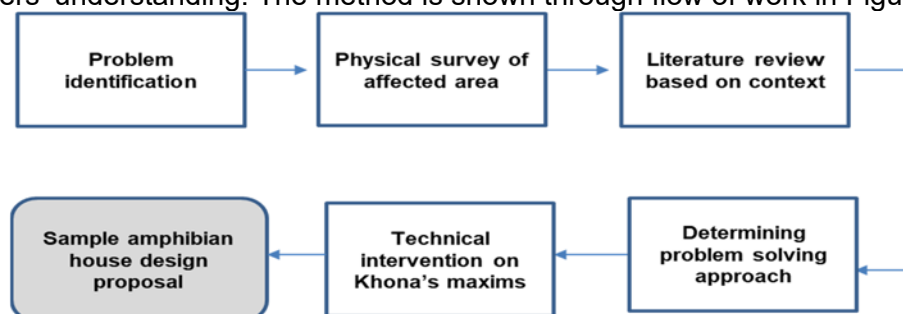


Figure 10: Broad Methodology of the study

Identification of the problem was primarily steered by determining the strength, interest and expertise of the researchers and was specified to flooding and its negative impacts. This led to the physical survey of the site, Chakaria. From survey report, the needs of the flood affected people, which could be addressed by the researchers, were identified. To start, background-study on available literature was conducted. Additionally, field experts were consulted to determine construction method, ease, social context, timely features and more. From literature survey, the four pillars of sustainability were focused. There were numerous ways found to incorporate economic, environmental and social sustainability. The gap was found in cultural sustainability of the region and therefore further study was conducted. Upon studying vernacular architecture it seemed relevant to the researchers to integrate Khona's maxims to be able to relay design ideas effortlessly to the users and to keep traditional housing approach alive. But to make the design relevant to time, technical intervention was required for the architectural solution. Therefore, the final design proposal was set out to become a mixture of ancient cultural wisdom and modern technical features which is resilient in flood while providing a wholesome sustainable environment to its users.

3.1 Amphibian House Design Proposal

The design process commenced analyzing information acquired from traditional and contextual aspect (cultural and environmental sustainability), user needs (social and economic sustainability) and knowledge of researchers. The house plan was generated incorporating landscape elements as instructed by Khona (Section 2.3), depicted in Figure 11 and Figure 12 – unobstructed on south to invite the south breeze, bamboo trees on west to provide shade and cool hot air, medicinal trees on north to benefit users and pond on east to cool passing warm air. Although it was possible to design two floors, considering accessibility and cost the decision was made to design a single one. The plan is free-flowing, centered by the living room resonating traditional courtyard. While the bedroom is the largest, the living room is the main activity center. Service areas are on west to provide further comfort to users.

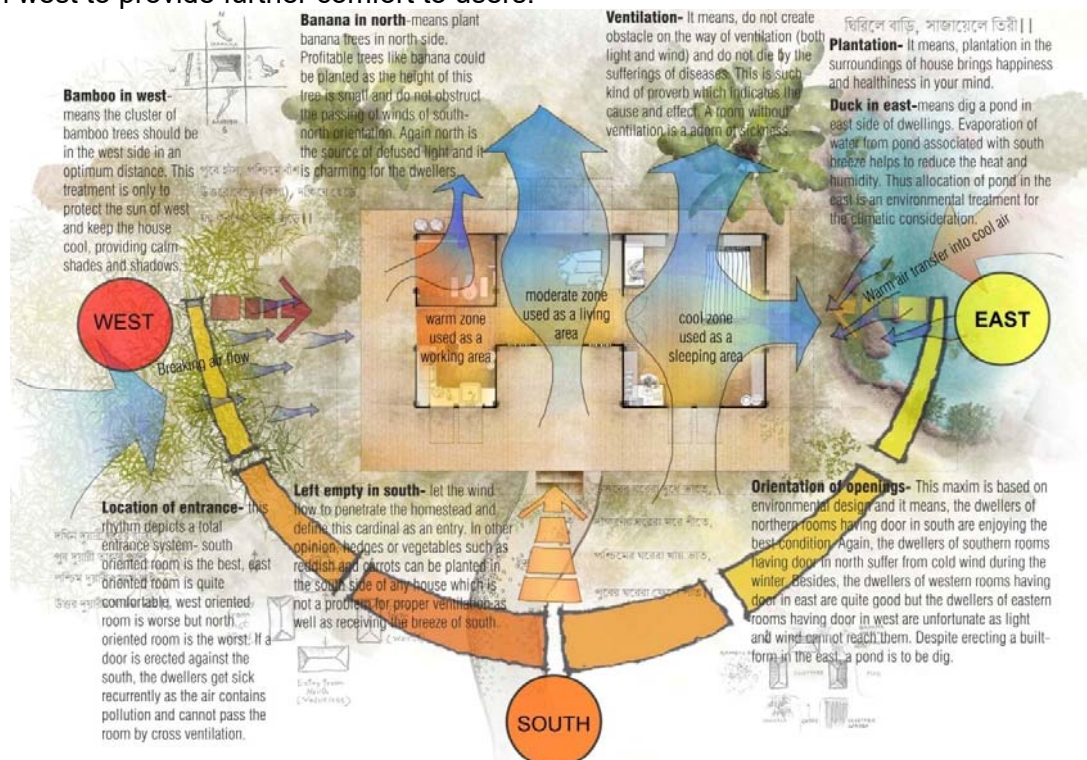


Figure 11: Climatic Consideration based on Khona's Parables

The climatic considerations are applied technically in the design as well, illustrated in Figure13. The shade of bamboo trees not just blocks the harsh summer sun, but allows the warmth of the winter sun as there are less leaves on the bottom. Also, it allows wind to flow through after cooling which enters the house from the lower part, pushing out the warm air inside up through the skylight. Openings on roof are a modern addition to vernacular design. This feature combined with the traditional house placement provides the best possible thermal comfort in this case. The house rests on a heightened plinth (Table 2). The modern twist to it is that under it water jars are stowed to store fresh and gray water, collect sewage and rain water, and provide buoyancy during flood.

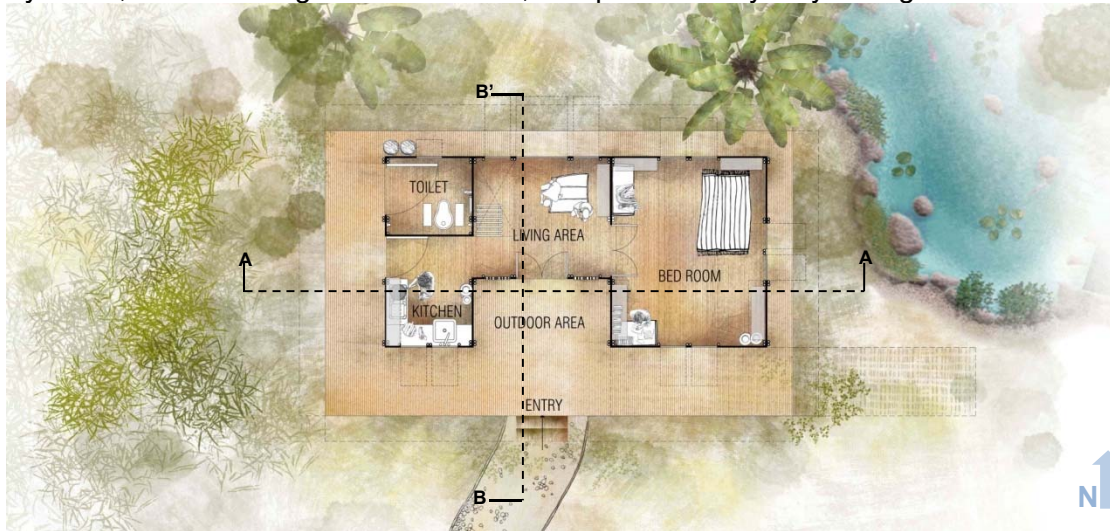


Figure 12: Plan of Amphibian House

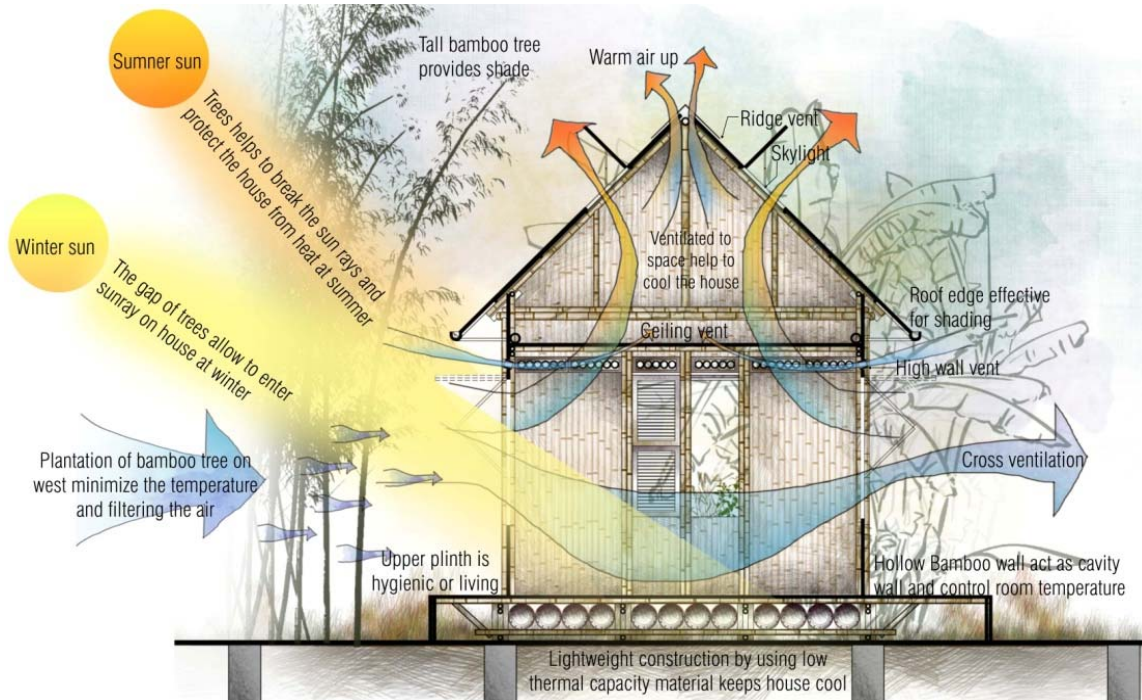


Figure 13: Application of Climatic Consideration in Sample Amphibian House

In Figure14, the south and east facades of the house can be seen. The south consists of wide openings and the entrance and is much longer than the east considering climatic conditions of the region. The east is comparatively slender, avoiding the chance of over-

heating by wider exposure to the sun. There are fewer openings than the south and they are more controlled. However, the openings are provided to invite the cooled air coming in from over the pond. As Khona says to not obstruct light and wind (Section 2.3), it is followed here but keeping in mind architectural specifications seeing opening dimensions and types. There is a multipurpose platform all around the house which can transform according to the needs of season based on activity and weather conditions.



Figure 14: South elevation and (a) East elevation (b)

As seen in the sections (Figure 15), the free-flowing plan allows the whole house to enable diverse activities in different times. The centralized planning concentrates its users to bond in its core and segregate when they need to, considering regional social behaviour (Fatemi and Islam, 2011). Also, this helps them use home-as-a-workplace during flood (Zahir, 2017), providing economic sustainability and reaffirming social ties. The mezzanine floor is used to store dry food and medical supply.



Figure 15: Section A-A' (a) and Section B-B' (b)

Another layer of environmental and economic sustainability is achieved through the selection of materials. The materials are locally sourced, environmentally friendly and economically viable in the context. Moreover, the local people, as per survey, are comfortable and familiar with them, creating an opportunity to involve the community in construction and implementation of such houses and their functions. As can be viewed in Figure 16, the following materials are used:

- Roofing – layers of thatch (16a, climatic consideration) over flattened bamboo panel, fitted on bamboo lattice frames (16b, rain protection).
- Supports – Bamboo posts and beams (16d) creating entire frame for the house.
- Openings – open bamboo screens (16i, wind flow), operable louvers (diffused light).

- Flooring – densely-packed flattened bamboo floor (16e) covered with woven jute mat (k) for the base, loosely-packed flattened bamboo for the mezzanine (16c).
- Walls – flattened bamboo wall (16j).
- Energy – Solar panels (16f) and Solatube (16g) on the roof to produce electrical power and rain gutter (16h) for collection of rain-water and protection of the walls.

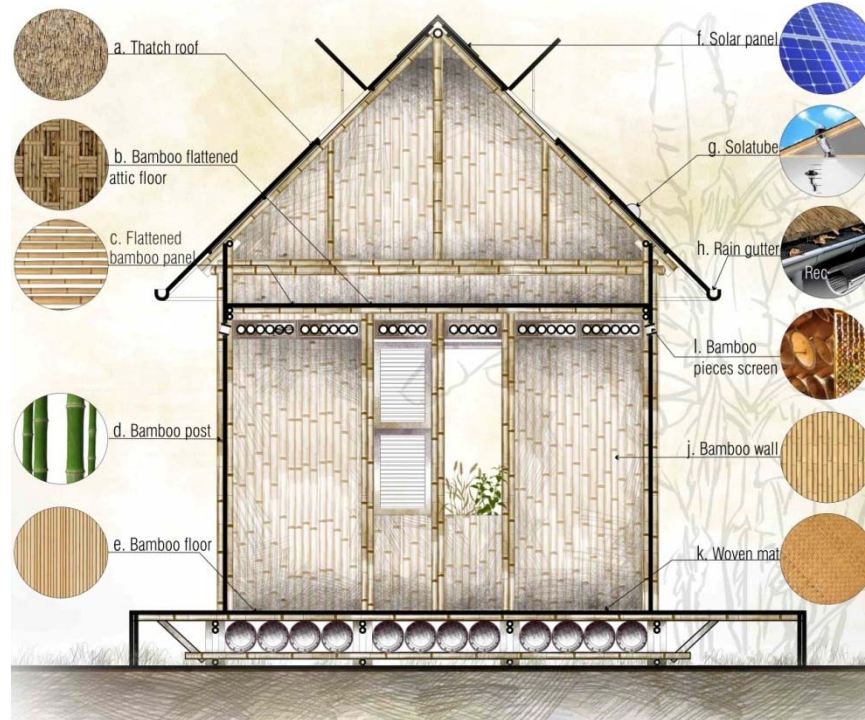


Figure 16: Components and Materials used in Sample House

Figure17 and Figure18 show different seasonal phases of the house depicting amphibian characteristics. Figure17 shows the house resting on the ground during dry season, which incorporates accessible entrance through a ramp. The base of the house stands on the support of folded bamboo frame (Figure19a) during this phase and stocks inside repurposed water jars (Figure19g) which are divided by their purposes –

- 5 jars for emergency fresh water
- 6 jars for collecting gray water
- 6 jars for collecting sewage
- The rest for regular water storage

These serve dual-purpose by providing additional buoyancy during flood.



(a)

(b)

Figure 17: Sample house during dry season

Figure 18 shows the house floating on the water, the bamboo frames (Figure 19a) open supporting plant bed during flood (Figure 19c) and tethered by metal ropes which can be adjusted based on water level by the use of attached metal pulleys (Figure 19f).

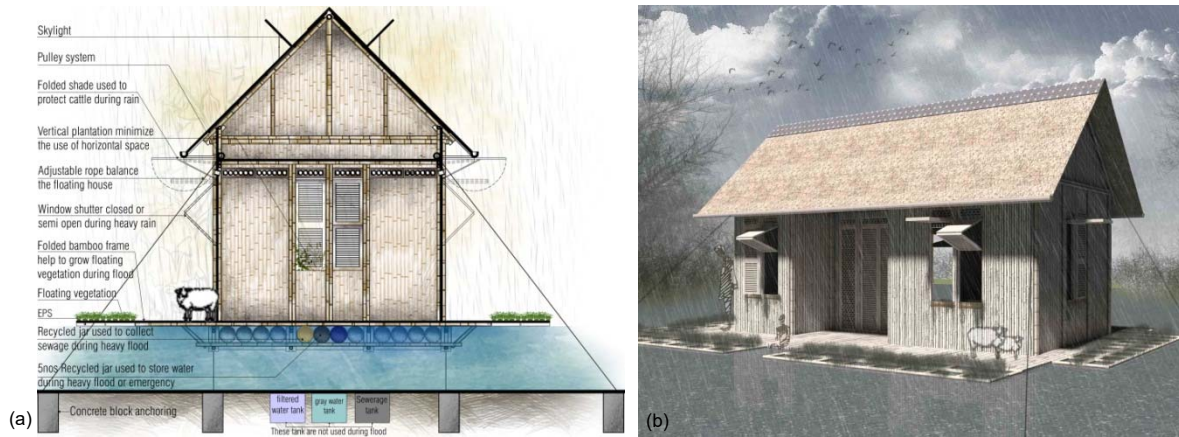


Figure 18: Sample house during flood

3.1.1 Smart House Features:

Following features, technical interventions on traditional methods of the region, make the sample house eligible to be considered smart on the basis of economic and environmental sustainability. Figure 19a, 19b shows folded bamboo mechanism of the base which enables the amphibian feature of the house. Figure 19c shows the different plantation in different phases – plant bed on bamboo frame during flood, movable crop bed during dry-season and vertical plantation on wall which is season-neutral. These shrubberies allow the habitants to grow vegetables and crops to partially satisfy their sustenance needs all throughout the year. The vertical plantation additionally provides another layer of cooling for the interior climate of the house.

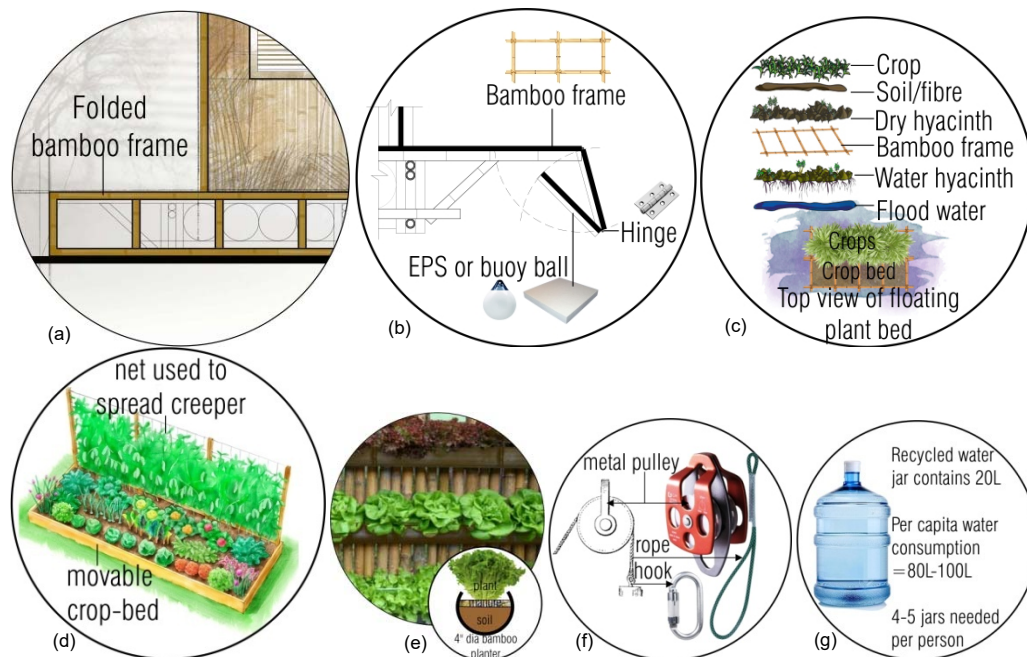


Figure 19: Folded bamboo frame mechanism (a, b), plant bed during flood (c), crop bed during dry season (d), vertical plantation (e), metal pulley (f), water jar (g)

Figure 20a shows the openings type 1, which are located on the north and south facades of the house to allow cool air inside and hot air to blow outside through skylight (Figure 20c). They can be adjusted as per the need of the climate. The same can be done for the type 2 openings (Figure 20b) located on the east and west sides. The openings are louver based and can be operated according to daylight or during rain as per the situation. Both these openings allow the cooling wind and diffused light inside but are capable to avoid glare and rain to enable the habitants a desired level of comfort. Operational phases of the skylight on the roof can be seen in Figure 20d. Adjusting these according to the time of the day or by season, allow the residents to have desired interior climate by letting the lighter hot air to pass through to outside while open and rain-protection and winter insulation while closed.

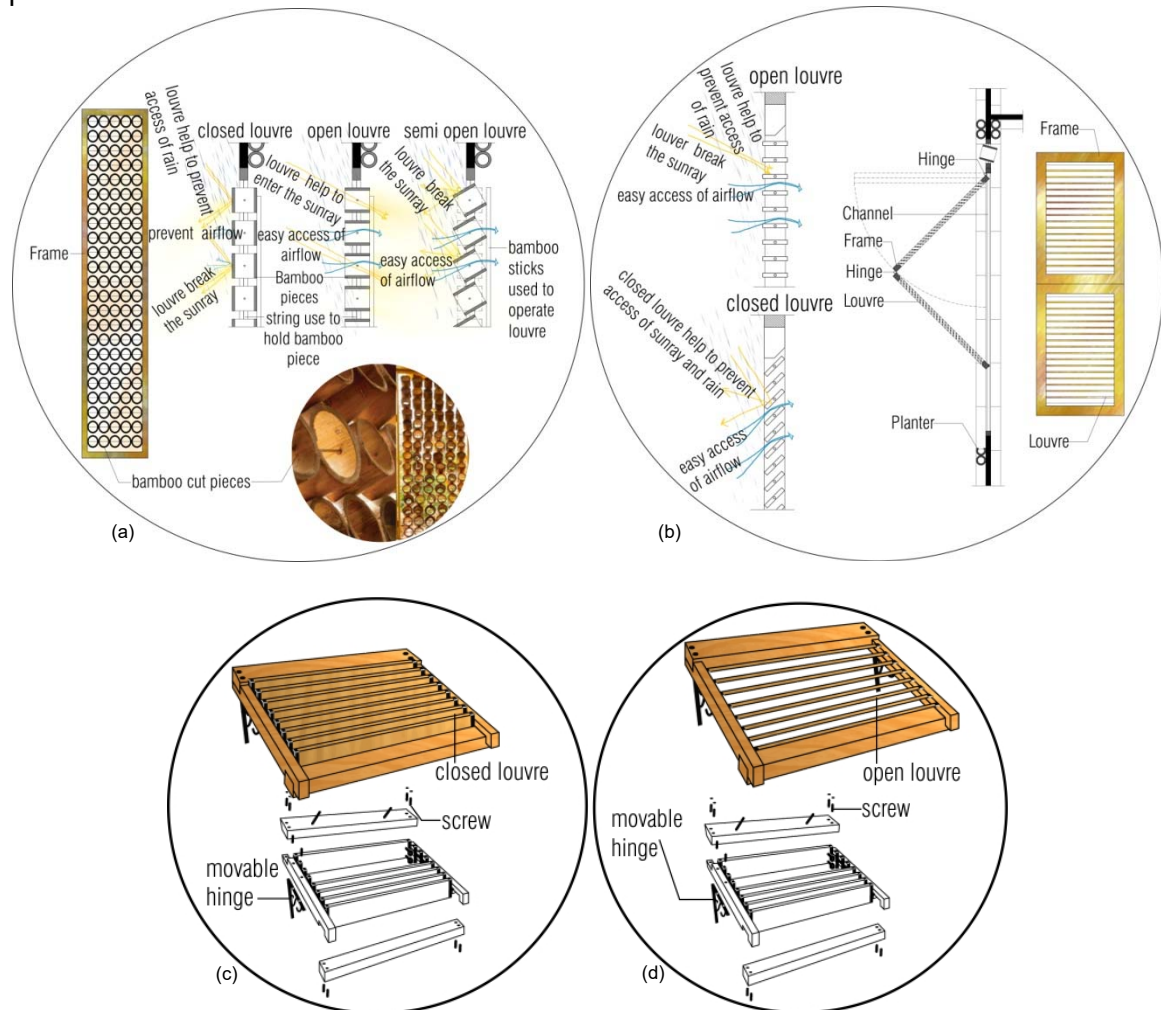


Figure 20: Smart opening details type 1 (a) and type 2 (b), Louvre operation of skylight as per climatic need (c, d)

3.1.2. Construction Details:

Considering economic and cultural sustainability, the construction method and elements are chosen in a manner that serves the following purposes – easy to adapt by the users through familiarity and low-cost techniques and materials and incorporation of smart features to derive maximum output environmentally from minimum input financially.

Each element of the house is labeled as per their vertical level for ease of understanding and practical application as seen in Figure 21. From the bottom the elements are as

follows – folded bamboo frame (Figure19), steps and ramp from ground to plinth, bamboo structure for base, EPS layer to provide buoyancy (Aman, Rahman and Zahir, 2016) to make the house amphibian, bamboo floor, bamboo walls enclosed over bamboo structure and punched with appropriate openings, mezzanine storage floor of bamboo, bamboo lattice frame for roof, a layer of thatch to provide insulation and finally solar panels to generate clean energy for the house (the numbers are based on individual house requirements).

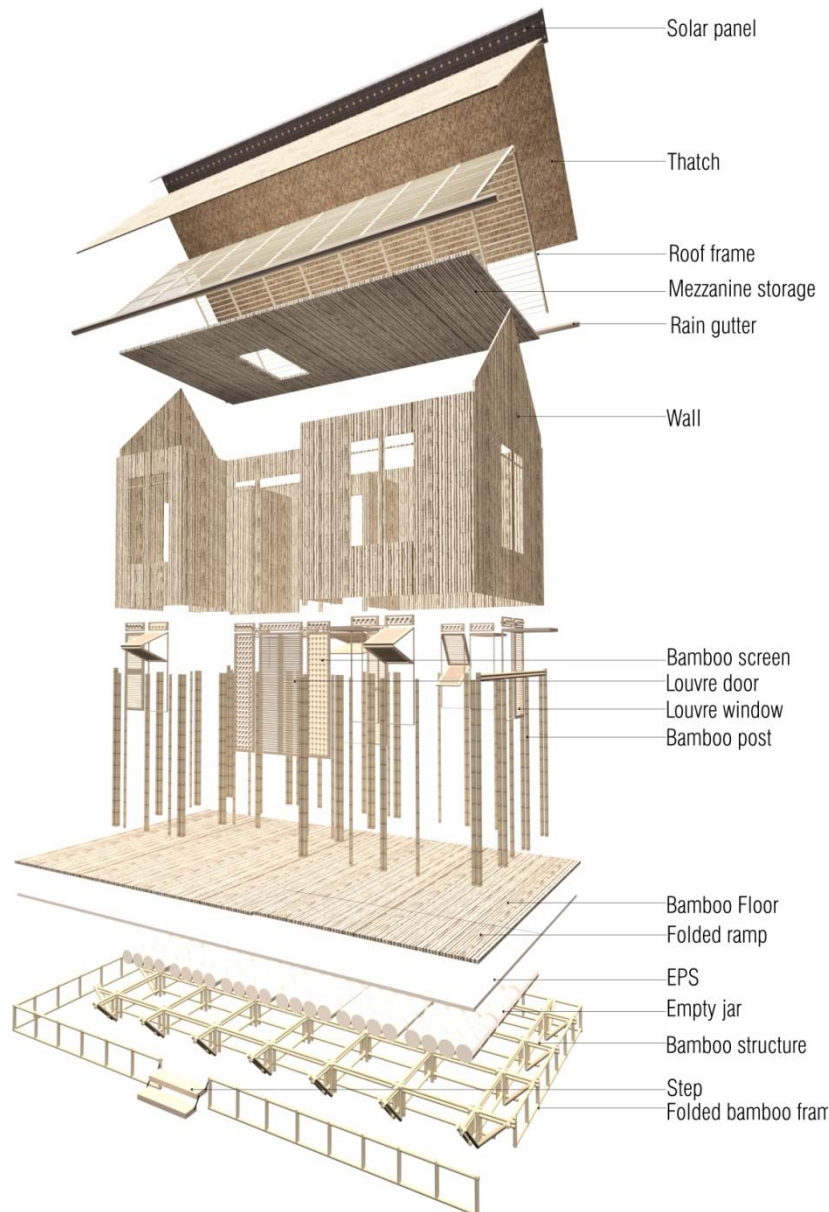


Figure 21: Exploded axonometric view showing details of sample house

Bamboo construction has been used in traditional architecture of the region for ages due to its availability, low-cost and longevity. It is taken as the chief constructional element here considering these as well as its lightweight yet sturdy nature to support the amphibian quality desired. Figure22 depicts various details of the bamboo construction of the sample house. Deeper details are illustrated in Figure22a, Figure22b, Figure22c and Figure22d while Figure23 depict the types of bamboo joints used traditionally (Wang, Dai and Guohui, 2008).

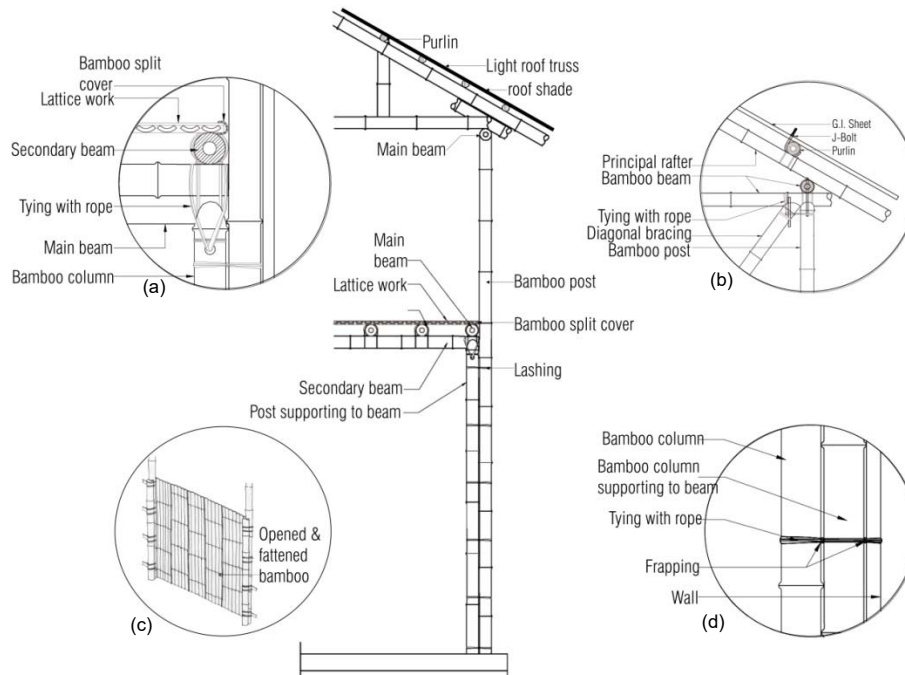


Figure 22: Bamboo construction details; beam and post details (a), roofing details (b), cladding by split bamboo for wall (c), wall construction details (d)



Figure 23: Types of bamboo joints used

3.1.3. Floating Mechanism and Calculation:

According to The Archimedes Principle, the weight of liquid that is displaced by a submerged body is equivalent to the buoyant force on it. As weight of water is 62.4 lb./ft³ (Molland, 2008), the thickness of the base of the house was estimated by finding the dead-load and live-load of the complete construction. To understand the depth of submersion during flood, the following formula was applied:

$$\text{Weight of the structure/ft.}^2 \div \text{weight of water/ft.}^2 = \text{submersion depth when floating}$$

To calculate dead load, the average weight of bamboo is considered to be 55 lb./ft² for each dwelling and live load is calculated as 50 lb./ft² (Aman, Rahman and Zahir, 2016).

4 Discussion

The result of this research is embedded in the design itself. Prevalent relevance can be found considering context and problem from the design (Section3.1). The gigantic volume of loss caused by flood (Section1) is a massive drawback for a developing nation like Bangladesh and efforts like these, if applied correctly, can be an easily implementable way to minimize sufferings. Also, the design addresses many aspects of the four pillars of sustainability which was an objective. It also has relevance to the smart village concept where it could be taken as a modular unit in entire village housing settlement – reducing wastage, energy-consumption, cost and loss of identity.

The research started out by analyzing the flood issues but upon investigation and comprehension of the context it dawned on the researchers that an effective way to implement a solution and provide longevity for it might be through a blend of traditional practices with technical aspects which led to the final result (Section3). The contribution of this study can be crucial in the ongoing researches and projects that tackle flood and other natural disaster as it is straightforwardly applicable and requires minimum level resources while providing a long term solution (Section2.5).

5 Conclusion

“Contemporary architecture should seek a greater understanding of local culture if it is to be sustainable”- Guy and Farmer, 2001.

As the world runs faster than ever before, problems stem from different arenas and perspectives; so does solutions. Contemporary practices are trending towards holistic living and can only be achieved by learning from history, tradition and by keeping cultural values thriving. Worldwide problems do not have only one method of solution; rather the solutions must be tailored considering aspects of context, users, impacts and influences.

This study simply started as a means of finding a flood resistant solution but throughout the journey from conception to completion, it grew beyond its own initial boundaries. If Government, NGO, NPO, private sponsorships and initiatives are taken to arrange practical workshops for such villagers to teach them the findings and application of this study, the villagers themselves can become empowered and independent, eliminating their problems to a large extent resulting in the further development of the nation itself.

Acknowledgements

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SEISMIC PERFORMANCE OF VERNACULAR STRUCTURES: A REVIEW

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Abstract: *This paper is a review of the performance of vernacular structures from different parts of the world and how well they responded to earthquake occurrences. Over a span of years, science and technology has come up with various aseismic engineered structures and systems to protect life and property. In this journey of development, we might have overlooked some aseismic attributes of old systems and structures that have survived earthquake disasters which have occurred much earlier also. These types of structures are the traditional structures that have been developed out of necessity and have made apt use of the locally available materials. From the timber-laced masonry structures of Turkey to the tall Chinese Pagodas, across the world these structures exist and have stood the test of time. While developing the concepts of these traditional methods, the prospects of sustainability, economy as well as performance can be looked into. A collection of findings is reported in this review, pertaining to the vernacular structures and the potential of the old practices being used as a base recommendation for the new practices, be it small scale or large scale construction.*

Keywords: vernacular, seismic performance, wattle and daub, himis, ikra

1 Introduction

In the present day, we have seen the advances in the approach to the construction of buildings and other structures which have brought in many technological breakthroughs which have proven more than efficient with regards to their performance with respect to the different loadings like gravity loads, seismic loads, wind loads, blast loads, etc. Traditional buildings have been also seen to be quite resilient in view of their performance when it comes to seismic loads. Earthquakes are nearly unpredictable and may be disastrous and cause loss of life and property. Over the years traditional buildings are being replaced by new buildings which have incorporated years of engineered methodologies and systems (Ortega et al. 2017).

Traditional seismic resistant construction techniques are adopted in such areas where there is a long-term exposure to earthquake hazards (Clementi et al. 2016). These steps have been taken with a view to mitigate the losses that may transpire in the future in case of such occurrences of hazards. These needs give rise to many developments pertaining to the local seismic nature, a key aspect of protecting such traditional methods and cultural distinctiveness.

History has shown that one of the major causes of deaths in the events of earthquakes is the collapse of structures. Earthquakes like the devastating Tangshan earthquake in China (1976) claimed 250000 lives in the city of 1 million people. All over the world, the influences of these earthquakes have pushed people forward into mitigating the devastating effect of this naturally occurring disaster (Gutierrez 2004).

Across the globe, different seismic cultures have been developed out of necessity. At the outset of these developments, various social communities have taken it upon themselves to deal with these issues with either minimal or no knowledge of the aspects of seismic activity. That being said, the traditional structures which are the starting point of these developments provoke researchers to widen their knowledge and analyse their seismic behaviour. Figure 1 shows vernacular structures with seismic resistant features, from different parts of the world.



FIGURE 1: Vernacular structures with seismic resistant features from different parts of the world.

Vernacular structures with aseismic properties have become an integral part of the built environment we live in (Gutierrez 2004). Their existence is very much acknowledged and is found in many parts of the world like Italy, Greece, Haiti, Turkey, India, Nepal, Japan, etc. The World Housing Encyclopaedia which recognised the need to build an inventory of information of the construction practices and strengthening them, has come a long way, with their sights set on building a framework of such information on a global platform (Brzev et al. 2004). The earthquake resistant building designs have been developed in light of the socio-economic attributes of a country and have been employed over the past hundred years (Daniell et al. 2014). There is a need to take a step back to evaluate the buildings which have good seismic performance such as *ikra* type housing (Das et al. 2014), *wattle and daub* construction (Gautam & Rodrigues 2018), *hatil* and *himis* (Zatir & Mokhtar 2014), and therefore use these concepts to use locally available materials and build upon them new concepts related to earthquakes.

Some of the different types of vernacular structures and their seismic performance are discussed below:-

1.1 Wattle and daub

In this type of construction vertical and horizontal elements are nailed together as shown in Figure 2. The vertical elements are usually the materials which are bulkier like tree trunks and the horizontal elements which are more reduced such as bamboo, reeds or twigs. In some cases an adobe is provided in between the elements. This basically forms a grid of elements in which the structure may consist of timber with earth infill or such other elements. This type of construction is very flexible due to the flexible joints (Minke 2001). This type of construction is mostly done due to ease of availability of materials. People still use this method of construction in the present days. A wattle and daub house in Haiti is shown in FIGURE 3 (Audefroy 2011).



FIGURE 2: Traditional wattle and daub system, Venezuela, (Minke 2011)



FIGURE 3: Wattle and Daub house, Decoville, Haiti, (Audefroy 2011)

The Nepal earthquake of 2015 had very less impact on vernacular structures. Wattle and daub being flexible in nature has very good pliability and has performed very well in this regard. It has shown to have performed well during earthquakes including those of 1934, 1988, and 2015 for which a magnitude of 7.8 hit the region. Though the magnitude was high, traditional structures fared comparatively better than the modern structures which were seen to have sustained maximum damage (Gautam & Rodrigues 2018). In Haiti earthquake January 2010, similar wattle and daub structure performed well. This type of construction called 'clissage' had used lime mortar and earth into the wooden grid and stone infill and responded rather well compared to their modern counterparts. These were found in Noailles, Croix de Bouquets an old village in the outskirts of Port-au-Prince (Audefroy 2011).

1.2 Ikra House

Ikra house also known as Assam type house shown in Figure 4 is made of locally available material and are lightweight structures. These have revealed to be more advantageous in terms of cost and have a better performance in terms of their seismic response (Das et al. 2014, Kaushik et al. 2006). It is seen to maintain the architectural aspect of symmetry and geometry in plan which is mostly square or rectangular. They are predominantly single storied buildings. Following a system of beam column connection made of wood which is supposed to add to the ductility of the building in its response to earthquake shaking. They may consist of cement or mud plaster as the finishing and have GI sheets built on wooden trusses. In wholeness, superstructure is connected to the masonry foundation using steel angles, bolts and nails. During the past earthquakes significant damages were not sustained by Ikra type housing (Das et al. 2014).



FIGURE 4: Ikra type housing, Assam, (Kakkad 2011)

In 1897 around 1500 people died due to the earthquake that hit the region, following after which another earthquake of M8.4 hit the Assam-Tibet region, and once again in 2011, a M6.9 earthquake hit the region. Hence the earthquake series have sparked a new interest in the traditional structures. These traditional structures being more flexible do not rupture under the pressure. In Nepal in the Siwalik plains, this type of construction also involves a bamboo mesh which is knitted and incorporated into the timber frame also known as 'Ikra'. Ikra type housing has a proper integral action which helps to make the building act as one unit (Kakkad 2011). Figure 5 shows a typical cross-section of an Ikra type wall.

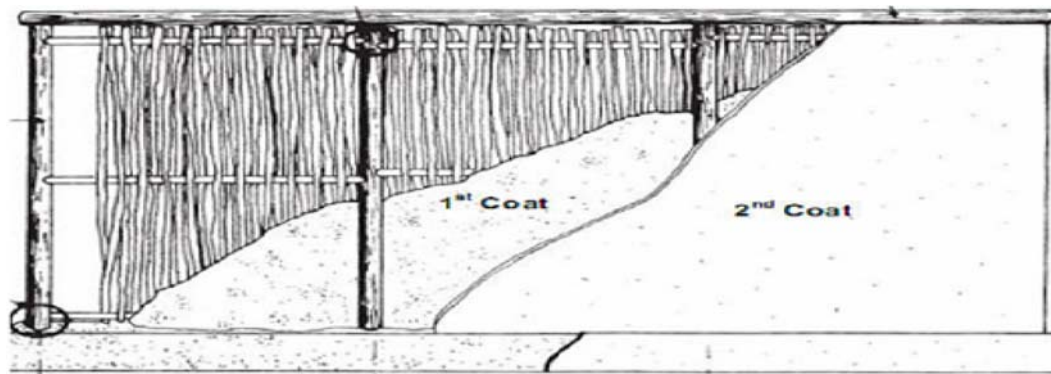


FIGURE 5: Bamboo strips in mud or lime mortar, Assam, (Kakkad 2011)

The use of bamboo in construction is very widespread in parts of the Northeast-India. It is seen that the ductility of the building increases. The lateral forces that the structures take are lesser in comparison to that of RC and brick Masonry systems i.e. 12.97% and 11.72% respectively. The structural integrity of the building helps to increase the ductility and hence its seismic performance. Stresses are developed at each connection of the purlins and engineering these points of failure can help the Ikra type housing perform better (Kakkad 2011).

1.3 Timber Reinforced Masonry Infill Walls (*Hatil & Himis*)

Turkish Ottoman style house has evolved as a timber-brick structure which has incorporations of heavy stone. The large scale destruction of the structures of Istanbul during the earthquakes of 1999 which occurred on 17th August and 12th November have prompted engineers and architects not only to re-evaluate the Reinforced Concrete construction but also to take a step back and consider the old abandoned Turkish construction methods (Tobriner 2000).

There has also been an extensive use of timber lacings in the masonry walls. There are mainly two types of construction based on the use of timber lacings i.e. the *hatil* and the *himis*. The *hatil* type of construction consists of Timber which is embedded into the masonry wall as shown in Figure 6. The construction of these either involves adobe, stone or masonry infill, or with no infill. The wooden frame however is built in such a way that the wooden skeleton can support itself and the stability is maintained by the diagonal wooden members (Gülkan & Langenbach, 2004).

In the *himis* type of construction, the timber frame is infilled with bricks or rubble stone and set with mud or lime mortar as shown in Figure 7. The thickness of these walls is about 100 mm to 120 mm. Hence this framework of timber in which bricks or stone is embedded constitutes a sheet of timber reinforced masonry in which the timbers are nailed together. There have been evidences of ductile behaviour of this type of construction using masonry infill and a timber frame. This is seen evidently by the cracks that have appeared after the earthquake occurrence, leaving some pattern of cracks in the interior and exterior walls.

In the interior walls, the cracks were mostly noticed at the interface of the timber and the masonry. This proves development of stresses along joints between the masonry and the timber frame.



**FIGURE 6: Hatil type of construction
(Gulkan 2004)**



**FIGURE 7: Himis type of construction
(Gulkan 2004)**

In the exterior walls, it was evident through the cracks that because of the timber studs dividing the infill, the masonry was not uniformly displaced. This means that even if other portions of the wall had lost significant amount of the infill, it did not affect the whole wall. The availability of these also reduced the formation of cracks in the panel of the wall reducing the displacement of the masonry subsequently. Another factor which helped in the ductility of the wall was the use of weak lime mortar which encouraged the sliding of the masonry. This was inferred when it got deformed instead of cracking and segregating the infill thus preventing the destruction of the whole structure. This also helped in the dissipation of energy as such. Thus instead of resisting the lateral forces the structures seem to have moved along with the seismic forces thus giving a plastic response. The cracking level is very low and it is distributed by the timber and the infill action. Turkish houses have these features which thus unite them with aseismic behaviour (Gulkan & Langenbach 2004).

1.4 Chinese Timber structures

The Chinese and their use of timber in construction of various heritage structures are very wide spread. Over a span of 1000 years or longer, Chinese timber structures have stood the test of time and with those earthquakes which have been recorded to have occurred over 1600 times (Shiphing 1991). Still the structures in their magnificence stand tall and unaffected. Such traditional structures need to be looked into to understand as to how they have been so efficient pertaining to their seismic performance.

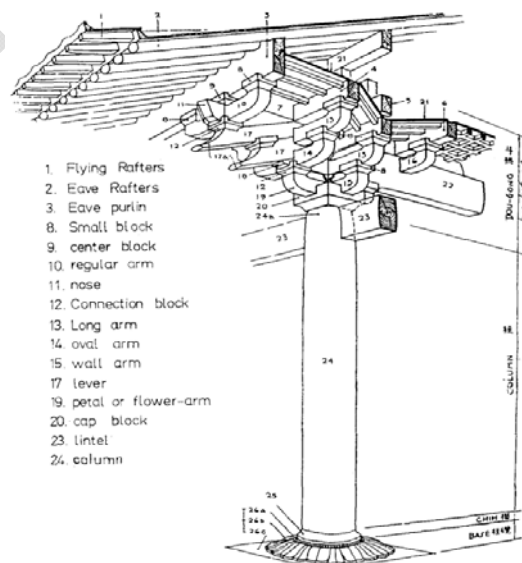
A typical Chinese timber structure is shown in Figure 8. It is a system consisting of beam-column-strut connections that form the basis of the structure. The timber columns rest on stone pedestals, on top of which major beams are connected. On top of these beams rest shorter beams which are supported on struts. Figure 8 shows a Chinese timber structure wherein the roof slopes as the beams get shorter in elevation from the centre in between which the purlins are installed on top of which the rafters are placed and subsequently the roof. The roof consists of a sheathing made up of a mixture of lime, mud and straw and on top of this mixture, tiles are placed (Shiphing 1991). Another unique feature of some buildings is the bracket-set-column system (shown in

This diagram illustrates the complex wooden framework of a traditional Chinese roof. The structure features a multi-tiered, curved roof supported by a series of vertical columns and horizontal beams. Key components are labeled as follows:

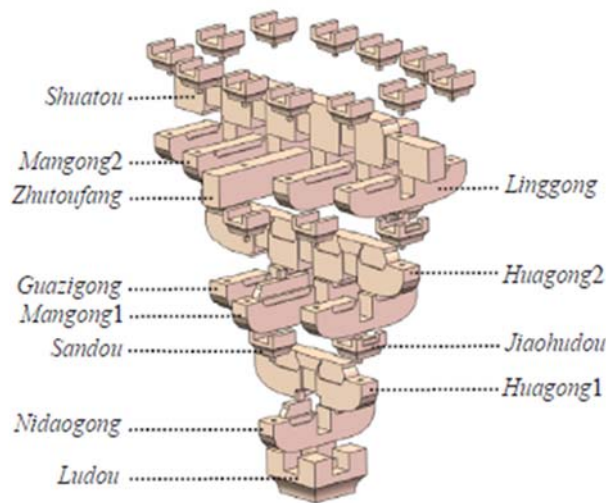
- Roof Structure:** Labels include "ridge" (脊), "sheathing" (椽皮), "rafters" (椽子), and "beam" (梁).
- Main Beams:** The central horizontal beam is labeled "main beam" (主梁). Other beams are labeled "longitudinal tie-beam" (longitudinal tie-beam) and "transversal tie-beam" (transversal tie-beam).
- Purlins:** The curved beams supporting the roof tiles are labeled "purlin" (檩条).
- Columns:** The vertical supports are labeled "column" (柱子).
- Other Labels:** Additional labels include "architrave" (额枋), "brace" (撑), "tie" (牵), and "beam" (梁).

The diagram provides a clear view of the structural elements and their interconnections, highlighting the precision and complexity of traditional Chinese carpentry.

In the Haichen earthquake of 1975, it was concluded that the buildings without the bracket did not perform as well as the buildings that had them, thus stipulation of the dougong's aseismic property was inferred (Shiphing 1991). It acts as a transmitter of loads. Again, in such types of structures, the light-weight roof and the property of the building to dissipate energy accounts for the good performance of the vernacular structures (Zhao et al. 2009).



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**FIGURE 10: Dougong bracket
(Meng 2019)**

Meng et al., 2019, has described that the energy dissipation of such types of structures although are weak, their capacity to recover from deformations is quite excellent. The mechanism of how the timber structure converts energy to nullify to some extent the effect of the earthquake is quite commendable and the timber structures therefore store energy quite efficiently. This therefore reduces damage to the components of the structure (Meng et al. 2019).

1.5 Dhajji-Dewari System

This is one of the traditional systems of the Kashmiri traditional structures. It is derived from Persian which means, 'patchwork quilt wall'. Thus it is of Persian origins and is quite similar to *himis* in Turkey. It is a system of incorporating masonry in various orientations, be it horizontal, vertical or even inclined. This forms a continuous wall or a membrane of wood and masonry. This timber-laced masonry wall construction divides the wall into a grid like structure that keeps the crack from propagating thus protecting the integrity of the wall and thus adds strength to the masonry wall. An interesting observation is that the floors are framed separately and thus the two floor joists are in between the horizontal timber plates (Islam & Shah 2018). They thus fit under 'platform frames' construction as such. Figure 11 shows a Dhajji-Dewari structure.



FIGURE 11: Dhajji-Dewari System (Hicyilmaz et al. 2011)

In the 2005 earthquake the *dhajji* framed structures performed well in their seismic response (Islam & Shah 2018). The brick laden timber frame acts like a confinement for the masonry and thus this patchwork which divides the wall into different panels arrests the loss in the integrity of the wall and thus progressive collapse is much reduced (Dar & Ahmad 2015). Moreover, simple symmetric plans, no abrupt discontinuities or stiffness variation in the diaphragm of the Kashmir House, account for its good seismic performance (Shah & Tayyibji 2008).

1.6 Bagdadi type of Construction

This type of construction involves the use of light weight material as the infill. These consist of old short wood pieces or trunk shells which are embedded into the timber frame instead of masonry infill (Ozturk & Cahantimur 2011). Figure 12 and Figure 13 shows Bagdadi construction in Turkey.



FIGURE 12: Bagdadi construction in Turkey structure (Ozturk & Chantimur 2011)



FIGURE 13: Interior Walls in Bagdadi (Ozturk & Chantimur 2011)

In the exterior part of the wall, lath or wood is used to plaster or finish the wall, whereas on the interior it may or may not be plastered. The wood used, were old and unusable as structural elements. These light materials make the structure light-weight, consequently, these structures performed well in earthquakes (Zatir & Mokhtari 2014). Moreover, such types of structures have good ductile behaviour and can sustain tension well (Traykova et al. 2018). Besides this, the well formed connections of the timber structures also contributed to the good seismic performance. Researchers have deemed this slightly more complicated and well developed in comparison to the Himish type of construction (Korkmaz et al. 2010).

1.7 Japanese Timber Structures

In Japanese Architecture, there is the use of wood characteristics which integrally forms a good system for construction. These characteristics may be like the use of thick columns, joints of beams, columns and brackets. The columns are set on top of base stones (Maeno et al. 2004). The roof-overhang has bracket capitals which connect the roof and the column (Ryo 1960).

These Japanese structures such as the five-storeyed Daigo-ji Pagoda shown in Figure 14 have the capacity to sustain large plastic deformations owing to material characteristics and composite construction. Such features cause damping effect. The brackets are seen to have a special role in ensuring this because they help to absorb the loads. They deform but the timber does not break but absorb large amount of vibration. Such structures are considered as highly earthquake resistant. Fujita et al reported that there was no documentation of these Pagodas being destroyed by earthquake occurrences (Fujita et al. 2004).



FIGURE 14: Five story Pagoda (Fujita et al. 2004)

Although 22 Pagodas were damaged during earlier earthquakes which were built during the Edo period, only 12 have been renovated and repaired. These structures have been through 16 earthquakes in their span of existence having magnitudes of at least 6M but have not collapsed, affirming the commendable seismic behaviour of these timber structures (Okubo 2016).

1.8 Bahareque

In Latin America, the term Bahareque is equivalent to the wattle and daub type of construction in that they too have a timber frame where in which the infill consists of bamboo, twigs or adobe. This is found in places such as El Salvador, Guatemala, regions of Venezuela and a few other South American countries (Lang et al. 2007). These are present both in rural as well as urban areas (as shown in Figure 15 and Figure 16 respectively). This involves a basket work of timber vertically placed with horizontal laths (reed, bamboo, etc.) which is then in-filled with mud, clay with a mixture of straw. This infill consists of two parts: the soft part consisting of mud and lime and a hard part made up of stone (Henneberg 2017).



FIGURE 15: Bahareque house in Rural Areas (Lang 2007)



FIGURE 16: Modern Bahareque Buildings in the Urban Areas (Henneberg 2017)

The lateral load resistance is offered by the frame and is seen to be flexible owing to the structural configuration and materials. They show elastic characteristics and are light-weight. Their performance is rather good in this respect with regards to earthquake shaking. Lopez et al, 2004, commented that the Bahareque type of construction has evolved since the earliest years of the Spanish invasion and stated that in attempts to mitigate the disasters that have occurred in the region, the most successful was the development of the Bahareque method of construction (López et al. 2004).

1.9 Pombalino

These types of structures were found in the earthquake prone region of Portugal. After the Lisbon earthquake of 1775 which hit the region on the 1st of November, with a magnitude of 8.6 (Chester & Chester 2001) measured on the Richter scale, Pombalino Buildings were developed and constructed (Cardoso et al. 2004a).

A typical cross-section of the pombalino structure is shown in FIGURE 17. The construction of these traditional buildings are characterised by the *gaiola pombalina* shown in Figure 18, which is like a cage like timber structure laced with a masonry infill hence forming a mixed timber-masonry structure. Cruz et al. 2015, stated that the construction of a whole town consisting of a single type of building with seismic provisions included in its conceptualization, is the first of its kind in history (Cruz et al. 2015).

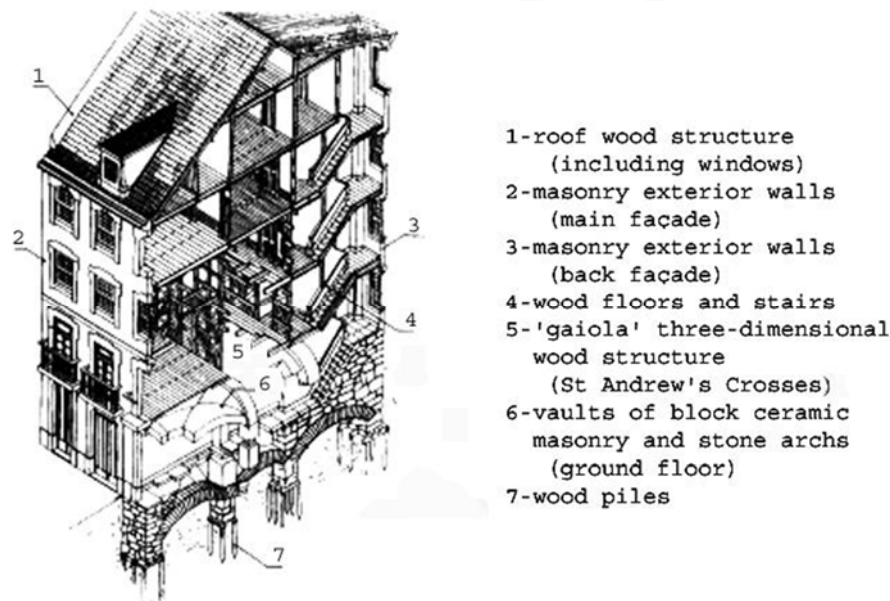


FIGURE 17: Pombalino Structure (Cardoso et al. 2004a)

The *gaiola* method involves enclosing of the masonry walls which are the main structural functioning walls and other interior walls are made of wood which act like partition walls and have no load bearing functions. The roof involves timber trusses and ceramic tiles. The floors are also made of wooden panels which act like a diaphragm (Cardoso et al. 2004a).

The first floor rests on masonry arches which not only provide a barrier against fires which may occur in the lower floors and also prevent the wood from getting affected by soil humidity (Lopes et al. 2014). This is all founded on wooden piles which are small in diameter structured by a timber grid.

The development of these structures was done in order to bring about the aseismic provision in these types of structures. Many researchers have gone to the lengths of assessing their performance to seismic loading (Cardoso et al. 2004b, Cruz et al. 2015, Cardoso et al. 2004a, Lopes et al. 2014).



FIGURE 18: Gaiola timber frame (Cardoso et al. 2004a)

1.10 Lefkas type of construction

This type of construction involves the use of timber and stone which primarily forms the structure of the building. In most of the timber stone composite construction method, the incorporation of the stone into the timber frame can be seen. But in the Lefkada region of Greece, the structures were seen to have timber and stone masonry which were independent of each other shown in Figure 19. Owing to the low slenderness (as a result of the proportions of height and width) the out of plane strength of masonry increases. There are also timber and mortise joints as shown in Figure 20, which distribute loads more uniformly. The corners are stiffened by the use of Bratsolia joints as shown in Figure 21 (Karababa & Guthrie 2007).



FIGURE 19: Timber Frame independent from the masonry infill (Karababa & Guthrie 2007)



FIGURE 20: Timber mortise Joints (Karababa & Guthrie 2007)



FIGURE 21: Bratsolia joints (Karababa & Guthrie 2007)

The traditional methods of construction especially the seismic culture has been a spectacle of interest. This was instituted by the European Council Cultural Heritage Unit. Developed during the 17th century and it is continued to be used even in the present day (Kalantoni et al. 2013). This traditional system of construction shows a good performance as evident from the reports and literature of the earthquake which occurred on August 14 2003 (Karababa & Guthrie 2007, Toulaitos 1992, Thomas et al. 2016).

Conclusion:

Vernacular structures like the Pagodas, Bahareque, Ikra house, etc. were constructed with locally available materials and techniques to mitigate the destruction caused by earthquakes. In almost all of the different types of vernacular structures there is extensive use of timber which is structured in various forms to form the structural framework of the construction such as the 'gaiola cage' in the Pombalino type of construction or the basket-like woven structure of the Bahareque, which are one of the many ways to form the skeleton of the structure. These structures are also seen to have in-fills which are of light-weight material. Although brick or stone masonry are used in their varied forms, other light-weight materials such as bamboo, reeds etc. are also incorporated. The light-weight roofs which are generally placed on trusses also contribute to the lower equivalent mass of the whole structure which is a desired feature of aseismic structures. The simple plan, maintenance of the geometry and symmetry aids in the seismic response of the structures. The timber structures have systems like the 'dougong brackets' which can be seen in the Japanese Pagodas and Chinese structures. Other distinct structural configurations are the diagonal elements and the horizontal short elements as seen in Himis, Hatil and Dhajji dewari, the mortise joints of the Bahareque and the Lefkadas structures, all of which, in their own way provide a mechanism which is aseismic. These effects include better load transfer mechanism, energy dissipation; arresting cracks on walls of timber-laced masonry, elastic response generated at joints, provide good seismic performance.

Seismic performance of the vernacular structures is excellent and some even surpass those of the modern structures. These design techniques can be incorporated in the present day engineered structures also. Also, the use of locally available materials needs to be encouraged. Perhaps architects and engineers should take a deep and closer look into the materials and the structural aspect involved to bring about the same result of seismic performance in the modern structures. The conservation of these structures also should be stressed by government bodies as well as NGOs. A sense of awareness should be inculcated in the various governing, academic and other communities of prominent influence.

Researchers have a broad scope in this field of Engineering and Architecture: performing analysis, conducting experimental work on the different types of vernacular structures and comparing them to the modern day structures to assess their behaviour and use these various concepts to develop new codes and guidelines to ensure that the construction methods will be continued and practiced with the needed underlying knowledge as we now have for our modern current day practice.

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COMPARATIVE ANALYSIS OF INDOOR COMFORT BETWEEN WOODEN AND COMPOSITE HOUSE IN THE COASTAL REGION, BANGLADESH

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Abstract: Houses are made to protect the occupants and to create indoor comfort for the residents. Two major indoor comfort factors are air temperature (AT °C) and relative humidity (RH %) which are very important for human health. In the coastal climate, the humidity and temperature level is relatively high than in other areas. In this study, indoor RH and AT of wooden and composite house in the coastal region (Chittagong, Bangladesh) have been measured by the environmental data logger. Then the measured data were analyzed based on two criteria: firstly, a difference of RH contents according to material types and secondly relationship between AT and RH. For monitoring the RH, Data loggers (HOBO ware pro. U30) and 5 in 1 velocicalc. (Model: LM-8102, Anemometer, Humidity meter, light meter, thermometer, sound level meter) was used. Data has been measured both during day and night time. The purpose of this study is to evaluate the differences between wooden and composite houses related to the indoor environmental comfort of the occupants. The research aim is to identify which type of house is more comfortable for the coastal region in the tropical climate. The result of field measurements and analysis indicated that houses with wooden walls contain more RH and have low AT than houses with other material walls.

Keywords: Air temperature, Relative humidity; Wooden house; Composite house; Coastal region.

1 Introduction

Houses protect the occupants from the adverse effect of nature and create comfort for the residents. But recent studies reveal that today human being spends more than 80-90% of their lifetime in building (ASHRAE 2010). That's why recent studies focus on the relationship between built form and climate hence the performance of the building and indoor environmental comfort in a particular climate. AT and RH are the two major factors of indoor comfort which are very important for human health. The climatic condition of the coastal region shows high humidity and moderate temperature throughout the year than in other areas. Bangladesh is a warm-humid tropical region. It has a large coastal belt in the south-eastern part of the country. The climatic condition of this region is different from the rest of the parts of the country. High humidity, moderate temperature (mean temperature range is 13°C-32°C) and heavy rainfall (over 2540mm) are the characteristics of this region (Rashid, 1991). Different climatic character results in different house type in this region. Due to the economic condition and availability of the wood majority of the rural people built wooden houses (both structure and envelope) in the coastal areas of Chittagong. But as a result of urbanization and modernization, most of the wooden houses are being replaced by brick walls and concrete structures. This change influences the indoor comfort condition within the house. Studies reveal that the thermal performance of these materials is lower than the traditional materials and responsible for the poor indoor thermal environment (Mallick and Ali 2003). This makes it worthy to study the indoor RH and AT of wooden and composite houses in this region. The purpose of this study is to evaluate the differences between wooden and composite houses based on the indoor environmental comfort of the occupants. The research aims at identifying which type of house is more comfortable for the coastal region.

2 Climate Consideration

For the research work Cox's Bazar, Chittagong is taken as the study area. It locates 21.4272° N, 92.0058° E and basically, a coastal belt belongs to tropical climate. High humidity and the moderate temperature is the major climatic condition all the year round with significant rainfall most months of the year. The average annual temperature is 25.6°C, relative humidity is 87.5% and rainfall is 3770mm. May, the hottest month of the year, has an average temperature of 28.5°C and January is the coldest month, with temperatures averaging 20.5°C. Throughout the year temperature varies by 8°C. Precipitation is lowest in January considered as the dry season with an average of 7mm rainfall and has very little effect. Most of the precipitation falls in July and August, averaging 1060 mm. The dry and wettest month has a difference in precipitation of 1053mm (Coxs-Bazar/climate-profile, Bangladesh).

3 Objectives of the Study

The main purpose of this study is to evaluate the environmental performances of local wooden house and composite house with respect to local climatic considerations. Another aim of this research is to develop an outline of an indoor environmental database of a local these houses in the context of humid- tropics.

4 Architectural features related to indoor comfort

i) Wooden house

Wooden houses in coastal areas of Chittagong are generally a single detached building. They have mainly two parts: all sides open lower space and upper enclosed

space. The lower portion has an average height of 1.8-2.75m generally used as a working zone for daily domestic chores and weaving purposes (Fig: 01). The elevated upper zone has a wooden floor rests on average 15-20 wooden columns and wooden beam. This pitched roof upper space has a lower average height of 2.1-2.28m and the highest average 3.5-4.16m. The four sides are enclosed with wooden envelopes of 12.5mm thick. The upper space has 3-4 bedrooms having windows at least on two sides for ensuring cross ventilation within the room. The lower part is connected to the upper part through a wooden stair having 9-11 steps.



Figure 1. Wooden house of the coastal area

These wooden houses have grasped many passive design features with respect to microclimate condition where high humidity and the moderate temperature is dominant most of the time (Fig.2). The proximity of the sea and hot humid sea wind are the major factors creating this condition. These passive features help to maintain a comfortable indoor environment. A field study reveals that these houses consume less energy as they included many passive techniques for cooling.

Generally, the wooden houses are constructed to provide maximum thermal comfort with natural ventilation. Elevated lower part not only helps to improve indoor thermal comfort but also reduces the moisture level within the house (Mishra 2016). The elevated space allows air to come in and out freely and provides shaded comfortable space for work.

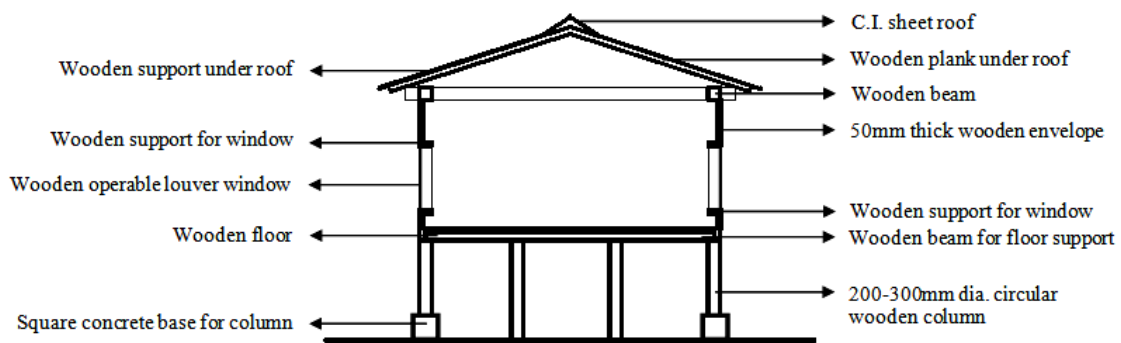


Figure 2. Different parts and construction materials of typical coastal wooden house

Another important passive feature of these houses is a special window having an operable louver (Fig.3). This traditional window provides occupants with some indoor-climate control. Occupants can control wind flow rate and even direction within the building just operating the louver. These significantly improve the indoor ventilation and air change rate within the upper part of the house (Mishra 2016). The house has a two/three-layer high pitch roof which helps to come out hot indoor air outside through an opening in the upper roof.



Figure 3. Operable wooden window

ii) Composite house

The composite houses in these areas are a recent shift towards modern and manufactured materials. The dimension and space distribution/zoning are the same as wooden ones. The construction of a composite house (Fig.4 and Fig.5) is actually a constructional copy of the wooden house, apart from the used materials and their construction technique.

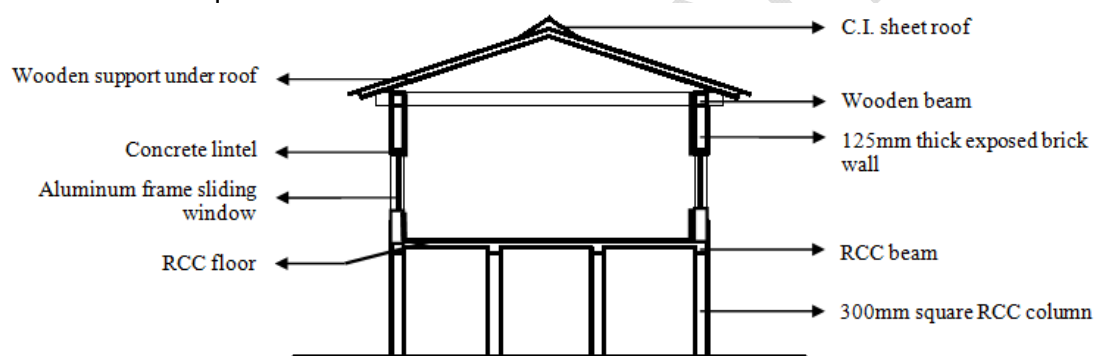


Figure 4. Different parts and construction materials of typical coastal wooden house



Figure 5. Composite house of the coastal area

This shift towards modern and manufactured materials results in many traditional passive features related to indoor comfort to eliminate from the local buildings. For example, the replacement of a wooden louver window by sliding ones results in a warmer indoor environment than before. The sliding window provides a 50% opening of the total window area. Moreover, glass windows trapped heat inside the building. Not only that, the thermal performance of these modern and manufactured materials is poor than the wood (Source: www.fao.org).

5 Data monitoring tools & techniques

This research aims at identifying which type of house is suitable for coastal areas of Bangladesh. This makes field monitoring essential with respect to AT and RH for both indoor and outdoor environments. From the literature review and pilot survey, specimen wooden and composite residential units have been selected with the purpose of evaluating indoor thermal conditions. Four building with wooden envelope and two with composite envelope in the coastal area of Chittagong are selected in such a way so that these houses show most of the characteristics of coastal area houses of this area (Table 1).

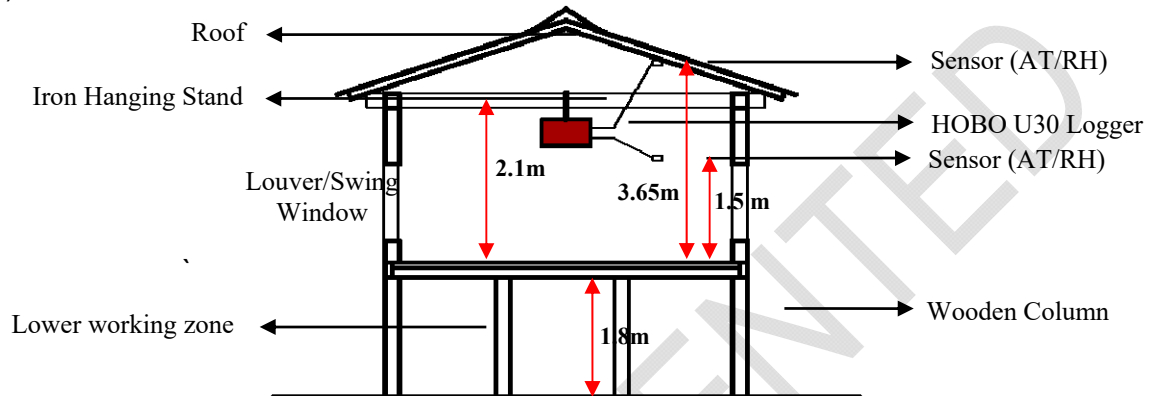


Figure 6. Data Logger installation position

Among these six units, one wooden and one composite house has been selected for long-term field monitoring. In this research long term indicates day long (24hrs) monitoring. For environmental data monitoring, the corner room has been selected as the study room so that two envelope walls have a direct connection with airy outdoor and get direct sunlight. The shaded part of the plan indicates the selected room and the spot in the plan indicates the position of the instrument in the room. The data logger has been set at a height of 1.5m from the floor level, which considered as the average human height of Bangladesh (Fig.6).

Thermal parameters AT and RH have been measured with Multi-parameter Environmental meter (Model: LM-8102) and HOBO data logger (HOBO ware Pro. U30). AT and RH have been taken at a height of 1.5m which is considered as the mean height of the human occupancy zone. AT and RH data are taken at an interval of 30min. Data monitoring has been conducted for 24hrs for both wooden and composite house during the month of August. Fig.7 shows the instruments used for the purpose of data collection. Besides that Infrared camera (Model: FLIR Z-CAMERA) has been used for capturing both indoor and outdoor thermal images of the houses.



Figure 7. Equipment for temperature measurement

6 House selection criteria and monitoring

As mentioned in section 4, four-building with wooden envelopes and two with composite envelopes in the coastal area of Chittagong have been selected for evaluating indoor thermal conditions which show most of the identical characteristics of this coastal area houses. Field study reveals that wooden houses of this area are the culture-specific socio-economic commodity. These houses are the outcome of the traditional knowledge gleaned through a long-term trial-error process, which is constructed with locally available materials and addressing the local climate constraints. Unfortunately, in recent times due to increased affordability, wealthy households are shifting towards manufactured materials subsequently diminishing the use of traditional building materials wood, which in turn results in an uncomfortable indoor environment due to high heat gain. Moreover, from field observation, it is seen that occupant's behavior and ability to control the environment have an impact on thermal comfort perception. That is why for this research houses have been selected considering identical cultural and economic conditions of the people. Not only that but also the room with nearly similar floor area has been selected for data monitoring. Table 1 shows the plan and elevations of the six selected residential units.

Table 1. Plan and elevations of selected buildings for field monitoring

Case no	House Type	Upper Floor Plan	North Elevation	South Elevation	East Elevation	West Elevation
01	Wooden (w1)					
02	Wooden (w2)					
03	Wooden (w3)					
04	Wooden (w4)					
05	Composite (c1)					
06	Composite (c2)					

As mentioned above, between the six selected residential units' one wooden and one composite unit is selected for daylong (24 hrs) data monitoring, shown in Table 2. However, AT and RH are recorded at five different times (6:00am, 10:00am, 02:00pm, 6:00pm and 10:00pm) for each selected units.

Table 2. Field environmental monitoring steps during the specific period

Building	Orientation	Floor	Monitored room orientation	Daylong Measurement	Built Period
W1	East-West	Elevated one-storied	South-West	No	About 60
W2	East-West	Elevated one-storied	North-East	No	About 75
W3	North-South	Elevated one-storied	South-East	No	About 75
W4	North-South	Elevated one-storied	South-East	Yes	About 80
C1	North-South	Elevated one-storied	South-East	Yes	About 10
C2	North-South	Elevated one-storied	North-West	No	About 05

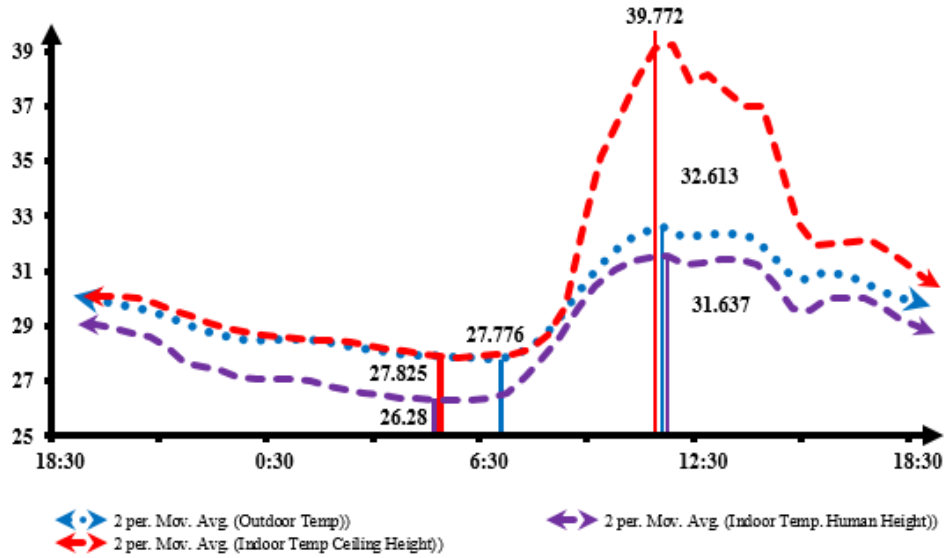
7 Result and Discussion

i) Day-long measured result

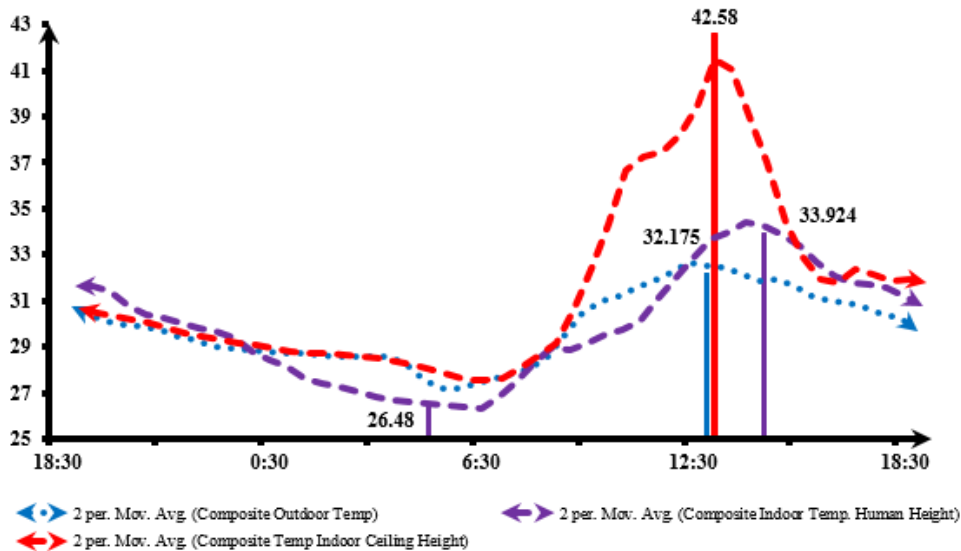
The measured AT and RH data for the -six different houses can be seen in the figure below. Fig.6 shows the result of temperature measurement of the average AT for the houses W1, W2, W3, W4, C1, and C2. Fig.7 shows the result of the RH measurement.

The outcome of field measurements of AT shows that for wooden house AT ranged from 26.28°C to 31.64°C at 1.5m (human height) and 27.83°C to 39.78°C at 3.65m (average ceiling height) from the floor level when outdoor AT ranged from 27.776°C to 32.613°C (Fig.8 (a)). The average AT of wooden house is 28.66°C and 31.29°C at 1.5m and 3.65m from the floor level respectively with an average outdoor AT of 29.78°C. Both outdoor, 1.5m and 3.65m height, AT reaches its peak at the same time between 11:00 am-12: 30

pm with an average temperature difference range of 1.12°C to 1.51°C between indoor and outdoor.



(a)



(b)

Figure 8. Comparison of the day-long measurement result, (a) Comparison of Outdoor and Indoor (Human and Ceiling height) AT of W4 (b) Comparison of Outdoor and Indoor (Human and Ceiling height) AT of C1

The temperature difference between the two heights (1.5m and 3.65m) is 2.63°C. Similarly, it is observed from Fig.8 (b) that, AT of composite house ranged from 26.30°C to 34.62°C and 27.5°C to 42.58°C at 1.5m (human height) and 3.65m (average ceiling height) from the floor level respectively. Outdoor AT ranged from 27.11°C to 32.82°C. The average AT of composite house is 29.88°C and 31.4°C at 1.5m and 3.65m from the floor level respectively with an average outdoor AT of 29.81°C with an average temperature difference range of 0.07°C to 1.59°C between indoor and outdoor. A temperature difference of nearly 1.22°C at 1.5m level and 0.11°C at 3.65m level between wooden and composite houses are spotted from the figure. Both outdoor and indoor

ceiling levels AT reach its peak between 12:30-1:30 pm but indoor AT of human height level reaches its peak between 4:00-4:30 pm.

This happens because of the thermal properties of the composite house's envelope. From the figure, it is also seen that the AT near the ceiling is higher than the AT value near the human occupancy zone which varies with time.

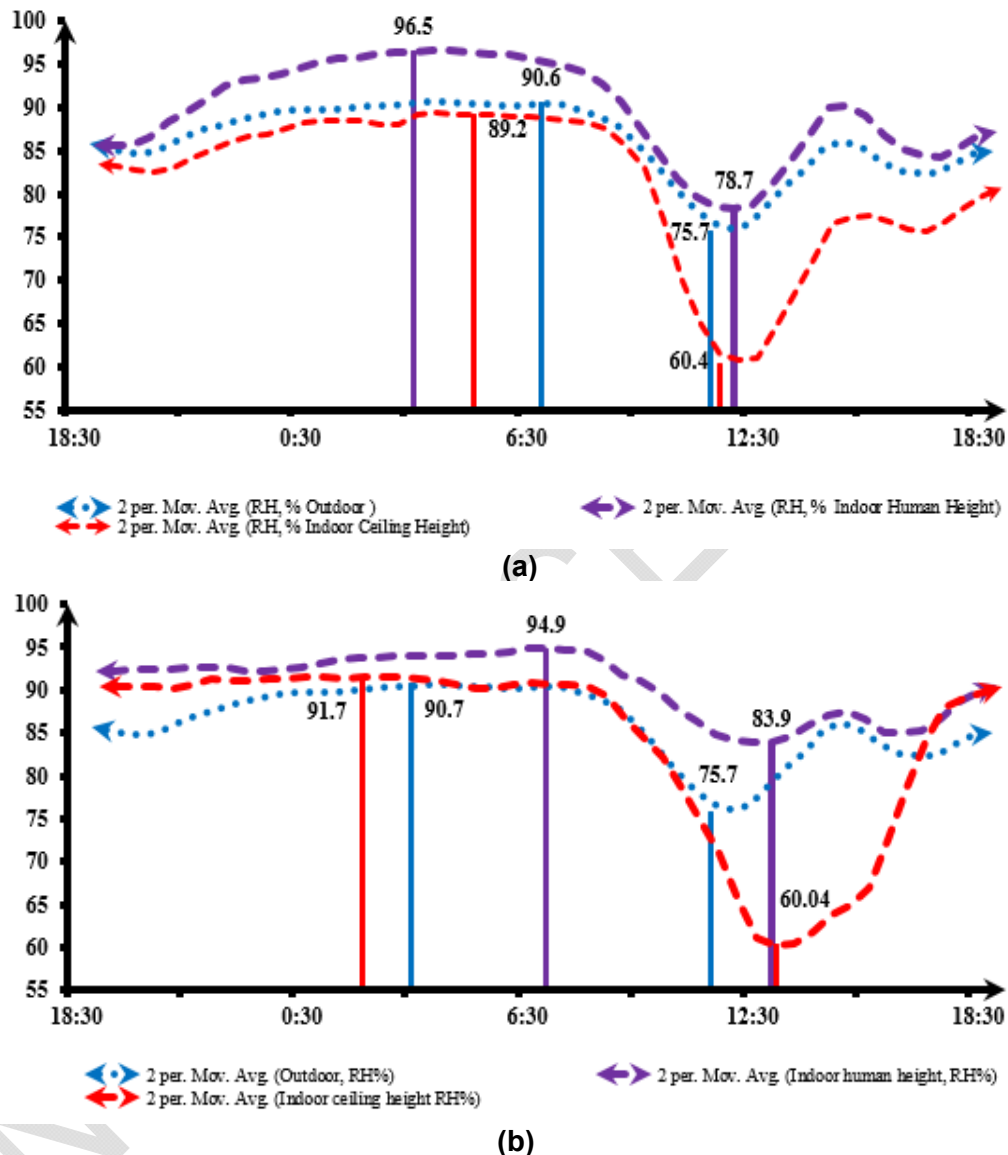


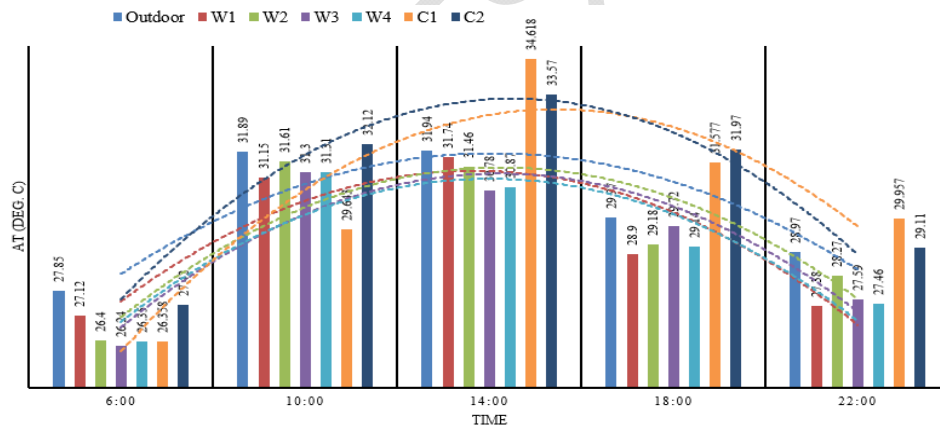
Figure 9. Comparison of the day-long measurement result, (a) Comparison of Outdoor and Indoor (Human and Ceiling height) RH of W4 (b) Comparison of Outdoor and Indoor (Human and Ceiling height) RH of C1

This happens because of the thermal properties of roofing material. C.I. sheet has a much lower thermal capacity and temperatures increase and decrease soon as the outdoor temperature rises and falls respectively. But temperature near 1.5m height increases and decreases slowly with the rise and fall of outdoor temperature and depending on the occupant's activity and presence within the zone.

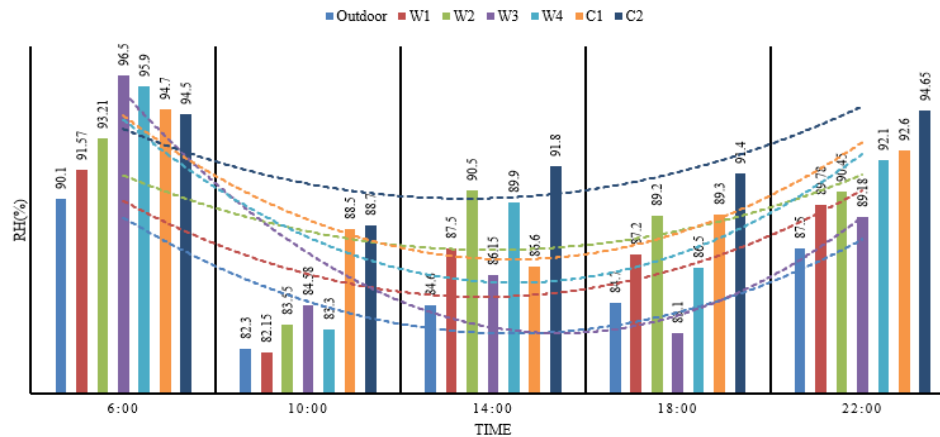
Fig.9 shows the graphical presentation of RH condition for the outdoor and indoor environment for both wooden and composite house obtained from field monitoring.

From the data of RH, it can be spotted that the RH of wooden house RH ranged from 96.5% to 78% at 1.5m (human height) and 89.3% to 60.6% at 3.65m (average ceiling height) from the floor level when outdoor RH ranged from 90.7% to 75.7% (Fig.9 (a)). The average RH of the wooden house is 89.53% and 81.23% at 1.5m and 3.65m from the floor level respectively with an average outdoor RH of 86.02%. The difference between indoor and outdoor RH ranged from 3.51% to 4.79%. Similarly, RH of composite house ranged from 94.9% to 83.9% at 1.5m (human height) and 91.7% to 60.04% at 3.65m (average ceiling height) from the floor level when outdoor RH ranged from 75.5% to 90.7% (Fig.9 (b)). The average RH of the composite house is 90.64% and 84.16% at 1.5m and 3.65m from the floor level respectively with an average outdoor RH of 86.02%. The difference between indoor and outdoor RH ranged from 1.9% to 4.62%. The RH of the composite house is lower than the composite house. A humidity difference of nearly 1.22% at 1.5m level and 2.93% at 3.65m level between wooden and composite houses is spotted from the figure. This is because of the physical structure of wood. Nature of wood is porous which enhances evaporation of moisture and various studies reveal the moisture buffering capacity of wood (Carmeliet, De Wit, et al. 2005; Hameury 2005; Osanyintola and Simonson 2006; Cerolini, Dâorazio, et al. 2009). In the composite house, the brick within the wall envelope holds water resulting in high moisture within the house than wooden ones. From the figure, it is also seen that the RH near the ceiling is lower than the RH value near the human occupancy zone which varies with time and AT of the relevance zone. RH shows an inverse relationship with AT and which is obvious.

ii) Time-specific data measurement results



(a)



(b)

Figure 10. Comparison of the time-specific measurement result, (a) Comparison of Outdoor and Indoor (Human and Ceiling height) RH of W4 (b) Comparison of Outdoor and Indoor (Human and Ceiling height) RH of C1

Fig.10 shows the graphical presentation of the time-specific data measurement results. From the data available it is seen that indoor AT of wooden houses is slightly low than the composite houses. The average AT of wooden houses is 29.2°C where it is 30.63°C for the composite houses. The difference is almost 1.43°C (Fig.10 (a)). The analysis is already explained above.

From Fig.10 (b) it is seen that indoor RH of the wooden house is slightly low than the composite houses. The average RH of wooden houses is 88.62% where it is 91.28% for the composite houses. A difference of nearly 2.66% has been spotted.

8 Scope and Limitation

The research work presented in this study concentrates on indoor performance evaluation of wooden and composite house in the coastal area, Chittagong region, Bangladesh. Some degree of uncertainty has been presented in the data collections during field investigations due to leakage of airflow between the roof and the envelope. However, given the limited time and scope of the study, this research has been concentrated on the indoor thermal issues only. The performance of dwellers and their productivity regarding active and passive ventilation systems, heating, cooling, lighting issues, acoustics, insulation, safety, and security are beyond the scope of this research.

9 Conclusion

This research has been conducted only on small houses in the coastal area, Bangladesh where the environmental factors have diverse effects. In this study, the basic thermal condition of the indoor spaces has been studied and limited numbers of strategies have been discussed which can be implemented in the context of the coastal region. From the study, the following findings have been obtained:

The thermal performance of the wooden house is better than the composite house though the temperature and humidity difference between wooden and composite houses is small. As temperature and humidity are high in coastal areas building envelop with high temperatures and moisture insulation quality will be appreciated. Because of thermal insulation and moisture, buffering quality of wood, wooden house performs better than composite one regarding thermal and humidity comfort.

The guidelines suggested in this study will help architects and engineers while designing a standard coastal dwelling with accommodating compliances for energy efficiency.

Acknowledgments:

Appreciation goes to the Environmental Lab, (Dept. of Architecture), Chittagong University of Engineering & Technology (CUET), Bangladesh.

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Improving Thermal Performance of Non-Airconditioned Indian Low-Income Housing: A Numerical Study

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Abstract: According to the report titled “India in Figures – 2018”, 25.7% rural and 13.7% urban population still continues to live below poverty lines. This rural and urban poor population builds their non-airconditioned dwellings with primary purposes of ensuring protection from local weather elements using conventional construction designs and locally available materials. The materials used in the construction of these dwellings may not be well suited for providing thermal comfort to the inhabitants. Thermal conductivity and heat storage capacities of the envelope are two major factors that contribute to the thermal performance and energy efficiency of any buildings. The primary focus of the present numerical study is to offer an insight towards improving the thermal performance of non-air conditioned single-family dwellings located in a typical hot climate zone in India. The architectural design for the dwellings used in this work is similar to that of houses proposed under “Pradhan Mantri Awas Yojna (PMAY)” for economically weaker sections of the country. The building envelope for these houses comprise of materials with higher thermal resistant and heat storage capacity. The simulations presented herein are performed using ‘EnergyPlus’ and ‘OpenStudio’ software. The simulation results show that, both, the lower material thermal conductivity and the sequence of placement of these materials in building envelope, are critical for improving the thermal performance of building envelope and enhancing the thermal comfort for its inhabitants.

Keywords: Low-income housing, Thermal comfort, Rural housing, Energy efficiency, Materials.

1 Introduction

Rapid population growth has drastically disturbed the socio-economic balance in Indian housing sector resulting in increased number of nuclear families. According to the 2011 Report of the Technical Group on Urban Housing shortage (TG-12), Ministry of Housing and Urban Poverty Alleviation, Govt of India, almost a quarter of Indian households, specially the economically weaker sections (EWS), lack adequate housing facility (Report 2004). In recent years, Indian government has placed greater thrust in the direction of providing proper housing to people belonging to EWS of urban and rural population through the Pradhan Mantri Awas Yojna (PMAY) scheme. According to one estimate, the scheme is expected to have an investment of more than USD \$2 trillion by 2022 (Decoding 2014). Majority of these housing requirements are localized in Uttar Pradesh, Madhya Pradesh, Bihar (i.e. central India), Rajasthan, Karnataka, Andhra Pradesh, Tamil Nadu and West Bengal. Due to the additional opportunities associated with the development of supporting infrastructure, the urban part of the PMAY scheme is attracting a lot of attention from organized housing developers. The rural (Gramin) part of the scheme (PMAY-G) aims to provide “Housing for All” by building approximately 19.5 million “pucca” houses by the end of year 2022. The government provides partial financial assistance to build single unit housing through PMAY-G. Owing to the availability of limited financing, these houses are built by the local laborers with repetitive (i.e. locally available) materials and design without paying any considerations to the principles of building physics. This could severely affect the thermal performance of these houses and the overall wellbeing of the residents, including thermal comfort. Extreme dwelling interior temperatures due to local weather conditions (summer or winter) have been identified as a major factor for occupant health risk (Ormandy 2012, Wu 2007).

In this regard, several studies have been performed to examine the thermal performance of building envelope of low income housing with respect to types of dwelling and insulation materials used for construction. During a nationwide study in UK, Hong et al studied the effects of thermal retrofitting in approximately 2500 low income houses for consecutively two years. The thermal retrofitting of these low income dwellings improved the thermal comfort level among its inhabitants from 36% to 79% (Hong 2009). Mavrogianni et al further supported the positive role of thermal retrofitting in improving the thermal comfort through a simulation-base study of 3456 combinations of dwelling types and other characteristics located in London area (Mavrogianni 2012). A number of such studies to investigate the thermal performance of low-income housing envelopes for winter as well as summer have been reported across the Europe (Sakkaa 2012, Santamouris 2015, Terés-Zubiag 2013, Sunikka-Blank 2012, Boerenfijn 2018). Along the same line, several researchers have conducted in-situ studies in order to evaluate the thermal performance and indoor environmental quality for existing vernacular buildings located in different parts of India (Singh 2010, Nix 2015, Netam 2016, Sarkar 2016, Nutkiewicz 2018).

Attempts have also been made to develop novel materials systems and strategies in order to improve the thermal comfort in low income housing worldwide. Long et al investigated the effects of thermal conductivity (k) and volumetric heat storage (C_v) of materials used in wall construction in their nationwide study in China (Long 2016). It was reported that materials with high heat storage capacity and low thermal conductivity are suitable for exterior envelopes. As a result, the exterior envelope with high thermal insulation (low conductivity) and interior walls with high heat storage capacity as well as low thermal insulation provides better combination for the thermal comfort of the

inhabitants. A similar results about the effect of thermal properties of external and internal walls has been reported by Di Perna et al and Stazi et al, respectively (Di Perna 2011, Stazi 2013). Raut et al developed thermally enhanced sustainable hybrid bricks and fiber-reinforced mortar (TESH) system to regulate the temperature distribution and to reduce the energy consumption for low income houses in Thailand (Raut 2018). The simulation results provided in this study report 10.2% reduction in total energy cost with TESH system. Bhikhloo et al investigated the possible area of improvement in building envelope for low income housing in Thailand by simultaneously modifying the construction material and building features (Bhikhoo 2017). In their results, the thermal conductivity of roof material and presence of balcony to promote the natural ventilation were the primary factors regulating the internal thermal comfort. Charde et al conducted a series of detailed experiments using four test rooms with hollow brick roof, brick walls and brick static sunshade projection in Indian climatic conditions. This combination of architectural features and materials significantly has been reported to improve the thermal comfort during both summer and winter by reducing the internal temperature fluctuations (Charde 2013a, Charde 2013b, Charde 2014).

Most of the studies mentioned above emphasize on the need of increasing the thermal resistance of wall and roof systems in order to improve the thermal comfort in the house. Therefore, the work presented herein attempts to explore the possibility of enhancing the thermal comfort in these proposed Indian EWS houses located in different weather zones of the country by replacing the conventional burnt clay bricks with pervious concrete bricks for walls along with different configurations of expanded polystyrene (EPS) sheets applied on the building envelope for additional thermal insulation. The manuscript has been arranged as following: Section 2 and its subsections provide the description of methodology and basic materials parameters used in this work. Results for indoor temperature fluctuations during summer and winter seasons for modified buildings envelopes with additional insulation and sunshade for all the study locations are reported in Section 3. Finally, Section 4 presents a summary of different observations and offers few concluding remarks.

2 Methodology

2.1 Locations and building configuration

In India, the PMAY-G scheme has issued certain guidelines with respect to the plan of EWS houses and the typical construction materials to be used for all the Indian states (Pahal 2016). Therefore, majority of these EWS houses in different parts of the country are being built following the above directives using locally available conventional construction materials. Such EWS houses with conventional construction materials are taken as the “Base Case (BC)” and the corresponding house plans are shown in Figure 1a – Figure 1c whereas the corresponding floor, walls and roof section are presented in Table 1. India has been divided in to different zones from climate point of view. The present work considers the EWS housing located in four largest climate zones, namely, 1. Delhi (Semi-Arid), 2. Uttar Pradesh (Humid Sub Tropical), 3. Rajasthan (Arid or Desert) and 4. Tamil Nadu (Tropical Wet and Dry). Due to the unavailability of house plan for Delhi region in the Govt. guidelines and the physical vicinity of the Delhi and Uttar Pradesh, EWS housing in these zones are considered to share the same floor plan. The one peculiar fact about the house plans suggested in “Pahal report”, used for base cases, is that while the houses in Uttar Pradesh, Delhi and Tamil Nadu have cast-in-place concrete with brick bat roof, the houses in Rajasthan zone are suggested to have corrugated iron sheets roof (Pahal 2016).

2.2 Building envelopes and material properties

The primary objective of this work is to enhance the overall thermal resistance of envelope of the EWS houses considered in the base case. In order to achieve this objective, the materials used in the elements of house envelopes, i.e. Floor, walls and roof, are modified. The burnt clay bricks used in walls of base case envelope are replaced by pervious concrete blocks. In addition, the thermal barrier performance roof and walls is enhanced by adding different layers of EPS sheets. The configuration of the house floor remains same as the base case. Similar modifications have been made to EWS houses located in all four climate zones and have been designated as Design Envelope (DE) followed by a numeric code represent the four climate zones mention in Section 2.1. These four different design envelopes (DE) are shown in Table 2.

Thermal properties of pervious concrete bricks used here are determined by Advanced Materials and Building Energy research group, Shiv Nadar University using TPS-500 Thermal constants analyzer available at Mahindra – TERI Center of Excellence (Sharma 2019). The thermophysical properties of the all the constituent materials are reported in Table 3.

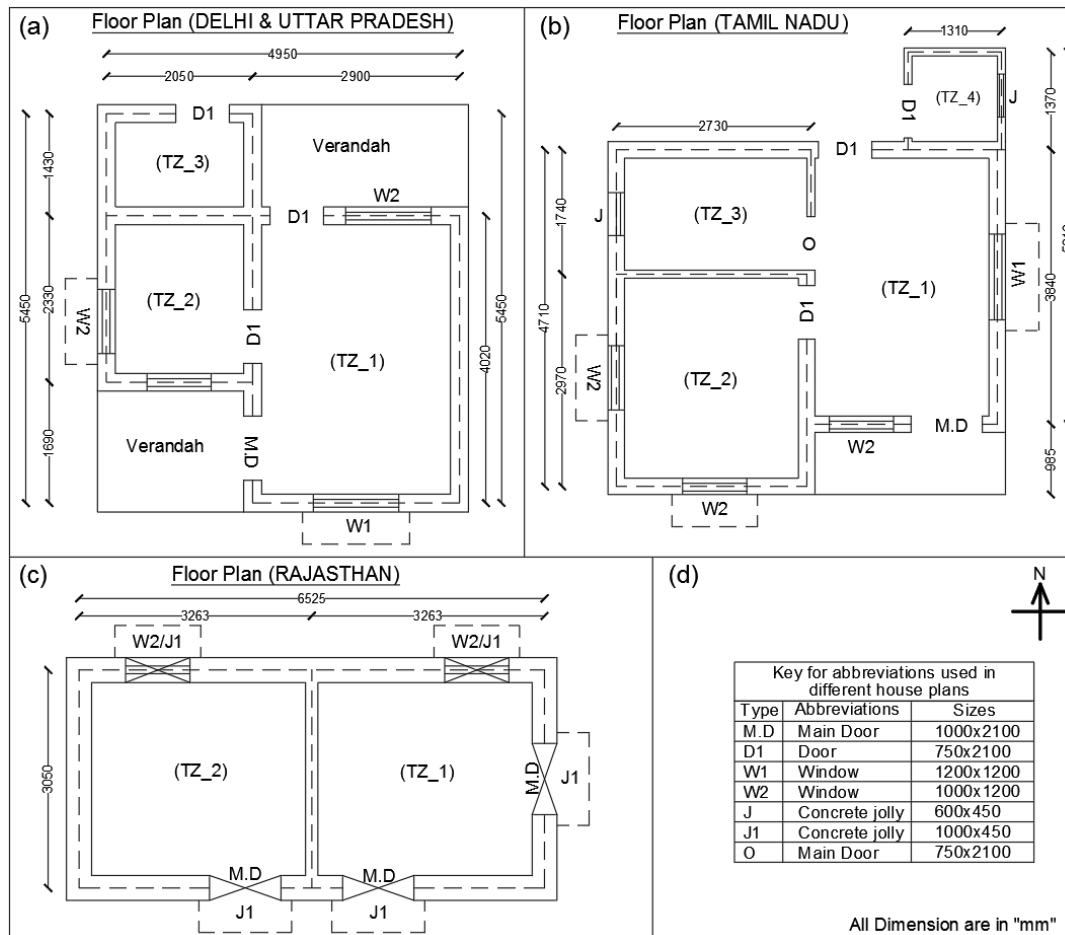


Figure 1: Representative house plans for four climate zones (Pahal 2016) (a) Delhi and Uttar Pradesh house plan (b) Tamil Nadu house plan (c) Rajasthan house plan (d) Key for the abbreviations used in different house plans

Table 1: Materials related details for Base Case (BC) house envelope suggested for different climate zones

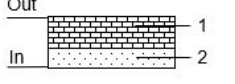
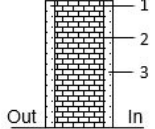
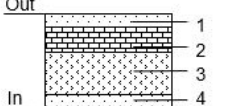
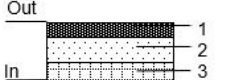
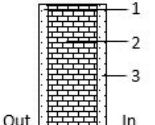
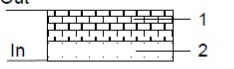
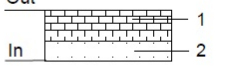
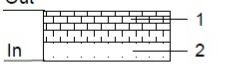
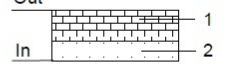
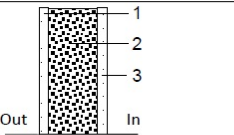
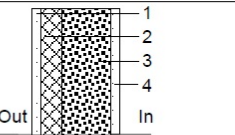
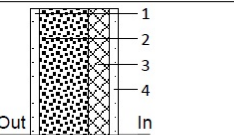
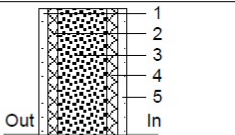
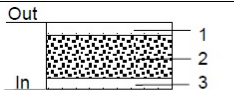
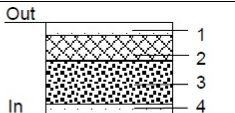
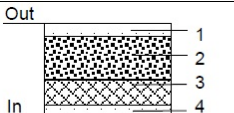
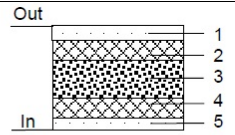
Location	Floor- Base Case (B.C)	Wall- Base Case (B.C)	Roof- Base Case (B.C)
Delhi, Uttar Pradesh & Chennai	 1. Brick Bat (75mm) 2. Cement Mortar (30mm)	 1. Cement Plaster (15mm) 2. Clay Brick (230mm) 3. Cement Plaster (15mm)	 1. Cement Mortar (30mm) 2. Brick Bat (75mm) 3. Concrete (125mm) 4. Cement Plaster (15mm)
Rajasthan	 1. Stand Stone (25mm) 2. Cement Mortar (30mm) 3. Kotta Stone (25mm)	 1. Cement Plaster (15mm) 2. Earth Brick (230mm) 3. Cement Plaster (15mm)	 1. Corrugated galvanized iron (CGI) (1mm)

Table 2: Materials related details for modified design envelopes (DE) suggested for different climate zones

Floor (DE_1)	Floor (DE_2)	Floor (DE_3)	Floor (DE_4)
 1. Brick Bat (75mm) 2. Cement Mortar (30mm)	 1. Brick Bat (75mm) 2. Cement Mortar (30mm)	 1. Brick Bat (75mm) 2. Cement Mortar (30mm)	 1. Brick Bat (75mm) 2. Cement Mortar (30mm)
Wall (DE_1)	Wall (DE_2)	Wall (DE_3)	Wall (DE_4)
 1. Cement Plaster (15mm) 2. Pervious concrete block (230mm) 3. EPS (40mm) 4. Cement Plaster (15mm)	 1. Cement Plaster (15mm) 2. Pervious concrete block (230mm) 3. EPS (40mm) 4. Cement Plaster (15mm)	 1. Cement Plaster (15mm) 2. Pervious concrete block (230mm) 3. EPS (40mm) 4. Cement Plaster (15mm)	 1. Cement Plaster (15mm) 2. EPS (20mm) 3. Pervious concrete block (230mm) 4. EPS (20mm) 5. Cement Plaster (15mm)
Roof (DE_1)	Roof (DE_2)	Roof (DE_3)	Roof (DE_4)
 1. Cement Mortar (30mm) 2. Pervious concrete block (125mm) 3. Cement Plaster (15mm)	 1. Cement Mortar (30mm) 2. EPS (75mm) 3. Pervious concrete block (125mm) 4. Cement Plaster (15mm)	 1. Cement Mortar (30mm) 2. Pervious concrete block (125mm) 3. EPS (75mm) 4. Cement Plaster (15mm)	 1. Cement Mortar (30mm) 2. EPS (40mm) 3. Pervious concrete block (125mm) 4. EPS (40mm) 5. Cement Plaster (15mm)

2.3 EnergyPlus

The energy simulation for these dwellings is carried out using OpenStudio and EnergyPlus v9.1 simulation engine. The Energy Plus program was developed by the US Department of Energy (US DOE). It is an effective tool for whole building energy simulation. Each building has been divided in to several thermal zone as reported in Figures 1a, 1b and 1c. The building external surfaces were exposed to outdoor climatic conditions except for the floor. The heat transfer between floors to the ground is carried out using “Groundheat transfer:Slab” parameter available in the EnergyPlus program. In this study, the building energy simulations were carried out using the ISHRAE standard weather files for all four Indian cities.

Table 3: Thermo-physical properties of the construction materials (SP41 1995, Sarri 2019, BEE 2017)

Materials	Thermal Conductivity (W/m-k)	Specific heat capacity (J/kg-k)	Density (kg/m ³)
Cement plaster	0.721	840	1762
Clay Brick	1.076	1078	1820
Concrete	1.7	840	2500
Cement mortar	0.719	920	1648
Earth Brick	0.75	880	1731
Kotta stone	1.8	840	2420
CGI sheet	61.06	500	7520
Pervious block	0.223	970	1920
Expanded polystyrene (EPS)	0.038	1340	16

3 Results and discussion

3.1 Indoor air temperature fluctuation in summer

In Indian dwellings, the thermal zones oriented along East – West directions get exposed to direct solar radiation for maximum amount of time during a diurnal cycle. Due to the maximum solar exposure, the East – West oriented thermal zones are critical from the envelope’s thermal performance point of view. Therefore, Figure 2a – Figure 2d report the indoor air temperature fluctuations in a diurnal cycle during summer for East – West thermal zones i.e. thermal zone 1 (TZ-1), in each of these building envelopes located in different climate zones, namely, Delhi (DH_TZ-1), Uttar Pradesh (UP_TZ-1), Rajasthan (RA_TZ-1) and Tamil Nadu (TN_TZ-1).

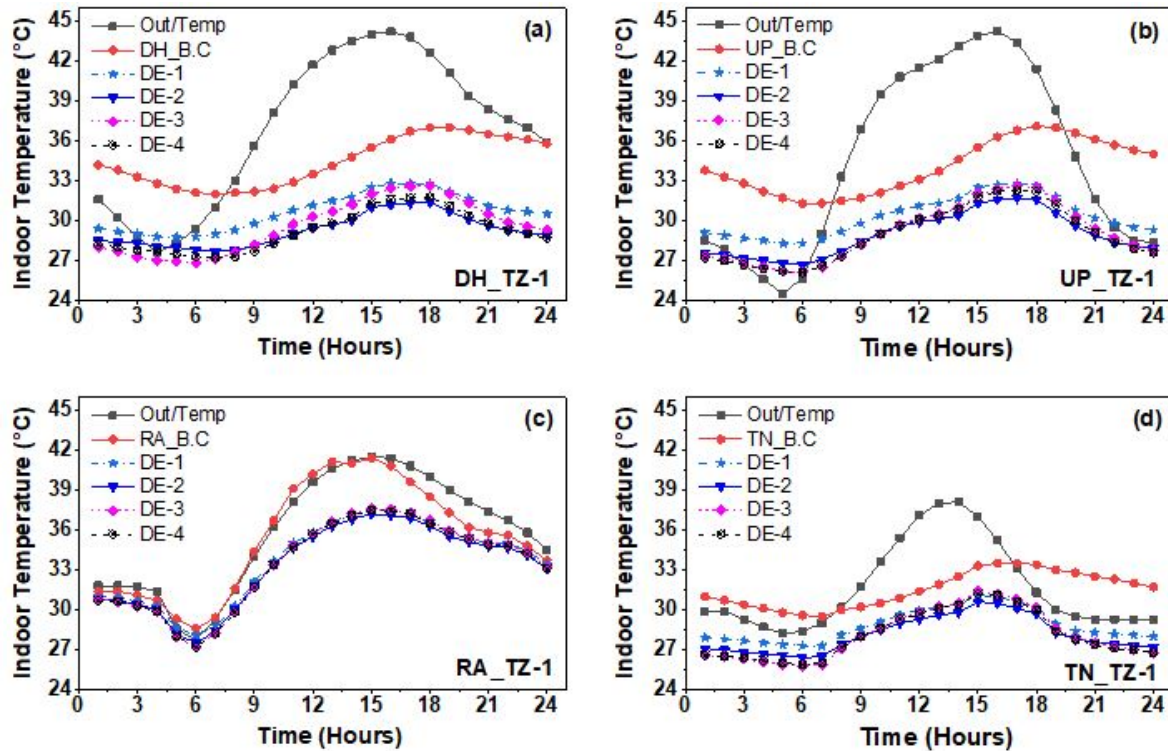


Figure 2: Summer indoor air temperature fluctuation in thermal zone 1 (TZ-1) of different building envelopes located in four climate zones (a) Delhi (DH_TZ-1) (b) Uttar Pradesh (UP_TZ-1) (c) Rajasthan (RA_TZ-1) (d) Tamil Nadu (TN_TZ-1)

As the day progresses, the building envelope starts heating up due to the storage of absorbed solar heat. The heat energy absorbed in the building envelope gets transmitted to the indoor ambience through convection and raises the indoor temperature. However, the total amount of heat transferred from the building envelope to the indoor ambience depends upon the overall thermal conductivity (k) and specific heat capacity (C_v) of the building envelope. Therefore, among all the material thermophysical properties, thermal conductivity (k) and specific heat capacity (C_v) are the two significant parameters in order to improve the thermal performance of the dwellings. The higher k value increases the amount of heat transferred through conduction from outer to inner surface of the envelope during the day and the high C_v value facilitates the enhanced heat storage in the envelope.

The materials used in base case envelopes possess relatively higher k and C_v values as compared to the material system used for the design envelopes. The base case envelopes yield inferior thermal performance and report higher inner air temperature. The material system, pervious concrete bricks combined with insulating EPS sheets, used in the construction of design envelopes possess lower combined k and C_v values and act as a thermal barrier which results in reduced interior temperature as reported in Figure 2a – Figure 2d for all the four climatic zones. The reduced combined C_v of the design envelope also reduces the inside thermal fluctuations as reported in Table 4. After combining the results reported in Figures 2a – 2d and Table 4, it is seen that design envelopes DE-2 consistently offers better thermal performance among all the design envelopes for each climate zone during the daytime, i.e. after 9:00 AM.

Table 4: Comparison of Indoor air temperature comparison between base case and the design envelopes for all the four cities for the summer season

Location	Clock Time	Outside Temp, °C	Indoor Air Temperature, °C				
			Base case	DE-1	DE-2	DE-3	DE-4
Delhi	12:00	41.7	33.5	31.2	29.5	30.3	30.1
	17:00	43.8	36.7	32.8	31.3	32.6	31.9
Uttar Pradesh	12:00	41.5	33.1	31.1	29.7	30.5	30.1
	17:00	43.4	36.8	32.8	31.7	32.6	32.3
Rajasthan	12:00	39.6	40.5	35.8	35.5	35.9	35.9
	17:00	40.8	40.3	37.2	36.8	37.4	37.3
Tamil Nadu	12:00	37.1	31.4	30	29.3	29.8	29.7
	17:00	33.1	33.5	30.6	30.1	30.8	30.6

3.2 Indoor air temperature fluctuation in winter

Due to the relative movement of sun during winter, roof and fenestrations (window, door, etc.) are the major sources for heat for the interior of the Indian dwellings. During winter, roof receives the higher amount of direct solar radiation as compared to the walls. The indirect, reflected and diffused, solar radiation is the primary source of solar energy for windows and other openings and heats up the building envelope during the daytime.

Figure 3a – Figure 3d show the fluctuation in indoor air temperature in thermal zone 1 (TZ-1) for base case and design envelopes during the winter for the buildings located in all four climate zones.

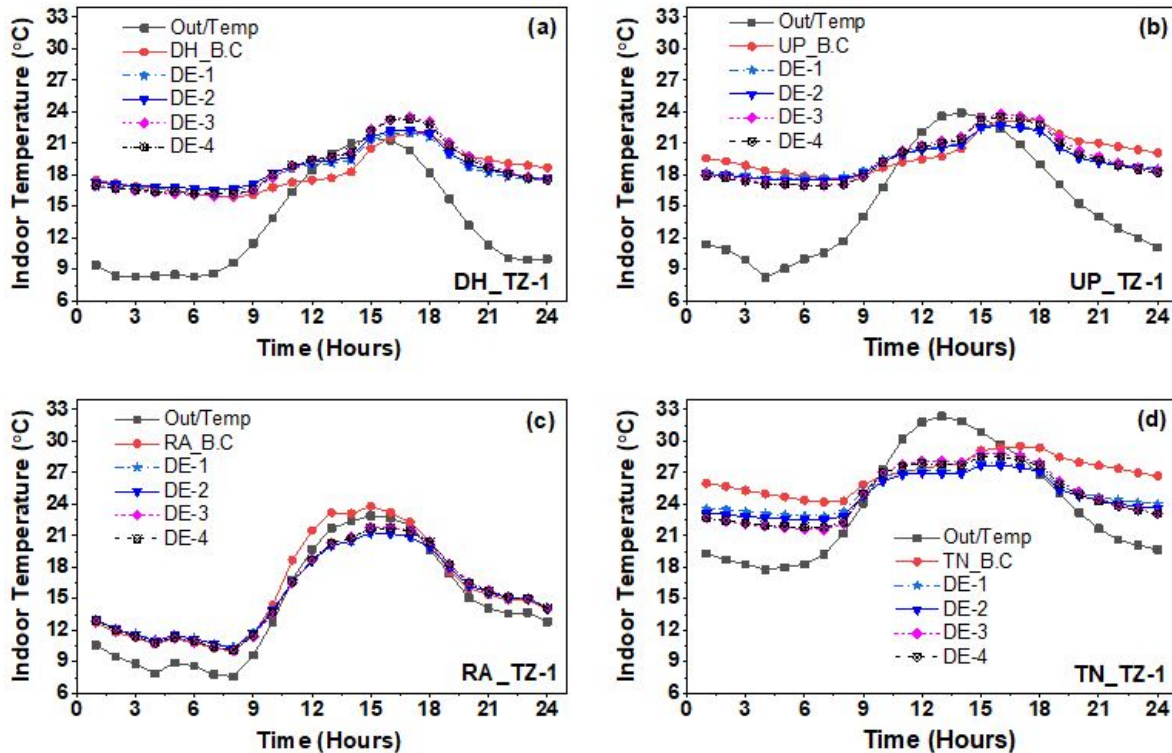


Figure 3: Winter indoor air temperature fluctuation in thermal zone 1 (TZ-1) of different building envelopes located in four climate zones (a) Delhi (DH_TZ-1) (b) Uttar Pradesh (UP_TZ-1) (c) Rajasthan (RA_TZ-1) (d) Tamil Nadu (TN_TZ-1)

During, the winter all the building envelopes protect well against the extreme weather temperature. However, not all the design envelopes perform alike in different climate zones. Figure 3a – Figure 3d show that the in case of climate zones Delhi and Uttar Pradesh, the daytime thermal performance of all the design envelopes is better than the base case and offer respite from the external cold climate. In particular, DE-3 and DE-4 perform moderately better than DE-1 and DE-2. According to Govt guidelines (Pahal 2016), the EWS houses have corrugated galvanized iron sheets as roof, supported on concrete walls. The highly conductive steel sheet roof facilitates fast heat exchange between the outdoor environment and internal ambience and therefore the internal air temperature for all the envelopes, including the base case, becomes comparable to outside temperature. Still, the thermal performance of all the design envelopes compares moderately better than the base case. In case of Tamil Nadu, the diurnal external temperature varies between average 18oC – 32oC where it feels like mild summer, and not like harsh winter as experienced in Delhi and Uttar Pradesh climate zones. In this case, all four design envelopes perform better than the base case. Their thermal performances are more pronounced as compared to the base case during the early morning and late evening hours as shown in Figure 3d. Table 4 provides a summary of indoor air temperatures at specific daytime hours for all the design envelopes located in these four climate zones.

Table 5: Indoor air temperature (°C) comparison for all the envelope cases with outdoor temperature for all the four cities for the winter season

Location	Clock Time	Outside Temp, °C	Indoor Air Temperature, °C				
			Base case	DE-1	DE-2	DE-3	DE-4
Delhi	12:00	18.5	17.5	18.9	19.2	19.4	19.4
	17:00	20.3	22	22	22.3	23.5	23.3
Uttar Pradesh	12:00	22.1	19.5	20.5	20.4	20.8	20.7
	17:00	20.9	23.2	22.6	22.5	23.6	23.3
Rajasthan	12:00	19.7	21.2	18.7	18.6	18.7	18.7
	17:00	22	22.8	20.9	20.9	21.5	21.4
Tamil Nadu	12:00	31.8	27.4	27.3	27	28.1	27.9
	17:00	28.5	29.5	27.7	27.5	28.5	28.2

4 Materials cost analysis for houses located in different parts of the country

Finally, Table 6 and Table 7 present the approximate cost of materials consumed in base case and houses with optimized design envelopes discussed in Sections 3.1 and 3.2. In order to maintain the uniformity, cost of all the raw materials has been adopted from the basic rate list of materials provided by the Central Public Works Department (CPWD), Govt. Of India (CPWD 2019). In case of material items are not available in the above list, the rate list issued by the respective state governments has been adopted (PWD 2019). Further, due to high variability in the local rates, the labor cost incurred in building the house has not been included in this analysis.

Table 6: Bill of Quantities for the Material: Conventional Envelope Case (CPWD 2019)

S. No	Description	Unit	Rate (INR)	Delhi and Uttar Pradesh		Rajasthan		Tamil Nadu	
				Quantity	Amount	Quantity	Amount	Quantity	Amount
1	Roof Concrete (M25 grade)								
	Fine Aggregate	m ³	900	1.12	1008	-	-	1.01	909
	Coarse Aggregate	m ³	1350	2.32	3132	-	-	2.1	2835
	Cement	Kg	4.94	1912	9445	-	-	1726	8526
2	Bricks	Nos	5	6300	31500	5700	28500	6100	30500
3	Cement Plaster	m ²	137	139	19043	104	14248	131	17947
4	Cement Mortar	m ³	3528	2	7056	1	3528	1.5	5292
5	Brick Bat	m ³	450	4	1800	3	1350	3.52	1584
6	Cocurated Galvanized Iron Sheet (1mm)	m ²	822	-	-	25	20550	-	-
7	Kotta Stone	m ³	284	-	-	0.50	142	-	-
		Total Cost (INR)			72984		68318		67593

Table 7: Bill of Quantities for the Material: Designed Envelopes Case (CPWD 2019, PWD 2019)

S. No	Description	Unit	Rate (INR)	Delhi and Uttar Pradesh		Rajasthan		Tamil Nadu	
				Quantity	Amount	Quantity	Amount	Quantity	Amount
1	Pervious Concrete Roof								
	Fine Aggregate	m ³	900	0.5	450	0.3	270	0.35	315
	Coarse Aggregate	m ³	1350	2.1	2835	1.6	2160	1.89	2552
	Cement	Kg	4.94	1152	5691	873	4313	1040	5138
	Fly Ash (20%)	Kg	0.01	288	3	219	2	260	3
2	Pervious Concrete Blocks								
	Fine Aggregate	m ³	900	1.1	990	1	900	0.98	882
	Coarse Aggregate	m ³	1350	6.3	8505	5.7	7695	6.1	8235
	Cement	Kg	4.94	3465	17117	3135	15487	3355	16574
	Fly Ash (20%)	Kg	0.01	882	9	798	8	854	9
	Labour cost for brick making, @15% of materials cost	--	--	--	3993	--	3613	--	3855
3	Cement Plaster	m ²	137	139	19043	104	14248	131	17947
4	Cement Mortar	m ³	3528	2	7056	1	3528	1.5	5292
5	Brick Bat	m ³	450	4	1800	3	1350	3.52	1584
6	Expanded Polystyrene Sheet (40mm)	Kg	180	35	6300	30	5400	34	6120
7	Expanded Polystyrene Sheet (75mm)	Kg	300	36	10800	28	8400	33	9900
		Total Cost (INR)			84592		67374		78404

According to these tables, the cost of house located in Delhi/Uttar Pradesh and Tamil Nadu with optimized design envelope is approx. 16% higher than the conventional case. However for Rajasthan, the materials cost for both the houses are comparable because in this case the expensive corrugated steel sheet roof of base case is replaced by the less expensive alternative in the house with design envelope.

5 Epilogue

The low income dwellings often provide inferior thermal performance due to use of locally available materials for the construction of these buildings. In this numerical study, pervious concrete block is chosen replace the conventional materials such as burnt clay bricks and concrete to improve the building thermal performance without affecting its structural integrity. Along with pervious concrete blocks, EPS sheets are provided on walls and roof to reinforce the thermal resistance of the building envelope. The presence of EPS sheets reduces the heat influx at the initial stage of temperature rise. Based on the results obtained in these numerical experiments, following observations can be made:

- During summer, design envelope DE-2 with EPS sheets on the outer side of the building envelope provides better thermal performance with maximum temperature reduction in indoor air temperature equal to 5.4°C in Delhi, 4.9°C in Uttar Pradesh, 4.7°C in Rajasthan and 3.4°C in Tamil Nadu as compared to the base case (BC) envelopes.
- In these low rise dwellings, the selection of materials for roof slab and walls require most attention while designing these envelopes. Among all the elements of the envelope, roof of the house gets longest exposure to the direct solar radiation in case of these low rise dwellings.
- The extra thermal insulation, e.g. EPS sheets in the current study, help in improving the indoor thermal environment during summer as well as winter.
- The introduction of EPS sheets in the optimized design envelope increases the total materials cost by 16% in Delhi/Uttar Pradesh and Tamil Nadu. In case of Rajasthan, the materials cost for the base case and house with optimized design envelope remain comparable due to the replacement of expensive corrugated steel roof sheets.

(1)

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EXPLORING ENVIRONMENTAL ADAPTABILITY OF TRADITIONAL MUD HOUSE, CHITTAGONG, BANGLADESH

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Abstract: Geo-climatic factors encourage people to develop different settlement strategies. House being the emblem of shelter and safety for human existence, have to adapt to the natural forces and unusual environmental behavior. That's why during the construction of a house, geo-climatic factors are given the key consideration particularly among those groups of people who have been living in close association with nature for years. Owing to adapt to the geo-climatic factors people have genetically been practicing different types of housing style and technology that reflects environmental concern resulting in precise characteristics of the house. In terms of the formation and developments of human settlement, Chittagong possesses a rich tradition with its diversified land of both coastal, plain land and hilly areas. Indigenous people of this area have developed their own housing form and technology which is eco-adaptive, environmentally sound and self-sustaining. This paper attempts to explore traditional mud houses practiced in Banshkhali Upazila, Chittagong through experimental research. Hope this study can help people to develop an understanding of traditional mud house design by investigating the traditional mud house as a suitable form of architecture of this region.

Keyword: Environmental adaptability; Traditional mud house; Tropical climate.

1 Introduction

People who live close association of nature for years develop their own knowledge of construction technique resulting in the precise character of traditional architecture coupled with culturally defined values and norms of a particular region (Salman 2018). The wisdom of these traditional construction techniques is achieved through trial and error process and handed down through the generations which have been ignored in a deeper understanding of human existence (Salman 2018, Fernando 2018). The topographical configuration of Chittagong consists of the coastal areas, flat land, and hilly area. That's why Chittagong possesses a wide variety of adaptive traditional architecture based on the traditional knowledge concerning topography and climate of this region (Roy 2015). Mudhouse is one such variety. Balancing the relationship between these natural elements and cultural traits, traditional mud houses of Chittagong created their own indigenous eco-adaptive, environmentally sound and self-sustaining traditional housing technology (Polin 2018, Pal 2015). These traditional mud houses cope with the inimical environment. It's a highly important and experimented archetype that exists over the years from generation to generation. But the rapid growth of science and technological expansion has barely left any space for this traditional knowledge. A serious and methodical study is required to carry out to uncover this housing technology. Unfortunately, no such study has yet been conducted which results a serious lack of environmental data regarding this traditional mud housing technology in this region. Since the expertise of construction workers, knowledge of housing construction and the information about construction materials and environmental evaluation are not yet recorded, so immediate documentation of this unknown traditional knowledge prior to it disappears should be given utmost importance. The thrust of this paper wants to assess the relationship between housing patterns and climatic factors to understand adaptive and coping strategies of mud houses of Chittagong, Bangladesh.

2 Problem Statement

The traditional houses of Chittagong are adaptive in nature and developed with balancing relations between natural elements and cultural traits. Local people use locally available rural resources (mud, timber, straw, etc.) as raw materials for their housing (Fernando 2018, Polin 2018, Pal 2015). Insufficiently, few methodical research has yet been conducted to unearth this local technology like 'Mud House', and document the local skill, knowledge, as well as traditional environmental features of conventional housing practice specifically in South Asian sub-continent. Therefore, serious lack of ethnographic data regarding eco-adaptive issues has been found on traditional housing technology in this region. Since the skill of construction workers, the technology of housing construction and the knowledge about local construction materials and indoor environmental data are not recorded properly, it is imperative to urgently document this hidden transcript of knowledge before it dissolves. Many local housing technologies have been established by the inhabitants that retain them least-affected but there is a serious shortage to conserve proper documentation of eco-adaptive, environmentally sound and self-sustaining traditional housing technology in this region.

3 Objectives of the Study

The main purpose of this study is to evaluate the traditional and environmental performances of Mudhouse with respect to local climatic considerations. Another aim of this research is to develop an outline of an indoor environmental database of a local Mudhouse in the context of humid- tropics.

4 Scope and Limitation

The research work presented in this study concentrates on indoor performance evaluation of Mudhouse in the Chittagong region, Bangladesh. Four elements of the Mudhouse envelope such as walls, windows, floors, and roofs have been considered for the research study. Characteristics of local building materials and their sectional layout have been studied to determine their thermal performance. Some degree of uncertainty has been presented in the data collections during field investigations due to leakage of airflow between the roof and the envelope. However, given the limited time and scope of the study, this research has been concentrated on the indoor thermal issues only. The performance of dwellers and their productivity regarding active and passive ventilation systems, heating, cooling, lighting issues, acoustics, insulation, safety, and security are beyond the scope of this research.

5 Climatic Context:

The climate of Bangladesh can be defined as a warm-humid climate, based on the widely used climate classification of tropical climate (Koenigsberger 1973). This character of climate can be drawn from the location of Bangladesh in the world map. The country with an area of about 147,570 square kilometres (km²), is located in the tropics between 20°38'N north latitudes and 88°01'E and 92°41'E east longitudes in southern part of Asia, and is bounded by India on the west, the north, and northeast, and by Myanmar on the southeast (ADB et al, 2006). Chittagong is one of the mega and port cities in Bangladesh located south-eastern part. The climate is tropical in Chittagong. Chittagong has significant rainfall most months, with a short dry season. The average temperature in Chittagong is 25.7°C (Fig. 1). About 2794 mm of precipitation falls annually. The driest month is January. There is 6mm of precipitation in January. In July, the precipitation reaches its peak, with an average of 743 mm. With an average of 28.5°C, May is the warmest month. At 19.9°C on average, January is the coldest month of the year. The precipitation varies 737 mm between the driest month and the wettest month. Chittagong lies at 22°22'0"N 91°48'0"E. It straddles the coastal foothills of the Chittagong Hill Tracts in south-eastern Bangladesh. The variation in annual temperature is around 8.6°C. The environment variables directly affecting thermal comfort are temperature, humidity, solar radiation, and air movement; these are the four constituents of the climate that are most important for the purposes of building design in Chittagong. The following review of these climate factors is based on various investigations and on data collected from meteorological stations of the city (BMD 2018).

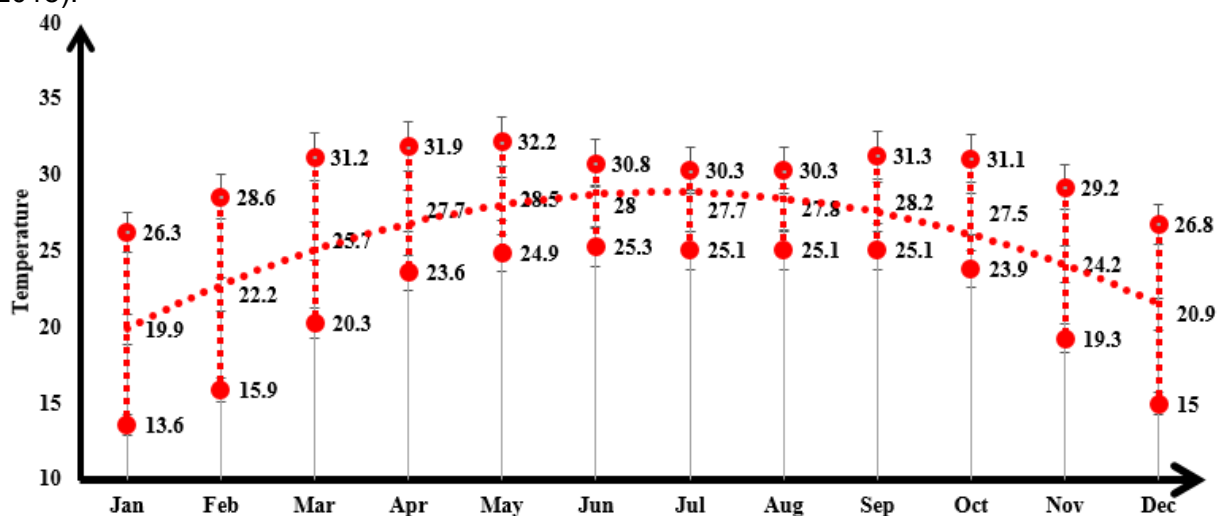


Figure 1: Climate graph, Chittagong, Bangladesh (Source: www.climatemps.com)

6 Research Methodology

Field observations, environmental data monitoring, and literature reviews have been conducted in this specific research. Data loggers (HOBO ware Pro. U30) with smart sensors and thermal monitoring tools (Thermal Imaging Camera, Thermo Hydrometer and Laser Non-Contact Thermometer) were used at the midpoint of the mud house floor level to measure day-long environmental data of temperature, oC (dry bulb), humidity, RH%, wind - gust flow, ms-1 and carbon dioxide to study the indoor environmental condition of the typical Mud house of Chittagong region, Bangladesh. Climate data was collected with the help of Data Loggers (HOBO ware Pro. U30) and sensors for a day (24 Hours) (Cunha 2015). Data was collected at two different heights (first floor and second floor) (Fig. 2), firstly at 750mm above (from the ground) which is the minimum height of working plane generally used in residential space in living area and secondly at 3050 mm above which is the minimum ceiling height of a production space. Observations on environmental factors made during the fieldwork have been categorized into groups. Some factors relate directly to thermal behavior, such as 'Indoor Air Temperature', 'Globe Temperature' and 'Surface Temperature'. These factors are directly influenced by the Mudhouse envelope. Finally, the qualitative approach allows a better understanding of the occupants' experiences of the indoor environmental quality in Mud dwellings that can be used in producing local housing design guidelines for the tropics.

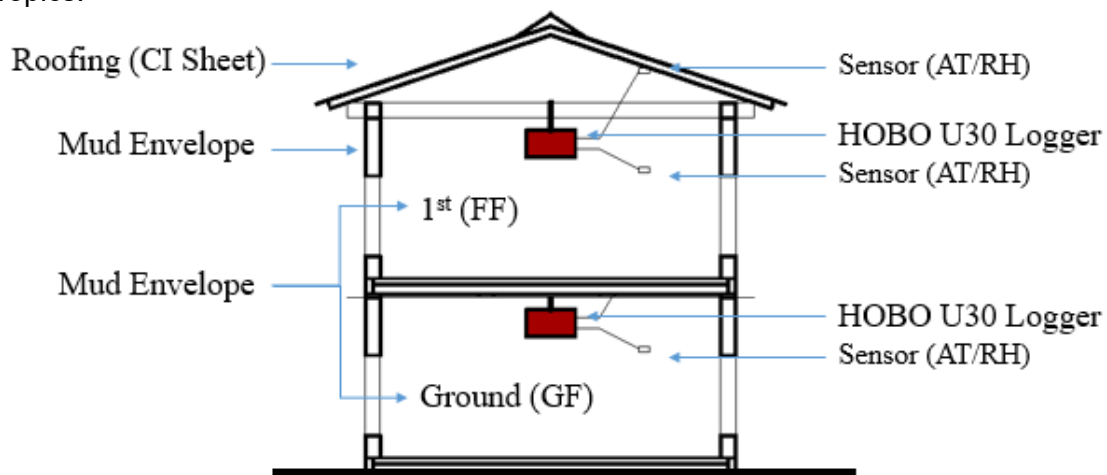


Figure 2: Environmental data monitoring system of Mud house

7 Field Observation and Discussion

Settlement Pattern & Climatic Adaptability

The settlement pattern of Chittagong varies depending on the topography and landscape of that area (Roy 2015, Das 2007). During field survey mainly two types of settlement: elongated-linear and scattered are marked in the study area. The houses of elongated-linear types are mainly found near the coastal belt and plain area near the dam and built on a high plinth above the flood level. Generally in these types of settlements, each and every house has the front space used as courtyard and backspace as the backyard. Backyard serves as the private space for the women of the community. The pond is placed at the backyard which serves as a water source for domestic chores. Every 2-3 family has its own pond. The toilet is placed in one corner of the backyard. The front yard has functional utility for husking and drying of paddy, drying of clothes, etc. But the use of this space is gradually being decreased under the pressure of population growth and technological advancement. As a result, many post-harvest works are being performed.

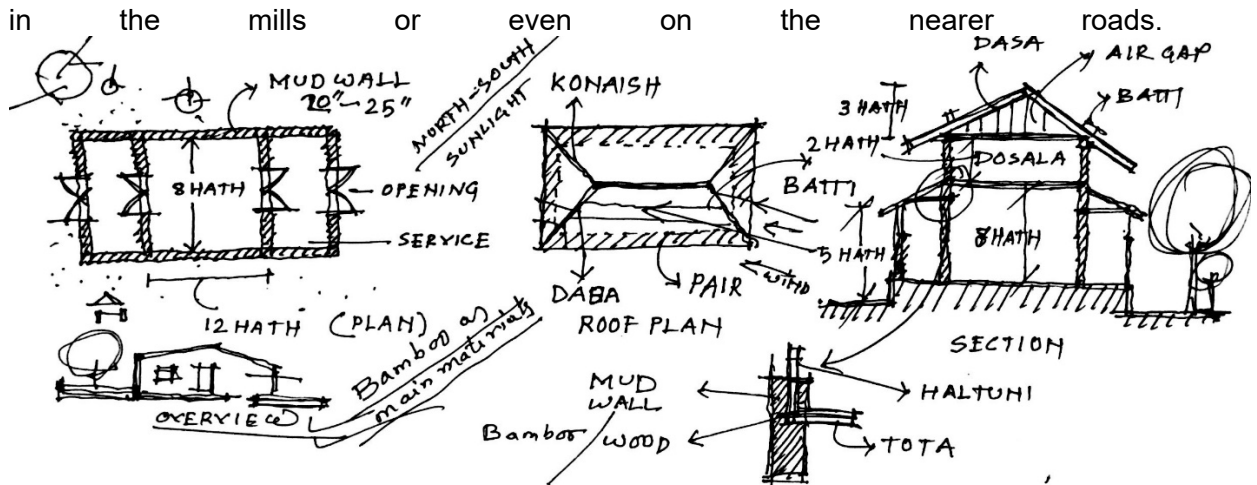


Figure 3: Traditional house pattern and lifestyle (surveyed)

Household and other farm-related functions, recreational and community space, for better air circulation, etc. are among the other manifold uses of the front yard. Cattle shed are placed at one corner of this front yard. The whole community (para) is surrounded by 'gor' (manmade channel) at the backyard which acts as a water reservoir during the flood and protects the community (para) from becoming flooded. Another major function of these 'gor' (channel) is that it protects the community (para) from the intrusion of the thief. Earth obtained from the excavation work of this pond/channel is used to raise the plinth above the flood plains demarcating it from the surrounding agricultural land. The height of the plinth varies from place to place. Scattered settlements are mainly found in hilly areas of Chittagong having houses with a shallow plinth for demarcating the house from the rest of the land. This also helps to protect it from the surface runoff. There is no backyard as the backspace is a steep slope for protection purposes. The front yard has a similar function as the front yard of the elongated-linear settlement. Spring is the main source of water in this settlement. It may be noted here that in rural Chittagong hand measurements are basically used by local builders. The size and layout of a rural house is determined by 'bandh' (length width = 'Bandh' in hand unit or 'hath'). There is a prejudice that the 'Bandh' must be an odd number which commonly varies from 13 'hath' to 27 'hath' (1 'hath'=0.45 m). Besides 'hath' there are other traditional units of measurement like 'Bighat' (half of a 'hath') and 'angul' (width of a finger). These are used in more detailed measurements (Fig. 04).

Height of the plinth varies in different regions within $\frac{1}{2}$ 'hath' (or 1'Bighat') to $2\frac{1}{2}$ 'hath'.
Height of walls varies from $4\frac{1}{2}$ 'hath' to 8 'hath'.

Anguli (width of 3 fingers) = 1 Girah

8 Girah = 1 Hath (elbow to the end of the middle finger, approximately 18")

$\frac{5}{6}$ Hath = One Kathi

20 Kathi = One Pand

20 Pand = One Begah

1 Mudum = 15" / 0.375 m, 1 Hath = 18" / 0.45 m, 1 Biew=3.5 Hath/ 1.58 m

8 Indoor Environmental Adaptability

For the research purpose, air temperature (ATOC), relative humidity (RH%), wind speed (ms⁻¹) and solar radiation (Wm⁻²) have been considered as the indoor environment of the test Mud house depends on certain external factors, where envelope materials and construction system can play an imperative role. The significant findings of temperature and humidity data recorded from field investigation for the test spaces with locally available construction techniques are described below. Here the thermal Images are showing the surface temperature difference between a lower and upper portion of the mud envelope of examining Mudhouse. Experimental thermal Images are showing that during the day time surface temperatures are not the same for the whole surface of mud wall and pitch CI sheet (Fig. 4).

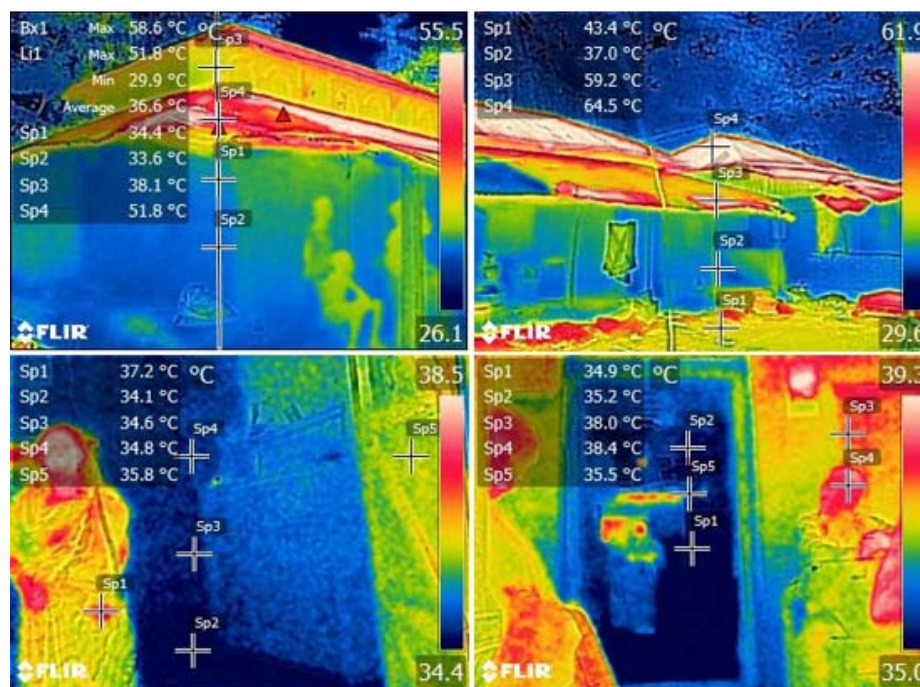


Figure 4: Thermal images showing the surface temperature of examined Mud house

It is noticed that the lower portion of the mud wall is less tempered than the upper portion of that wall. Fig. 5 is showing that in the peak working hour during day time the indoor heat increased and the maximum temperature found 35.8°C when the outdoor temperature range was (39.29-33.3)°C. In the peak hours, when space fills with the users, the level of indoor thermal ranges was high than the off period. The indoor temperature was in a higher condition 34.94°C- 31.77°C for GF and 42.33°C- 35.31°C for FF in the peak working period (all fan switched off) than the outdoor temperature during

the peak period because of internal heat gains factors and sudden drop of temperature due to sudden cloud in the sky and rain. The indoor temperature (Fig. 5) was in a higher regime during the peak hours because of internal heat gains factors and the maximum range of indoor temperature was 34.94°C (GF) and 42.33°C (FF). In the after-hours, when space closes, the level of temperature became lower and humidity grew higher. Time lag happened due to trapped heat in indoor space. According to the logged data, the maximum exterior surface temperature during the field investigation was recorded at 35.8°C. The situation will be worse if the airflow is introduced to achieve thermal comfort. The minimum exterior wall surface temperature was recorded as 26.91°C (near about the comfort range 26°C) and generating a difference of about max 2.19°C. The time lag between daily maximum and minimum temperature varies between 4.91°C to 5.12°C.

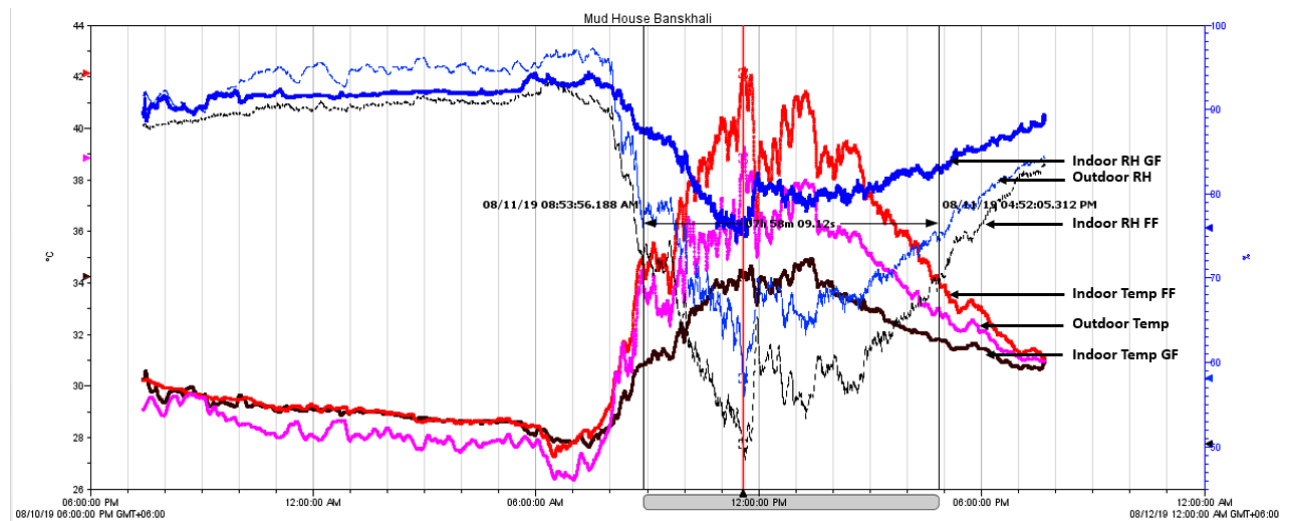


Figure 5. Comparison of indoor-outdoor thermal profile of Mud house

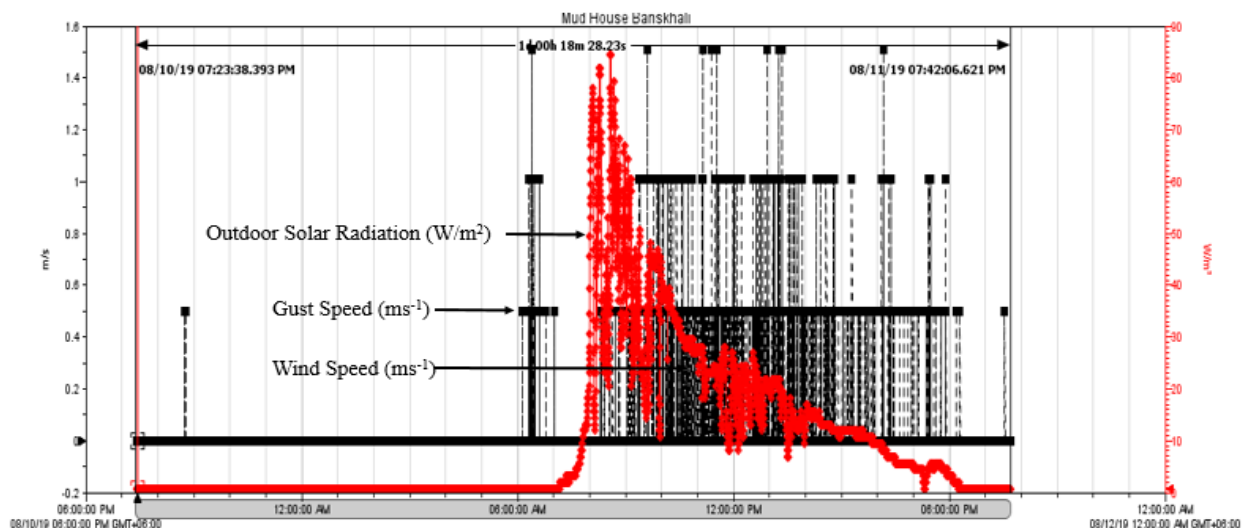


Figure 6: Comparison of indoor solar radiation, wind and gust profile of Mud house

A warm exterior wall increases the indoor temperature of the room below by convection and radiation process; therefore it is a significant factor to be considered. Moreover, focusing only on temperature and humidity adaptability, it can be experimental that the temperature increases exponentially after 11 a.m. and decreases after 6 or 7 p.m.

Plotting the meteorological data of the surveyed dates with the temperature records of data loggers data; Fig. 5 shows that the temperature inside the spaces is trapped and higher than the meteorological data with a “Time Lag”. The diurnal difference in maximum and minimum temperature ranges between 7.1°C to 13.12°C. Time lag varies between 6 to 7 hours. Fig. 6 indicates the internal solar radiation, wind and gust speed whole day scenario of the examined indoor space.

The survey found that most of the users are suffering from cold, cough and nausea diseases in the winter season in this mud house if not properly maintained. According to their data, most people living in homes suffer from eye irritation due to less sunlight during the day. A headache, blood pressure increased, weakness is the common health symptoms for the users. Dusty, stuffy air, poor ventilation, too dry and low daylighting is a common phenomenon observed from the questionnaire survey and known to be the most users. TEMTOP LKC-1000S+ air quality detector (Calautit 2017) has been used to measure PM_{2.5}/PM₁₀ and air quality index (AQI) in this study. From the data monitoring, it was found that in average indoor AQI fractions are very much higher (almost 2-3 times) than the normal range according to the Department of Environment (DoE), Bangladesh. It was also found that in the kitchen while cooking indoor air quality became very poor within 15-20 min which indicated a ‘Very Unhealthy’ condition for the dwellers. According to the health impact, it may cause breathing discomfort to people on prolonged exposure, and discomfort to people with heart disease.

9 Conclusion

This evaluation provided a detailed assessment of the day-long indoor thermal performance of a typical Mudhouse with respect to human comfort criteria and occupant responses. The major observations of this study are that different envelope materials have different surface temperature scenario and ‘Time lag’ of a mud wall (maximum and minimum) temperature varies between 4.91°C to 5.12°C in during the day time surface temperatures are not same for the whole surface of mud wall and pitch CI sheet. Current analysis and studies have been developed with a simplified model based on real-time applications according to field monitoring, scheduling, comfort criteria, and indoor control strategies. These models can be further extended and developed to integrate uncertainty due to climate forecasts and other control algorithms.

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COMPUTER AIDED ANALYSIS TO SELECT OPTIMAL RURAL HOUSING TECHNIQUE FOR RURAL AREAS OF ASSAM

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Abstract: *The accurate decision making about the selection of optimal housing technique is a very sensitive issue. It depends totally on the ranking of the techniques from a list of possible alternatives available in the construction engineering. The different opinions put forwarded by the experts relating the ranking process, which make the problem more complicated. The field of multi-criteria decision making is now mature, with several well-developed methodologies. In this paper, a relatively new concept of multiple criteria decision-making procedure popularly called analytical hierarchy process (AHP) under multiple expert systems is suggested. A computer programming in C++ is developed to demonstrate the potential application of the procedure with the help of a case study regarding the ranking of different housing techniques. For the sake of simplicity in data collection and its analysis for information recovery, the ranking problem was framed under four criteria, ten experts and four possible alternatives. The final ranking value of alternatives was computed by finding the average priority value of criteria and alternative priority value under each criterion. The results obtained were validated with the help of popularity index value based on real life survey. The study aims at providing an analysis of rural housing technique in Assam so that it may provide a base for designing and redesigning the houses in more scientific and optimal manner to give a better living environment to the rural people of Assam. In order to evaluate the applicability of the proposed methodology, a case study relating the ranking of different housing techniques were tested under 4 criteria, 4 alternatives and 10 groups of experts chosen randomly from the rural community. The criteria chosen are earthquake (EQ), gentle flood (FL), landslide (LS) and cost (CS). Among all these criteria gentle flood (FL) scored highest APC value and hence it is the most influencing criteria when someone constructs its house. The aim of the experimentation was to ascertain which housing technique out of 4 housing techniques (alternatives) namely Ikra house (IK), Mud house (MD), Chang house (CH) and Bamboo house (BA) is having the maximum ranking value w.r.t each and every criteria. It is observed from the results that the maximum value of RVA is 41% and it is scored by Chang house (CH) which is gentle flood proof, earthquake resistant and its cost of construction is also low.*

Keywords: Multi-criteria Decision making, Alternatives, Analytical Hierarchy Process and Ranking Value.

1 Introduction

Among the three basic needs food, shelter and clothing, shelter i.e. housing stands as the most difficult problem to the modern society (Rahman & Sharma, 1996). The problem involves with land, construction material, site and situation. The factors like site and situation is more dominant in case of rural housing. In regard to building material it has been observed throughout the world, traditional houses constructed with only locally available materials (Lal, 1990). Site selection of houses normally depends on local geographical condition. Physical features, slope, climate, drainage, wind velocity, sunrays are the dominant physical factors in locating the rural houses (Koenigsberger 1974). In regard to building space, house type, layout, height, plinth level, roof pattern and interior arrangement largely depend on the culture and tradition of the communities (Kaushik Prachuryya, Kaushik Praschaya, 2014).

There are several factors which govern the construction of traditional houses such as social, cultural, economic, etc. In early ages houses were constructed by considering geographical conditions, approachable site, etc. to maintain the pleasant atmosphere inside the house. These houses were showed their living style, belief and social attachment. Nevertheless, these houses shows their creative thinking and skills (Das Navanita, Pal Shulanki, et.al., 2014).

1.1. Introduction of region - Assam

In India, Assam is in the north eastern part and shares its border with Arunachal Pradesh, Nagaland, Manipur, Mizoram, Tripura and Meghalaya. It has hills, plain lands and river valleys. It spreads over an area of 78, 523 sq. kilo-meters. Barak Hills and the Brahmaputra Valley are its most important landmass. In Assam, maximum people live in rural areas. River Brahmaputra made Assam a very fertile area and it helps Assam to be a agriculturally developed state (Das Navanita, Pal Shulanki, et.al. 2014).

1.2. Climate

Humidity of Assam is high and it faces heavy rainfall most of the time in a year. The hilly lands faces subalpine climate whereas the plains faces humid climate (Das Navanita, Pal Shulanki, et.al. 2014).

1.3. Disasters

Assam had a long list of disasters and therefore, its people face many hurdles in living. Flood, soil erosion, land slide, cyclones, earthquake, etc. are some major problems in Assam. Assam state stands on seismically active zone and it experiences M 8.7 and M 8.4 scale earthquake in the year 1897 and 1950 respectively. From many decades, Assam experienced tremendous flood. The main flood affected areas are Dhemaji, Majuli, Morigaon, Dhuburi, Goalpara, etc. (Das Navanita, Pal Shulanki, et.al. , 2014).

1.4 Multi Criteria Selection

The multiple criteria selection usually depends on (i) technical factors that deal with the appropriateness of the technology; (ii) structural factors that deal with the coordination, information and control and (iii) strategic factors that deal with the management of resources and uncertainty (Noori, H., 1990). Several research papers are available on the ranking of alternatives based on the cost accounting technique like net present value, internal rate of return etc. These approaches have considered only the quantitative factors. Many very important subjective factors such as competitive advantage and social issues have not been included in the approach. Owing to the unstructured nature of the problem, many researchers have proposed various approaches, which have not been very successful to deal with the qualitative factors associated with the problem. Dweri (Dweri, F., 1999) has suggested fuzzy decision support system while finding the attribute weight by AHP for finding the facility selection routine. Deb and Bhattacharyya (Deb, S.K. and Bhattacharyya, B., 2002, 2004) have proposed methodology considering the rating attitudes of decision-makers and trade-off among various selection criteria in the

aggregation process to assure an accurate selection policy. Multiple criteria decision-making methods were used with the support of fuzzy system to find the selection order of machines for placement in open continual plane considering zero base area allocation (Deb, S.K. and Bhattacharyya, B., 2003). In this paper, the authors have applied a relatively new and simplified version of the analytical hierarchy process suggested by T.L. Saaty on their previous work relating multi-criteria decision making technique suggested by Deab B.V and Nishry, J.J. (Bhuyan. M., *et.al*, 2010), (Deab B.V and Nishry, J.J., 1965), (Saaty T.L., 2001). AHP is a decision making tool for dealing with complex, ill structured and multiple attributes decision problem. It helps in evaluating multiple attribute alternatives when subjective assessments of qualitative factors are integrated with quantitative factors. AHP has been used in a wide variety of decision areas, including manufacturing and production systems. A computer programming in Borland C++ was developed to demonstrate the potential application of the procedure with the help of a case study regarding the ranking of different housing techniques used in rural areas of Assam, India. For the sake of simplicity in data collection and its analysis, the selection problem was framed under four criteria, ten experts and four possible alternatives.

2. Types of Traditional Houses in Assam

2.1. Ikra house

Assam type or Ikra house are the most common type of housing technique used by people of Assam. These houses are constructed by bamboos, wooden planks, thatch etc. These materials make the house light weight and it resist earthquake also. Ikra house is mainly single-storey and it has stonework or brickwork walls which is about 1 m above the plinth. This masonry supports the walls consisting of bamboo woven together with a wooden frame, and plastered with cement or mud plaster. GI sheets are used in roof which is supported by bamboo trusses. Steel angles, and flats with bolts and nails are used in Bamboo superstructure. There were no reports of any significant damages to Ikra structures during past earthquakes (Das Navanita, Pal Shulanki, *et.al*. 2014).

2.2. Mud house

Mud house is constructed with a mixture of water and some combination of soil, silt and clay. The dimensions of Mud house are lengths between 5 and 10 meters, and widths between 3 and 5 meters. The height of the house is 1.6-2.5 meters. Roughly, the ratio of the length and width of the house can be expressed as 3:2 or 2:1 (Das Navanita, Pal Shulanki, *et.al*. 2014).

2.3. Chang house

Chang house is originated from old Himalayan ranges. The tribes of North East India generally use this type of housing technique. These houses mainly located in hilly areas, banks of rivers and forest. It is highly protective and gentle flood resistant. Mishing community of Assam mainly used this housing technique. It has a good spacious room with kitchen and helpful for joint family (Das Navanita, Pal Shulanki, *et.al*. 2014).

2.4. Bamboo house

In bamboo housing technique, the main component is bamboo. These bamboo and plinth is firmly connected with each other and it is protected from gentle flood. These houses are designed for heavy monsoons and their roofs are made of grass which last upto 10 years. The walls are plastered with mud and it is cost effective also (Das Navanita, Pal Shulanki, *et.al*. 2014).

3 Analytical Hierarchy Process

The AHP is a decision making tool for dealing with complex, ill structured and multiple attributes decision problem. It helps in evaluating multiple attribute alternatives when subjective assessments of qualitative factors are integrated with quantitative factors. T.L. Saaty developed it during 1970s. Since its initial development, AHP has been used in a

wide variety of decision areas, including manufacturing and production systems. The traditional decision making approaches consider only the quantitative factors, failing to recognize the many importance qualitative factors such as environmental link, supervision link etc in a manufacturing system. Moreover traditional layout decision overlooks the problem of inconsistencies of designers. The AHP uses a nine-point scale defined to get intensity importance factor (a_{ij}) as: 1- equal importance, 3-moderate importance, 5-strong importance, 7-very strong importance, and 9-extreme importance. The even numbers 2, 4, 6 and 8 are for compromise, and the reciprocals show the inverse pair wise comparisons. These numbers represent the weight factors (priorities) of the reasons involved in the decision making process. The intensity importance of factor i over factor j is equal to reciprocal of intensity importance of factor j over factor i . Thus, it can be written as $a_{ij} \times a_{ji} = 1$.

3.1 Procedure for the Use of AHP

Since AHP involves a comparison of two factors, the matrix that contains the weight assignments must be a square matrix. Let A represents the matrix and its size as $n \times n$. AHP uses a process known as systemization. The procedure is as follows:

- Step 1. Form the importance intensity matrix $A=[a_{ij}]$ by using Saaty's 9 point scale.
Step 2. Find geometric mean of a_{ij} for all the participants to get groups numerical assignment when factor i is compared with factor j with popular 9 point scale of Saaty.
Step 3. Obtain column total (S_j) by adding the weight assignments in each of the column j .

$$S_j = \sum_{i=1}^n a_{ij} \quad \forall j = 1, n.$$

Step 4. Divide each element of matrix A by its column total (S_j) to get normalized pair wise comparison matrix:

$$V = [v_{ij}]$$

$$\text{where } v_{ij} = \frac{a_{ij}}{S_j} \quad \forall i = 1, n.$$

Step 5. Estimate relative priorities of each factor by computing the average of the normalized weights in each of i row. Let p_i represents the relative priority of factor i . Then,

$$p_i = \frac{\sum_{j=1}^n v_{ij}}{n} \quad \forall i = 1, n.$$

$$\text{Also } \sum_{i=1}^n p_i = 1.$$

Following steps are performed to compute the consistency ratio estimation.

Step1. Multiply each of the columns of comparison matrix A by the relative priorities corresponding to that column and add to obtain an $n \times 1$ matrix called B . Thus the new matrix can be expressed as:

$$B = \begin{pmatrix} b_1 \\ b_2 \\ - \\ - \\ b_n \end{pmatrix} = \begin{pmatrix} p_1 a_{11} + p_2 a_{12} + \dots + p_n a_{1n} \\ p_1 a_{21} + p_2 a_{22} + \dots + p_n a_{2n} \\ \dots \\ p_1 a_{n1} + p_2 a_{n2} + \dots + p_n a_{nn} \end{pmatrix}$$

Step2. Compute consistency ratio (CI) as follows

$$CI = \frac{\lambda_{\max} - n}{n - 1} \quad \text{where } \lambda_{\max} = \frac{1}{n} \sum_{i=1}^n \frac{b_i}{p_i}$$

Step3. Obtain consistency ratio as $CR=CI/RI$ where RI is a random index which represents the consistency index of a randomly generated comparison matrix taken from standard random index table which is given by Saaty for the number of factors used in the decision-making. Any value of $CR \leq 0.1$ is considered as an acceptable ratio of consistency.

3.2 Formulation and Model Generation

In this paper, a multiple criteria decision making problem based on simplified version of AHP is proposed. The subjective (qualitative) as well as objective (quantitative) criteria associated with the problem are assigned by the experts within approximated information value available to determine the ranking value of the alternatives. The concept of hierarchical structure analysis with three distinct levels is used in this paper. The first level (level zero) is to set objectives or goal, the second level (i.e. level 1) is set to evaluate the priority vector of the decision criteria (e.g. earthquake, gentle flood, landslide and cost). In the level 2, the priority vector of alternatives under each criterion is evaluated. The hierarchical structure of the different criteria and alternatives under analytical hierarchical process is shown in fig.1. A group of experts is assigned to employ rating sets within Saaty's nine point scale to evaluate preference information by pair wise comparison methodology. Similarly, the experts assess the suitability of each alternative under each criterion and assign a preference value within [0-9] scale depending upon the importance of the alternatives under that criterion.

Let, m = total number of criteria, n = total number of alternatives, E = total number of experts and

APC_i = Average priority value of criteria 'i' under E number of experts,

APA_{ij} = Average priority value of alternative 'i' for criteria 'j' under E number of experts,

RVA_i = Ranking value of alternative 'i', then

$RVA_i = \sum APC_j \times APA_{ij}$

where $i=1,2,3,\dots,m$ and $j=1,2,3,\dots,n$.

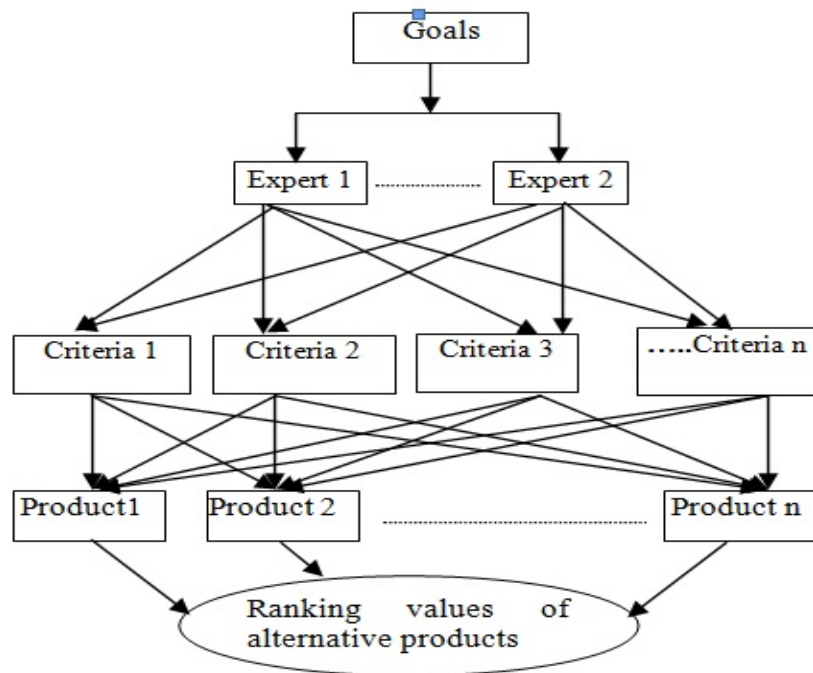


Fig.1. Hierarchical structure with three distinct levels

3.3 Computer Simulation and Case Study

In line with analytical discussion made in the above section, a computer programming in Borland C++ was developed to handle a case study relating ranking of different housing techniques by applying proposed simplified AHP based multiple criteria decision making methodology. The steps of algorithm are mentioned below:

- (i) Develop paired comparison matrix for level 1 with respect to goal for determining priority value of criteria for each expert, and then find the average priority value of criteria (APC_i). Also get adjusted priority value of criteria (AAPC) if any APC value is less than 10%. If all APC values are more than 10% then $APC = AAPC$.
- (ii) Develop paired comparison matrix for level 2 with respect to alternatives for each criterion under each expert.
- (iii) Get average priority value of alternatives for each criterion under all experts i.e. APA_{ij}
- (iv) Get ranking value of alternatives i.e. RAV_i and select Maximum RAV_i as the best alternative.

In order to evaluate the applicability of the proposed methodology, a case study relating the ranking of different housing techniques were tested under 4 criteria, 4 alternatives and 10 groups of experts chosen randomly from the teaching community. The criteria chosen are earthquake (EQ), gentle flood (FL), landslide (LS) and cost (CS). The aim of the experimentation was to ascertain which housing technique out of 4 housing techniques (alternatives) namely Ikra house (IK), Mud house (MD), Chang house (CH) and Bamboo house (BA) is having the maximum ranking value. Trade off analysis matrix used for decision-making in this paper was prepared by collecting data from literature.

4 Results and Discussion

Ten most reliable sets of data after vigorous screening were used in the computer programming to get the values of APC, APA and RVA of four alternatives. The final paired wise comparison matrix of level 1 with the average priority values of criteria (APC) is shown in table 1. Neglecting the priority values of criteria less than 10% in table 1, the adjusted average priority values of criteria are shown in table 2. Similarly, the paired wise comparison matrix of level 2 was developed and the average priority values of

alternatives under respective criteria including the value of APA are shown in table [3 – 5]. The calculated value of RAV is shown in table 6.

Table 1: Paired Comparison Matrix of Level 1 with APC

Criteria	EQ	FL	LS	CS	APC
EQ	1	0.14	6	0.125	11
FL	7	1	8	7	58
LS	0.167	0.125	1	0.125	4
CS	8	0.14	8	1	27

Table 2: Adjusted Average Priority Values of Criteria (AAPC)

Criteria	EQ	FL	CS
AAPC	12	60	28

Table 3: Paired Comparison Matrix of Level 2 with APA under Criteria EQ

Alternative	IK	MD	CH	BA	APA
IK	1	8	6	6	56
MD	0.125	1	0.125	8	13
CH	0.16	8	1	7	26
BA	0.16	0.125	0.14	1	5

Table 4: Paired Comparison Matrix of Level 2 with APA under Criteria FL

Alternative	IK	MD	CH	BA	APA
IK	1	7	0.125	7	23
MD	0.14	1	0.125	0.14	4
CH	8	8	1	8	61
BA	0.14	7	0.125	1	12

Table 5: Paired Comparison Matrix of Level 2 with APA under Criteria CS

Alternative	IK	MD	CH	BA	APA
IK	1	0.14	6	0.14	12
MD	7	1	7	6	58
CH	0.16	0.14	1	0.14	4
BA	7	0.16	7	1	26

Table 6: Ranking Values of Alternatives (RAV)

Alternative	IK	MD	CH	BA
RAV (approx.)	24	20	41	15
PIV	42	5	40	13

It is observed from the results that the maximum value of RVA is 41% and it is scored by Chang house (CH). In order to validate the computer simulation results a popularity index value (PIV) was determined by searching literature, taking expert's views, etc. It is found that the PIV of Ikra house (IK) is a little bit higher than Chang house (CH) thus validating the authenticity.

5 Conclusions

In the study, the aim of the experimentation was to ascertain which housing technique out of 4 housing techniques (alternatives) namely Ikra house (IK), Mud house (MD), Chang house (CH) and Bamboo house (BA) is having the maximum ranking value. A computer simulation is also shown to evaluate the efficient housing technique. From the analysis following conclusions are drawn:

- I. The paper has proposed and explained the potential applicability of a simplified MCDM based on analytical hierarchy process under multiple experts. The computer programming developed by the authors can easily handle the preference values assigned by different experts.
- II. The methodology presented is easy to understand and able to handle any unstructured problem which needs systematic analysis through qualitative parameters.
- III. It is observed from the results that the maximum value of RVA is 41% and it is scored by Chang house (CH).

From the literature it is observed that Assam is a high earthquake and flood prone area and therefore, if the above housing techniques are introduced in the modern day construction, it would lead to a better earthquake and gentle flood resistive design.

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COMPOSITES IN HOUSING AND INFRASTRUCTURE – A REVIEW

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ABSTRACT: *Housing and infrastructure are two critical aspects that need attention in the overall development of a village. Use of composites in the civil engineering applications has increased multifold; it continues to grow and it can play a very important role in transforming an average village to a developed one. This work reviews the applications of composites in housing and infrastructure and explores the possibilities in the context of a typical village. Composites are different from conventional construction materials; a brief presentation is given first to introduce the reader to the subject.*

Keywords: *Composites, GFRP, CFRP, AFRP, Housing, Infrastructure*

1. INTRODUCTION TO COMPOSITES

Affordable and quality housing together with developed roads, bridges and other elements of infrastructure are critical aspects of rural development. Proper planning and implementation of plans are important their construction. Materials and technology to convert such materials into usable products play a crucial role. In this respect, composite materials, looking beyond the conventional materials such as concrete, steel and wood, etc., show great potential.

1.1 Definition and Basic Characteristics

Composites are a class of useful engineering materials made by macroscopic combination of two constituents – reinforcement and matrix, where the constituents are derived typically from conventional materials such as metals, ceramics and polymers (Buragohain 2017, Jones 1999, Mallick 2013 and Mathews 1999). Reinforcements are discrete, usually hard and strong; they are the primary load bearing constituent held together by the continuous matrix. Composites are of different types. Depending on the type of the matrix, they are classified into metal matrix composites, ceramic matrix composites, carbon/carbon composites and polymer matrix composites. Polymer matrix composites (PMCs) are popular in many applications and often the term composites (or composite material) without any qualifying term is used as synonymous with PMCs. Composites can also be classified based on the geometry and physical shape of the reinforcements and physical form of the resultant material; in this way they can be classified into various classes such as particulate composites, short fiber composites, flake composites, unidirectional composites, laminated composites and sandwich composites.

Some of the commonly used matrix materials are epoxy, polyester, phenolic and vinylester. These are reinforced by fibers of carbon, glass, aramid and boron. The reinforcements and matrix have their own individual characteristic properties that are greatly enhanced when they are combined to form a composite material. Composite products are generally known for light weight characteristics, which is feasible due to their typically high specific strength and stiffness properties. A composite laminate is composed of several laminae or plies; the mechanical and thermal properties of the laminae are direction dependent and it is possible to virtually tailor the resultant laminate material properties, which gives the designer the flexibility to exploit the material properties in the most efficient way. This flexibility, however, comes at the cost of higher complexity in the design and analysis with composite materials. Clear understanding of mechanics of composites and tools such as classical laminate theory, etc. and a systematic approach to analysis are essential. Some of the other typical

advantageous characteristics of composites include: high fatigue and impact properties, resistance to corrosion, simple manufacturing methods and economy of product development.

1.2 Manufacturing Processes

Composites manufacturing is different from manufacturing with conventional materials. It is primarily a process of addition of materials involving four essential steps of impregnation, lay-up, consolidation and solidification. Use of machining is usually minimal. There are several manufacturing processes that are in practice in the composites industry; these are of three broad types – closed mold, open mold and continuous molding processes. Contact lay-up, prepreg lay-up, spray-up, compression molding and resin transfer molding, etc. belong to the closed/open mold categories, whereas, filament winding, pultrusion and tape winding, etc. are continuous molding processes (Buragohain 2017, Mazumdar 2002, Campbell 2004 and Starr 2000:1-18). It is to be noted that many variants of these basic processes are in vogue.

1.3 Testing Procedures – Destructive and Non-destructive

Both destructive and non-destructive tests are an integral part of composites product development. Destructive tests are regularly carried out for design data generation and as quality control measure. A building-block approach is adopted involving tests at (i) coupon level (constituents, lamina and laminate), (ii) structural element level (joints, etc.) and (iii) component level (sub-scale model and full-scale product) (Buragohain 2017, CMH-17 2012). Tests at the lower level are more in number but simple and mostly standard driven, whereas component level tests are few in number but complex. Non-destructive tests such as ultrasonic testing, radiography and thermography, etc. are employed for product acceptance at different stages of product development.

1.4 General Applications

Development of composites has been greatly influenced by the developments in the materials area. Glass fiber and unsaturated polyester resins were developed and commercialized in the 1930s and use of glass fiber reinforced plastic (GFRP) in boats and radomes started in the 1940s. The first demonstration of use of composites in aircrafts was also made around the same time; however, with advent of high-performance composites like carbon fiber reinforced plastics (CFRP), aramid fiber reinforced plastics (AFRP) and boron fiber reinforced plastics (BFRP), the composites industry got a major boost from demands from the aerospace and defense sectors in the 1950s. Since then, composites have gained acceptance across a wide spectrum of industrial sectors and today there are applications of composites in aerospace and defense, automotive, building and construction, chemical, consumer goods, electrical and electronics, marine, and others (Buragohain 2017, Jones 1999, Gay 2003, Jones 2015, Eckold 1994, Mangalgiri 1999, Rawal 2001, Krumweide 1998, Wilhelm 2001, Denton 1998, Karbhari 2001, Loud 1998, Tucker 1998, Shalaby 1998 and McConnell 1998).

Advanced composites have been available for the last eighty years; however, they started getting attention of civil engineers, as evident from published works, only in the 1980s and 1990s (Karbhari 1998, Seible 1997, Triantafillou 1998, Sonobe 1997, Fardis 1981, Fardis 1982 and Meier 1992). Today, these materials are used in various areas of housing and infrastructure.

2. COMPOSITES IN HOUSING

2.1 Advantages and Potential

Advantages of composites and their potential in housing and infrastructure sector are well acknowledged (Sundaram 2017, Stewart 2010, Kendall 2007, Kendall 2008, Stewart 2011, EPTA Industry Briefing 2019, Evernden 2009, Halliwell 2008 and Moy 2013). A lucid review

of composites in the housing market is presented by Halliwell (2008). As per a recent report, market share of construction applications of glass fiber reinforced plastics (GFRP) is about one third of total GFRP applications. In the case of CFRP, it is about 5% (Witten 2018). Economic considerations and other limitations have been addressed (Lopez 2016, Burgoyne 2007, Paris 2018 and Nanyam 2017).

The advantages of composites in housing are due to their unique properties. Typical properties of composites are compared with other conventional materials in Table 1. The advantages can be grouped into:

- **Easy handling, transportation and assembly:** Low densities of composites make them lighter than most other conventional materials that, in turn, help in off-site construction of panels, their handling, transportation and assembly. As a result, it is possible to achieve higher reliability, faster realization and overall economy.
- **Better structural performance:** Low densities of composites together with high strengths result in high structural performance as reflected by high specific strengths and stiffness.
- **Design flexibility:** Anisotropic properties of composites and their ability to mold complex shapes give the designer to think and create unique geometrically optimized, structurally sound and cost-effective designs.
- **Environmental benefits:** Composites are resistant to rot and termite attacks, warpage and distortion due to moisture absorption; thus, they are durable and cost-effective. Also, composite panels can be designed and fabricated as thermal insulators, and houses can be built using such panels.

Table 1: Representative properties of building materials

Material	Steel	Aluminium	Concrete	Wood	GFRP	CFRP
Density ($g/c\ m^3$)	7.8	2.8	2.4	0.8	1.8	1.45
Tensile strength (MPa)	430	250	9	80	500-700	870-2700
Compressive strength (MPa)	430	250	35	45	400-600	550-1200
Modulus (GPa)	205	70	20	12	18-36	140-450
Co-eff. of thermal expansion ($\times 10^{-6}\ mm/mm/^{\circ}C$)	12	23	10	14	12-36	(-)-0.3-0.7
Thermal conductivity (W/mC)	50	170	1.6	0.1	0.3	55

Notes: 1. GFRP properties are in the longitudinal direction with polyester resin and 2. CFRP properties are in the longitudinal direction with epoxy resin

2.2 Housing Applications

Applications of composites in the housing sector can be divided into the following: (i) secondary structures (ii) primary structures and (iii) rehabilitation of existing building.

2.2.1 Secondary structures

Composites are used in many secondary housing applications, of which some of the common examples are door/window shutters and frames, roofing sheets, insulating panels, canopies, bathroom fittings, etc.; these are now available commercially, for example: Rawji Industrial Corporation (www.rawji.com), SVS Composites (www.vstrong.in), Granallite (www.woodsaver.co.in), Fiber Tech Composites (www.fibertech.co.in), DorteK (www.dortek.com), GRP Building Products (www.grpbldgproducts.co.uk) and Man Friday GRP Solutions (www.manfriday.co.uk), etc.

Roofing systems: GFRP roofing sheets are used in applications such as parking sheds,

house extension, farmhouse, etc. They are usually made by contact lay-up and continuous molding processes using chopped strand mat (CSM) with polyester resin and available in several thickness and corrugated profiles. Canopies, ridge, eaves gutter, valley gutter, etc. are other examples of roofing products.

Doors and windows: GFRP doors provide a good alternative to traditional wooden, steel and PVC doors in both internal and external use in residential as well as industrial buildings. They are lighter and stronger than their conventional counterparts. Also, they are rot and termite resistant, warping free and long lasting; some commercially available doors have lifespan of 35 years (SVS Composites, www.vstrong.in). Composite doors are also highly useful in applications where hygiene is a critical requirement (Dortek, www.dortek.com). Compression molding in several variations is adopted for making the door/window panels, whereas pultrusion is the common process for manufacture of door/window frames. Sheet molding compounds (SMC) with glass and polyester respectively as the reinforcements and matrix are the common materials.

Lining systems: Composite cladding systems by GFRP panels and imitation bricks provide a cost-effective solution where traditional brickwork is either impractical or expensive (EPTA Industry Briefing, Evernden 2009, Halliwell 2008). These systems are lightweight, easy to transport and install, hygienic, durable; they are available in many shades and styles that meet the requirements in both commercial and domestic applications. Another example of lining application is that of lift pit lining where CSM reinforced polyester resin composites are used for making high quality waterproof prefabricated liners (Man Friday GRP Solutions, www.manfriday.co.uk).

2.2.2 Primary structures

Composites are now used in several primary structural applications in house construction. Offsite construction plays a major role in meeting the needs in these applications. Composite panels, beams and columns are manufactured in plants, and transported to the site and assembled using connectors and adhesive to build houses. Typically, these houses are single-storied or double-storied; however, construction of composite multistory buildings has also been demonstrated. Pultrusion and contact lay-up for sandwich construction are the primary processing techniques used in fabrication of structural elements in composite house construction; common materials are glass fiber and polyester resin. Specific elements of house construction have been addressed, for example flooring (Ahmed 2019) and roofing (Mintz 2016).

Pultrusion is a continuous molding process in which profiles with uniform cross-section are made by impregnating continuous reinforcements and drawing these impregnated reinforcements through a heated die (Mazumdar 2002, Wilson 1998). Various aspects of pultrusion, viz. process, materials, design and applications are addressed in detail by several authors (Shaw-Stewart 2000, Bogner 2000, Gauchel 2000, Evans 2000, Starr 2000 and Wilson 2000). Works carried out in the field of pultrusion are broadly in materials and processing technique. Pultruded profiles made by rovings alone are very strong and stiff in the axial direction but not so in the transverse direction; transverse properties are improved by incorporating fabrics and mats. Response of pultruded profiles to non-structural loads including corrosive environment, fire, rot and termite attack, etc. is important. Vinyl ester and phenolic resins respectively are suitable in corrosive environment and fire hazard. Behavior of these composites in elevated temperatures with fire hazards is addressed (Correia 2013 and Correia 2015).

While GFRP has been the most common composite material used in the fabrication of structural elements for house construction, other materials have also shown promise. Gao et al (2013) and Gao et al (2014) have investigated pultruded CFRP panels for use in building floors; these panels were found to meet all design requirements.

Pultruded profiles of different types have been developed that can be quickly assembled to build a house. Startlink®, a modular construction system involving pultruded profiles, is presented by Hutchinson and Singleton. Composite building panel systems like COMPOSOLITE® and DURASHIELD® are available commercially; these panels that have cellular construction can be connected to one another by means of unique connectors and are used in building elements such as walls, roofs, floors and covers, and other civil engineering applications (Strongwell, www.strongwell.com).

Sandwich composite systems are laminated composite panels that consist of a thick light weight core bonded between two thin skins. Extensive work has been done in this area, e.g. (Vinson 1999). Some of the critical areas of sandwich composites are materials, design, processing and testing and evaluation including non-destructive evaluation (Islam 2012, Mohamed 2016, Grido 2019, An 2016, Yalkin 2016, Dawood 2010, Dawood 2018, Scutaru 2019, Ibrahim 2014 and Juntikka 2007).

A review of composite sandwich systems in civil engineering is given by Manalo (2017), wherein broad application areas including housing, bridge deck and beams, floating and protective structures, and railway sleepers are identified. In the housing sector, use of composite sandwich panels in all primary load bearing structural elements, viz. roofs, floors and walls, has been explored (Keller 2008, Satasivam 2014, Erp 2008 and Sharaf 2011).

3. COMPOSITES IN INFRASTRUCTURE

FRP composites are used in the strengthening and rehabilitation of existing structures as well as construction of new structures; a detailed review of technological status as on 2002 was given by Bakis et al (2002). A more recent review is given by Hollaway (2013). Application of polymer composites in construction by external strengthening and rehabilitation of existing structures is reviewed in detail by Pendhari et al (2007), Islam et al (2011) and Rabinovich et al (1998).

3.1 Existing Bridges and Other Structures

Existing bridges and other structures undergo deterioration over time by regular wear and tear and they develop cracks due to seismic activities. Design requirements also change due to changing traffic conditions, socio-economic needs, etc. However, replacement of these aging structures is not always a feasible option; use of FRP composites has been found as an efficient alternative to strengthen/rehabilitate such existing structures. Strengthening and rehabilitation are done primarily by external bonding of reinforcements, wherein the underlying strengthening techniques are flexural strengthening, shear strengthening, confinement and others. Extensive experimental and theoretical works have been carried out to investigate behavior, including flexural and shear resistance, failure modes and durability, etc., of various structural elements strengthened by FRP composites; a limited list is given here as example: columns (Demers 1999, Kaminski 2006 and Deniaud 2006), beams (Ramana 2000, Siddiqui 2009, Danraka 2017 and Alagusundaramoorthy 2003), beam-column connections (Granata 2001, Mahmoud 2014 and Attaria 2019) and walls (Mosallam 2007 and Mosallam 2017).

External bonding of reinforcements involves either circumferential winding of unidirectional reinforcements over longitudinal reinforcements laid-up on the steel/concrete structure or sheet lay-up in the circumferential and/or longitudinal directions (Karbhari 1998). Glass, carbon and aramid fiber/fabric reinforced composites have been used. In general, CFRP strengthened structures are found to perform the best (Toutanji 1998). Carbon fiber reinforced pultruded plates are used as bonded external reinforcement for repair of defective structures and the technology has reached commercial maturity (Burgoyne 1999).

3.2 New Bridges

Bridge construction using composites has been researched by many and these materials

have been used in many new bridges. Some examples of hybrid and all-composite bridges are given by Sonnenscheina et al (2016). Pultruded GFRP and AFRP rods were developed for prestressing steel tubes and a number of bridges were built (Burgoyne 1999). Structural performance including static and fatigue response of composite sandwich bridge decks was investigated by Ji (2011). GFRP decks are also explored by Stankiewicz (2012). Connections are important for the overall structural integrity of a bridge and other structures; several authors have addressed them (Mara 2014, Mara 2016 and Fang 2019). Design aspects have also been addressed for optimization and standardization of new bridges and existing structures (Fabeane 2017 and Pilakoutas 2011). A pedestrian sandwich bridge, a truss bridge by hand lay-up and pultrusion and an all-composite composite bridge by pultrusion were demonstrated successfully in the recent past (Chrosielewski 2017, Singh and Li 2014). Composite bridges have been in use for more than a decade and the technology has graduated from mere demonstration to commercial acceptance in some countries like the Netherlands (Mathijssen 2013 and Smits 2016). Works on composites in bridge engineering have not been limited to only polymer composites; other areas explored include timber-concrete composite (Fragiacomo 2018) and bamboo (Musthaffa 2018), etc.

4. POSSIBILITIES IN A SMART VILLAGE

Housing and infrastructure possibilities in a smart village would depend on many factors that are associated with (i) available natural resources and (ii) socio-economic, geographical, climatic and cultural conditions. A few such possibilities using composites for a typical village in Assam (where COSVARD 2019 is being held) are identified as follows:

- Composite house
 - Composite residential house
 - Composite emergency shelter
- Portable bridge
- Public utility

4.1 Composite Residential House

An all composite modular house with a simple floor plan is presented as a possible case in an alternate housing scheme for a smart village. The concept can be readily extended to other simple floor plans. The prefabricated modular house presented here comprises the following primary components:

- Foundation plates
- Foundation panels
- Columns
- Beams
- Floor panels
- Wall panels
- Door and window frames
- Door and window shutters
- Roofing panels
- Roofing frames
- Roofing sheets

It is emphasized here that the objective of proposing this concept is to extend the advanced

composites to the housing sector in such a way as to make these materials accepted as main line building materials and the many benefits associated with them are reaped by the society. Simplicity and reliability are essential requirements in this regard; materials and processing techniques for the above elements are proposed accordingly (Table 2). All the composite processing activities shall be done in factories that would need minimum capital investment. Glass/polyester composite laminates/skins are to be used for all composite parts whereas rigid foam is to be used as the core wherever applicable. Glass/polyester sheet metal compounds (SMC) are to be used in the manufacture of door and window shutters. Plates, panels, beams and columns will need edge machining but no surface machining is expected.

Table 2: Composite modular residential house – materials and processes

Component	Material	Process
Foundation plates	GFRP laminate	Hand lay-up followed by compression in a mold and room temperature curing
Foundation panels	GFRP skin and foam core	- Sandwich construction with outer skins, inner ribs and core - Hand lay-up of skins and ribs followed by compression in a mold and room temperature curing
Columns	GFRP skin and foam core	- Pultrusion followed by in-situ foam casting - Alternatively, hand lay-up around a pre-shaped foam core followed by compression in a mold and room temperature curing
Beams	GFRP skin and hollow core	Pultrusion
Floor panels	GFRP skin and foam core	- Sandwich construction with outer skins, inner ribs and core - Hand lay-up of skins and ribs followed by compression in a mold and room temperature curing
Wall panels	GFRP skin and foam core	- Sandwich construction with outer skins, inner ribs and core - Hand lay-up of skins and ribs followed by compression in a mold and room temperature curing
Door and window frames	GFRP open profile	Pultrusion
Door and window shutters	GFRP SMC	Compression molding
Roofing panels	GFRP skin and foam core	Hand lay-up around a pre-shaped foam core followed by compression in a mold and room temperature curing
Roofing frames	GFRP skin and hollow core	- Beams: Pultrusion - Support panels: Sandwich construction with outer skins, inner ribs and core. Hand lay-up of skins and ribs followed by compression in a mold and room temperature curing.
Roofing sheets	GFRP laminate	Hand lay-up followed by compression in a mold and room temperature curing

Sandwich construction (Figure 1) is adopted for making the panels (Table 2). A laminate is made by hand lay-up and room temperature curing in an open mold. The mold design, involving simple flat metallic plates, guided spacers and tightening bolts, ensures easy and fast assembly / dis-assembly of the mold and dimensional accuracy of the cured laminate. Ribs of appropriate dimensions are machined out of the laminate. The sandwich panel is realized by laying up the lower skin on an open mold followed by placing the pre-shaped foam blocks separated by the ribs. An upper skin is laid-up and the mold is closed for room temperature curing. The manufacturing process is simple and the panel has been tested under centrally applied twin concentrated bending loads to evaluate its structural performance (Figure 2). Deflections and strains were recorded. Results of the manufacture and experimentation of the sandwich panel are utilized to determine the sizes of the various panels of the proposed residential house and emergency shelter.

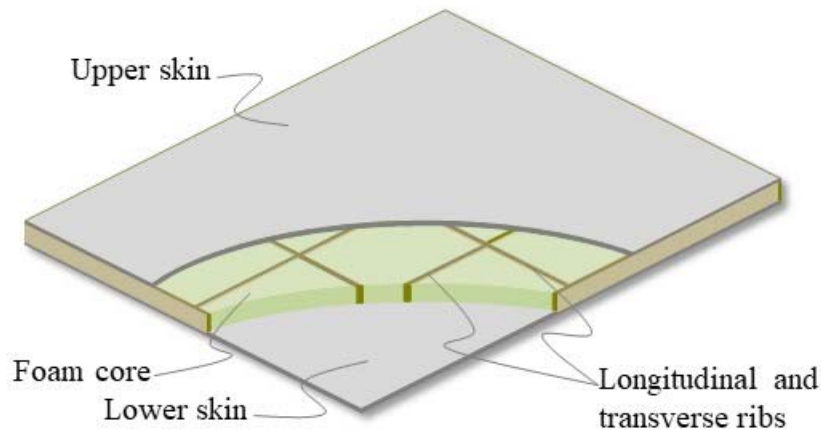


Figure 1. Typical sandwich panel

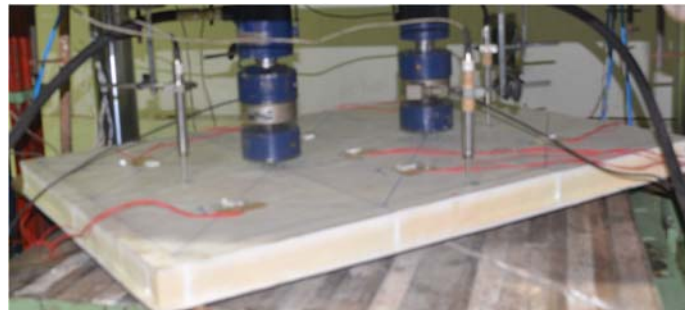


Figure 2. Sandwich panel under testing

All housing components are to be manufactured and finish trimmed / machined in factory premises and transported to the site where only assembly is carried out. Trenches are dug at the site for the foundation panels. Foundation plate are placed and levelled. Columns and foundation panels are placed on the foundation plates and bonded taking care of orientations and levels (Figure 3). Wall panels are then mounted and bonded between the columns and on the foundation panels (Figure 4). Door and window frames are also mounted and bonded at this stage. Door and window shutters can be assembled at a later stage after completion of total house assembly works. Conventional metallic accessories like hinges, latches, etc. can be used together with specially designed metallic inserts. Next, cross beams are mounted on the top of the walls from column-to-column and bonded followed by erection of the roofing support panels and roofing frames (Figure 5). Finally, the roofing sheets are mounted and bonded. The complete all composite house is shown in Figure 6. The manufacturing process of the house components and their assembly are expected to be simple, fast and cost effective. Table 3 gives a break-up of size, weight and processing time of various components. On an approximate and conservative estimate, the

maximum unit size and weight are worked out as $4500mm \times 1200mm \times 300mm$ and $430kg$ respectively. Total weight of the components works out to approximately $3500kg$ out of which composites way about $2600kg$ and foam weighs the rest.

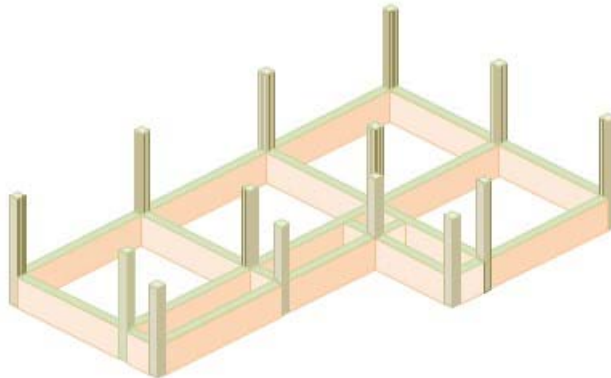


Figure 3. Foundation plates, panels and the columns

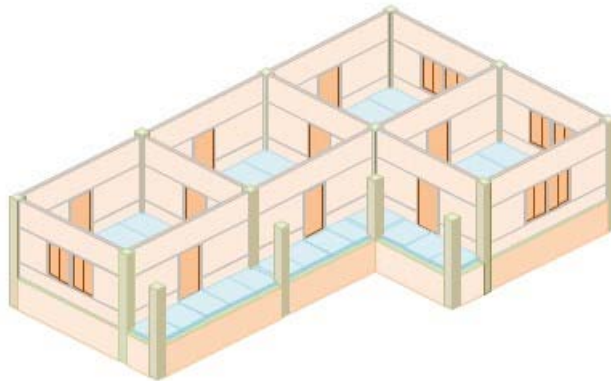


Figure 4. Wall panels with doors/windows and floor panels on foundation

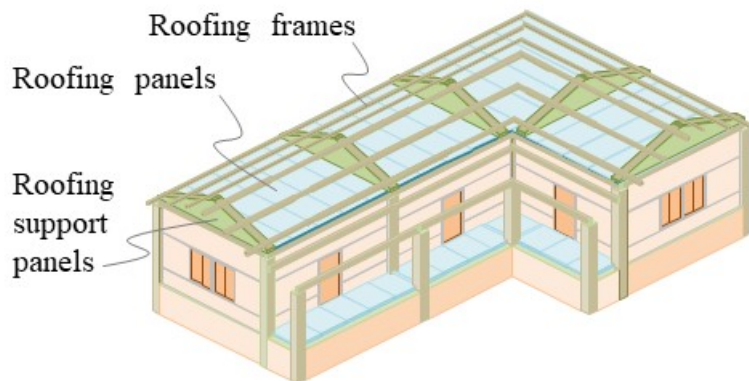


Figure 5. Roofing panels, roofing support panels and frame on the beams

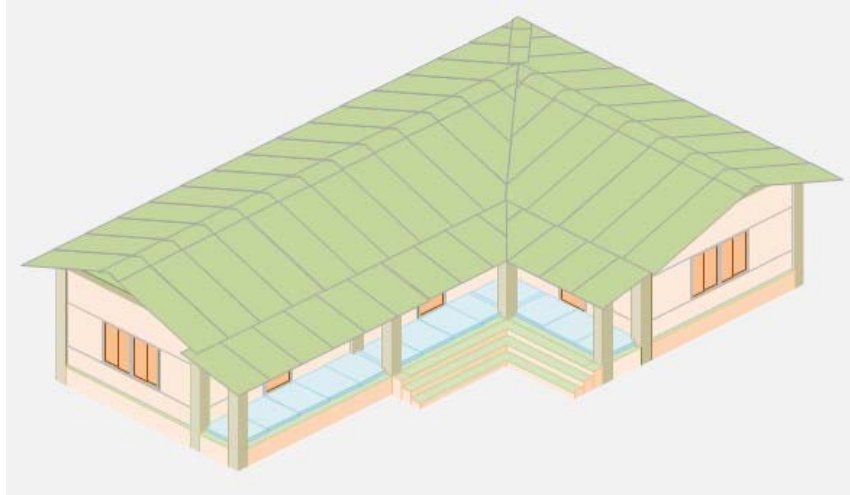


Figure 6. An all composite modular residential house

Table 3: Composite modular residential house – component wise size and weight

Component	Maximum unit size ($mm \times mm \times mm$)	Maximum unit weight (kg)
Foundation plates	$400 \times 400 \times 20$	6
Foundation panels	$4500 \times 1200 \times 300$	430
Columns	$4200 \times 100 \times 100$	32
Beams	$4800 \times 100 \times 100$	36
Floor panels	$4100 \times 940 \times 100$	218
Wall panels	$4700 \times 1050 \times 100$	242
Roofing panels	$4100 \times 940 \times 100$	218
Roofing support panels	$4800 \times 1000 \times 300$	221
Roofing sheets	$3600 \times 1000 \times 3$	20

4.2 Composite Emergency Shelter

Emergency shelters have been addressed among others by Abdolpour et al (2016 and 2018). There exist immense possibilities for composite emergency shelters for flood affected people of Assam and many other such places. The basic objective of such an emergency shelter is to erect temporary dismantlable houses on high land in quick time when the need arises. A scheme for such a dismantlable composite house is proposed here for further work. It is a simple frame-structure consisting of columns, beams and panels for floor, walls and roof. Figure 7 shows some of the primary components of the emergency shelter. The components of the house, their materials, manufacturing processes, sizes and maximum unit weights are listed in Table 4. As seen from the sizes and weights, these components can be easily transported and assembled. Total weight of the shelter house is estimated as $822kg$. The assembly procedure involves snap-fit joints that make it possible, after the emergency need is over, to dismantle and store the components for future. Different stages of assembly and the final composite house are shown in Figures 8 and 9 respectively.

Table 4: Composite emergency shelter – component wise size and weight

Component	Maximum unit size ($mm \times mm \times mm$)	Maximum unit weight (kg)
Support blocks	$300 \times 300 \times 300$	9
Columns	$2400 \times 100 \times 100$	10
Beams	$3000 \times 300 \times 200$	22
Floor panels	$3200 \times 1000 \times 100$	52
Wall panels	$3200 \times 750 \times 100$	40
Roofing sheets	$3400 \times 1000 \times 5$	18

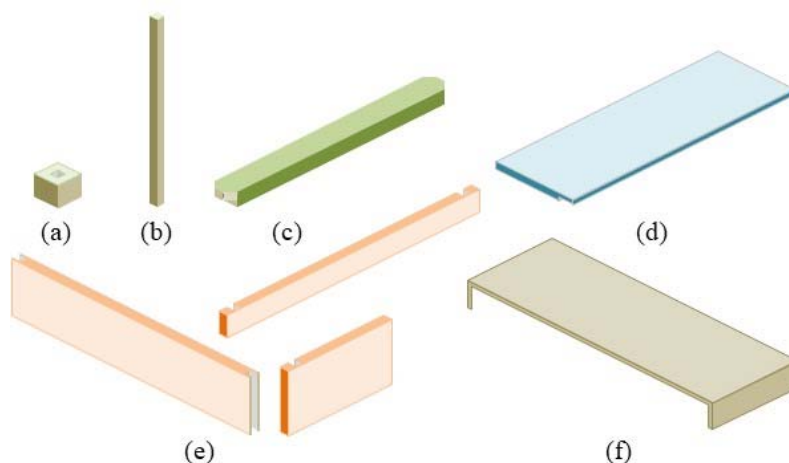


Figure 7. Typical components of a composite emergency shelter (a) support blocks, (b) columns, (c) beams, (d) floor panels, (e) wall panels and (f) roofing sheets

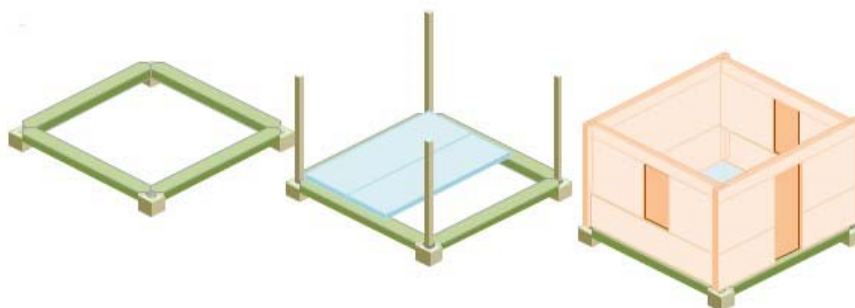


Figure 8. Different stages of assembly

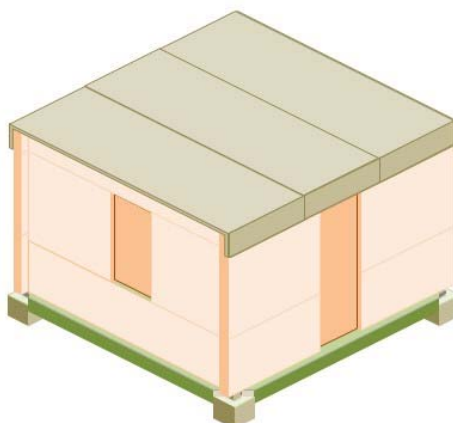


Figure 9. An all composite emergency shelter

4.3 Portable composite bridge

Composite portable bridges can be a highly effective, reliable, safe and durable alternative to bamboo and timber bridges in the interior villages. A conceptual portable single-span composite bridge is presented here. The objective is to introduce an easy-to-manufacture and quick-to-launch bridging system for short gaps. The bridge should be capable of supporting normal village traffic load. It consists of two sets of girders, support panels and deck panels. The girders are provided with integral slots for keys that can be used to connect adjacent girders. The components (Figure 10) of the bridge are to be manufactured as GFRP sandwich panels involving minimum technological complexity. The girders are launched, aligned and bonded to the support panels on either end. The deck panels are then bonded onto the girders to complete the bridge (Figure 11).

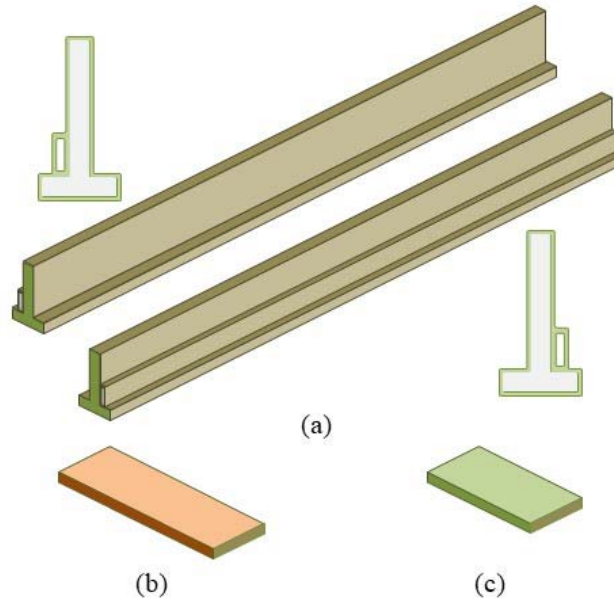


Figure 10. Typical components of a single-span composite bridge (a) girders with integral slot for connecting key, (b) support panels, (c) deck panels

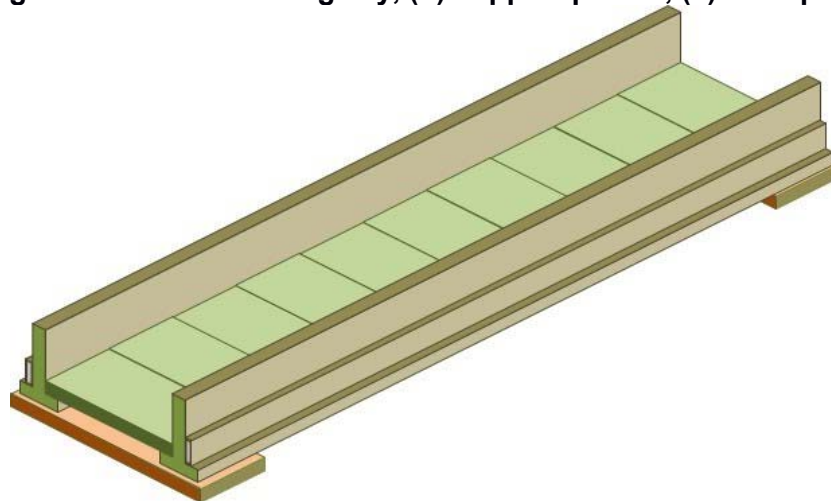


Figure 11. Assembled single-span composite bridge

4.4 Public Utility

Another area in a smart village where composites can play a role is in public utilities such as public toilet, rest shed, public dust bin, make-shift foot path, etc. A new dimension can be added by considering locally available materials such as bamboo as the reinforcement. Extensive research has been carried out to explore use of bamboo in composites (Shah

2018, Sharma 2015, Sharma 2015 and Reynolds 2016). Skill of local population in making bamboo craft can be extended to making preforms for such utility products. These preforms can be impregnated by polyester resin that would increase not only functional and aesthetic appeal but also product life making them cheaper in the long run.

5. CONCLUSION

- A brief introduction to composites is given. Composites have unique performance characteristics and manufacturing processes. They are associated with distinct advantages and they have applications in a wide spectrum.
- A generic review of applications of composites in housing and infrastructure is given. Extensive work has been done on fiber reinforced composites for civil engineering applications and composites have found acceptance in not only strengthening and rehabilitation of existing structures but also construction of new structures.
- A few possibilities of using composites in a smart village are identified and conceptual construction methodologies presented. Basic processing method of the elements and assembly procedure are kept simple for easy acceptance by the common man. Further research and a concerted effort would be necessary to translate these concepts to reality.

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Embodied emissions analysis of emerging construction technologies for mass housing in India

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Abstract: The construction and use of buildings is responsible for a significant proportion of global greenhouse gas emissions. With global population growth continuing unabated, alongside increasing living standards in developing regions, this is predicted to continue. While global efforts to reduce the emissions associated with buildings have achieved significant operational efficiencies and emissions savings, buildings still represent a considerable opportunity for achieving the deep cuts in emissions that are needed to avoid the predicted catastrophic consequences of climate change. With the embodied emissions of buildings accounting for an increasingly significant proportion of a building's life cycle emissions, and this being of little focus to date, this is one area in which some of these emissions cuts could be achieved. The Building Materials and Technology Promotion Council (BMTPC) of India have developed a list of potential building construction technologies aimed at improving the performance of housing in India. While these are assessed across a number of parameters, their embodied emissions are often not considered. This study assesses the embodied emissions of these technologies with the aim of determining whether they offer a potential solution for reducing building embodied emissions compared to more traditional housing construction. It was found that the proposed emerging technologies may increase the embodied emissions associated with housing by up to 400% when compared to more conventional forms of construction.

Keywords: *Construction technologies, embodied emissions, housing, India.*

1 Introduction

Global greenhouse gas emissions continue to rise, despite efforts by many regions of the world to reduce them. Significant cuts in emissions are still needed to avoid potentially catastrophic consequences on human civilisations and broader global ecosystems, and time is drastically running out (IPCC, 2014). Buildings alone represent approximately 39% of annual global greenhouse gas emissions (UN Environment and International Energy Agency, 2017) and thus represent a crucial opportunity for achieving deep emissions cuts. In light of this, considerable effort has been put into reducing the emissions associated with building operation, by achieving greater efficiencies in heating, cooling and lighting, in particular.

Despite these efforts, and considerable reductions in building-related operational emissions over recent decades, net building-related emissions continue to rise. Key reasons for this are a growing global population, increasing housing demand, and rising expectations and needs (for air conditioning, for example). India alone is currently undergoing a rapid and massive expansion of its housing stock. It is predicted that at least 200 million new houses will be required in India alone by 2030 (Planning Commission (Government of India), 2008). As part of this, around 20 million new houses are planned from 2015 to 2022 under the Pradhan Mantri Awas Yojana (PMAY), or Housing for All scheme. This will place further demand on energy resources and lead to a considerable increase in greenhouse gas emissions based on the predominately fossil fuel-based energy mix of the country. According to Hardeep Puri, Minister of State for Housing and Urban Affairs, 'India has embarked on the most comprehensive, planned programme of

urbanisation undertaken anywhere in the world. This massive push involving huge projects will be green and resilient, according the highest priority to environmental concerns.’ (BMTPC, 2018).

1.1 Embodied emissions

Commonly lacking from the building-related emissions reduction efforts are the non-operational-related emissions. As per Figure 1, buildings go through a number of stages throughout their life. This begins with planning and design, through to eventual disposal. The operational-related emissions (B6) represent an increasingly small proportion of total building-related emissions. As buildings become more energy efficiency, emissions related to material production (known as embodied emissions) are becoming increasingly significant, approaching 100% of emissions for zero operational emissions buildings. Much greater emphasis is thus needed on this part of the building life cycle, as highlighted by the World Green Building Council (Adams et al., 2019).

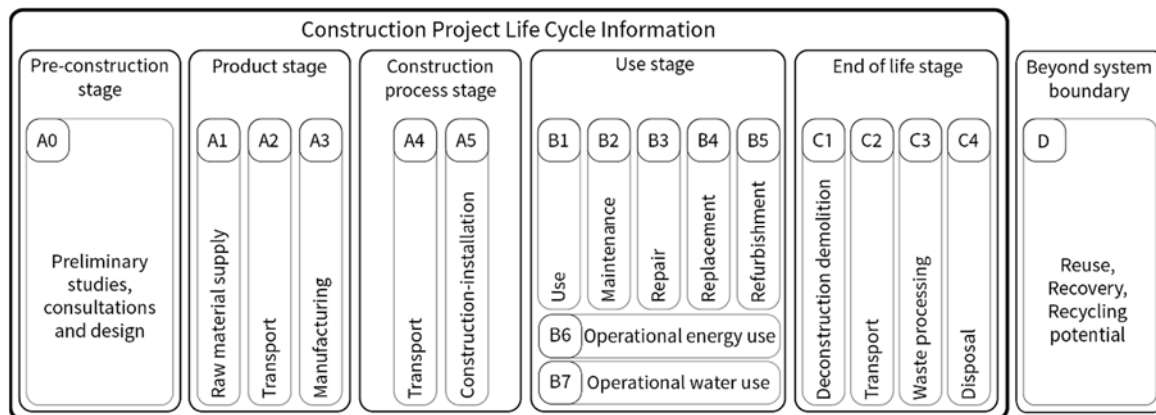


Figure 1: Life cycle stages of a construction project (based on EN 15978 (2011))

1.2 Emerging construction technologies for India

The Building Materials and Technology Promotion Council (BMTPC), part of the Ministry of Housing and Urban Affairs for the Government of India, have acknowledged that conventional construction practices are slow, have been declining in quality, and are energy, resource and emissions intensive (BMTPC, 2018, 2019). Much of these issues stem from the widespread use of insitu reinforced concrete and brick construction.

The BMTPC aims ‘To work towards a comprehensive and integrated approach for promotion and transfer of potential, cost-effective, environment-friendly, disaster resistant building materials and technologies including locally available materials from lab to land for sustainable development of housing.’ (BMTPC, 2019). In an attempt to achieve this, they have published the Compendium of Prospective Emerging Technologies for Mass Housing (BMTPC, 2018). The third edition of this report was released in September 2018 and contains 24 emerging technologies for use in the construction of mass housing in India (Table 1).

Table 1: List of prospective emerging technologies for mass housing (BMTPC, 2018)

Technology Name	
1	Monolithic Concrete Construction System
2	Modular Tunnel Form
3	Insulating Concrete Forms
4	Monolithic Insulated Concrete System
5	Structural Stay-in-place formwork system
6	Lost-in-place formwork system- Plaswall Panel system
7	Lost-in-place formwork system- Plasmolite Wall Panels
8	Sismo Building Technology
9	Advanced Building System – Emmedue
10	Rapid Panels
11	Reinforced EPS Core Panel System
12	QuickBuild 3D Panels
13	Concrewall Panel System
14	Glass Fibre Reinforced Gypsum Panel System
15	Prefabricated Fibre Reinforced Sandwich Panels
16	Rising EPS (Beads) Cement Panels
17	Light Gauge Steel Framed Structure (LGSF)
18	Light Gauge Steel Framed Structure with Infill Concrete Panel Technology
19	Factory Made Fast Track Modular Building System
20	Speed Floor System
21	SRPL Building System (Waffle-Crete)
22	Precast Large Concrete Panel System
23	Industrialized 3-S system using RCC precast with or without shear walls, columns, beams, Cellular Light Weight Concrete Slabs/Semi-Precast Solid Slab
24	Walltec Hollowcore Concrete Panel

It has been suggested that these technologies are able to provide benefits such as 'low maintenance, better durability, improved thermal & acoustical performance, better hazard resistance, low wastages, less pollution & above all green & sustainable development' (BMTPC, 2018). In addition, in alignment with their aims, the BMTPC (2018) states that 'The emerging technologies included in the Compendium have low life-cycle cost and thereby resource-efficient and environmentally-responsible.' As part of their activities, the BMTPC tests and certifies the performance of building materials under the Performance Appraisal Certification Scheme (PACS). This includes the profile and usage of the material, process of manufacture, performance characteristics, and social aspects.

PACS includes a performance criterion for energy consumption during manufacture (embodied energy) (Figure 2), but from observation of all of the issued PACs on the BMTPC website, none have reported on this criterion. This highlights a significant gap in our understanding of how these emerging technologies may address the aims of the Indian Government and BMTPC of promoting green, environment-friendly building materials and technologies in order to achieve the sustainable development of housing.

6.2 Energy consumption / conservation / efficiency

Attach a brief note on the Energy consumption / conservation / efficiency aspects of your product, if any
(For points that may be considered see 6 of Annex)

6 6.2 Energy consumption / conservation / efficiency

6.2.1 Compare the energy consumption / conservation / efficiency (qualitatively / quantitatively) with other similar products for the same end use, both in the manufacture of the product and the use of the product

Reduced energy inputs/consumption over other products which perform the same function

In manufacture					In Use			
NA	Y	N		ELECTRICITY	NA	Y	N	
NA	Y	N		COAL	NA	Y	N	
NA	Y	N		PETROLEUM BASED FUEL	NA	Y	N	

Figure 2: Energy consumption criterion within PACS (BMTPC, 2019)

1.3 Aim

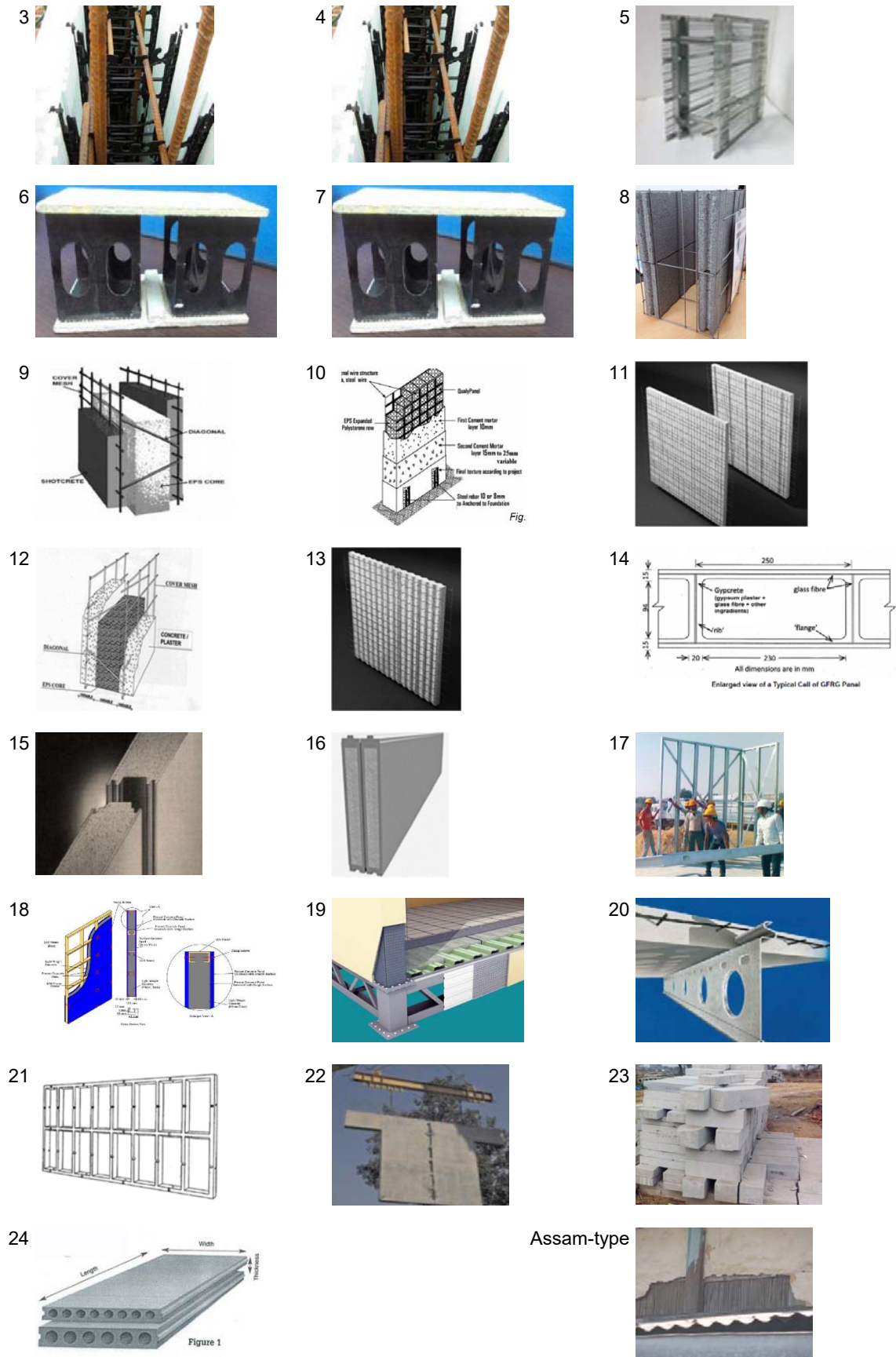
The aim of this study was to quantify the embodied greenhouse gas emissions associated with the emerging construction technologies identified by the BMTPC. It was hoped that this would shed some light on the potential embodied emissions implications of moving from more traditional construction techniques to these more modern methods of construction.

2 Approach

This section outlines the approach used to quantify and analyse the embodied greenhouse gas emissions of the various construction technologies listed in Table 1. This is represented by A1-A3 in Figure 1.

2.1 Selection of technologies

The analysis was limited to the technologies that could act as a direct replacement for conventional building elements. Hence, technologies 1 and 2 which are temporary formwork systems rather than building elements, were excluded. The remaining technologies were grouped into wall and/or flooring systems. All remaining technologies except for 20 and 23 were analysed as a wall element, while technologies 9-11, 14 and 20-23 were all analysed as a flooring element. Variations within each technology are possible, such as thickness and type of materials. For consistency, the most common form was selected. Where variations in wall thickness were possible, walls were assumed to be 250 mm thick, or as close as possible to this. See Figure 3 for images of all technologies analysed. Finishes were excluded. In addition, typical construction of the Assam-type house was used as a comparison and benchmark. For this, wall construction was assumed to be timber-framed, infilled with Ikra reed and bamboo panels and finished with cement-based plaster. Floor construction was assumed to be wooden plank flooring on wood runners and beams (Kaushik & Ravindra Babu, 2009).



Assam-type

Figure 3: Emerging construction technologies (BMTPC, 2018)

2.2 Embodied greenhouse gas emissions analysis

The embodied greenhouse gas emissions analysis of the technologies was conducted by quantifying the embodied emissions of each constituent material within each technology (wall or floor element). The functional unit chosen was one square metre of wall or floor. The quantity of each material was determined based on the details provided by BMTPC (2018). Each material was then multiplied by its respective embodied emissions coefficient (in MJ per unit of material), obtained from the EPIc Database (Crawford et al., 2019). Material-based embodied emissions values were then summed for each technology/element to determine the total embodied emissions for the element. A breakdown of the embodied emissions quantification for each technology is available at <https://doi.org/10.26188/5dd8eda8d90ae>.

3 Results

This section presents the results of the embodied greenhouse gas emissions quantification for the individual technologies. Figure 4 shows the embodied greenhouse gas emissions for the wall technologies, by material. These are compared to the typical wall construction of the Assam-type house, just one example of a conventional construction approach. This shows that cement-based materials (plaster, FC sheet and concrete) and steel contribute significantly to the total embodied emissions for most technologies. Compared to the typical wall construction of an Assam-type house, representative of primitive or traditional construction, the emerging technologies range from 25 to 400% more emissions intensive.

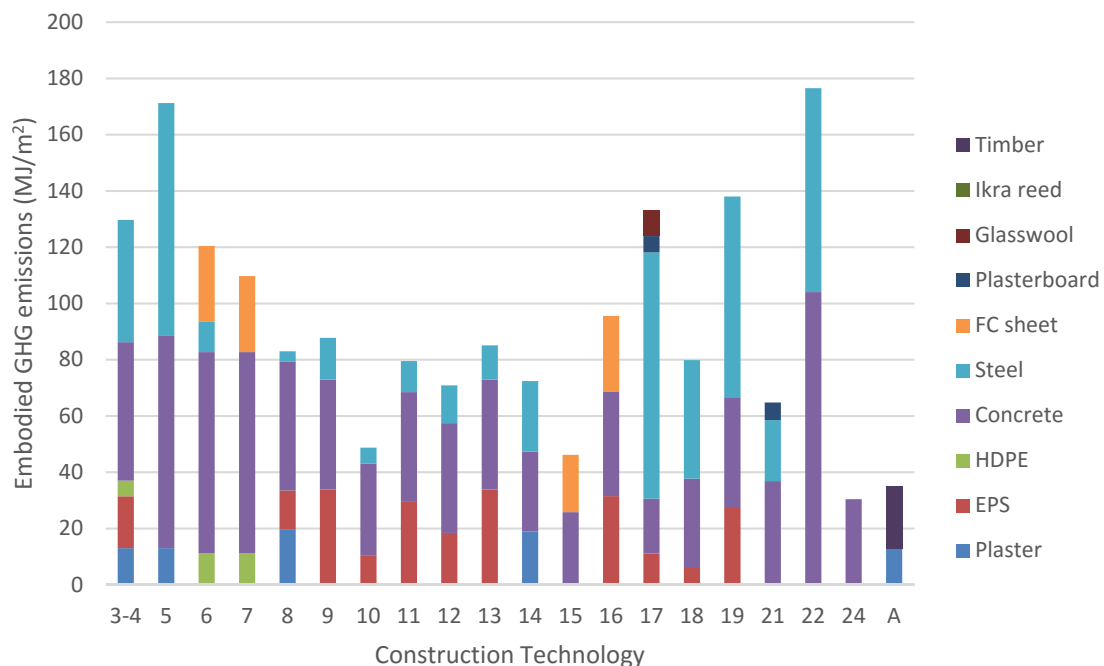


Figure 4: Embodied greenhouse gas emissions of emerging wall construction technologies, by material (A = Assam-type house used for comparison)

Figure 5 shows the embodied greenhouse gas emissions for the floor technologies, by material. These are compared to the typical floor construction of the Assam-type house, in this case assumed to be made of kiln-dried hardwood timber beams and floor boards. This shows again that concrete and steel contribute significantly to the total embodied emissions for most technologies. In this case, the Assam-type house doesn't represent a significant reduction in emissions. In this study, a conservative approach has been used for comparison purposes (i.e. assuming more emissions intensive conventional

construction), meaning that the large amount of timber used results in embodied emissions that are on par with the emerging technologies. If the timber was air-dried instead of kiln-dried or an earth-based floor was used this would substantially reduce the embodied emissions of the Assam-type house. It should also be noted that carbon sequestration is not considered in this analysis, which would again bring down the net embodied emissions of the timber floor.

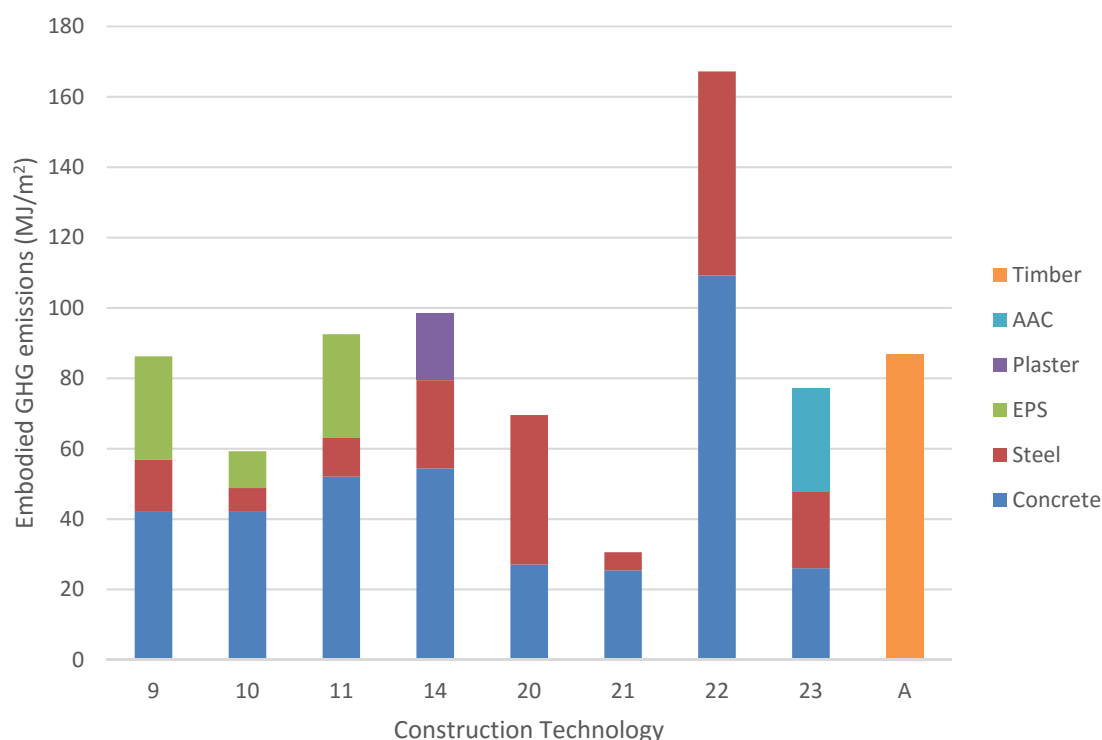


Figure 5: Embodied greenhouse gas emissions of emerging floor construction technologies, by material (A = Assam-type house used for comparison)

4 Discussion and Conclusions

The emerging construction technologies identified by the BMTPC are heavily skewed towards steel and concrete-based solutions. These materials are known to be highly emissions intensive and so it is no surprise that the embodied emissions analysis conducted finds that the majority of these technologies result in a significant increase in embodied emissions compared to more primitive construction approaches. Compared to the typical wall construction of an Assam-type house, representative of primitive or traditional construction, the emerging technologies are 25 to 400% more emissions intensive. There is also a direct correlation between the quantity of materials used and the overall embodied emissions of the technology. This highlights the potential for design rationalisation and dematerialisation strategies to assist with building-related emissions reduction.

Housing in India has traditionally used, and in many areas still relies heavily on, primitive materials that are often renewable and low in embodied emissions. As living standards and expectations increase, there is a huge risk that non-renewable and highly emissions intensive materials, like concrete and steel, may become more desired and prevalent, diminishing, rather than enhancing the environmental sustainability of housing in India. This highlights that considerable further effort is needed in order to find appropriate solutions that provide improved living standards for Indians with materials that are durable,

low cost, safe and above all, avoid the production of greenhouse gas emissions. A balance must be struck between all of these factors.

While this study has considered the embodied greenhouse gas emissions of emerging construction technologies, there are other environmental flows that should also be considered. With raw material depletion, water use, pollution and loss of biodiversity some of the other issues of concern, globally, these should also be considered in any decisions relating to material selection.

There are a number of limitations of this study. It should be noted that the comparison has been made based on an equivalent wall or floor thickness (where standard product thickness doesn't apply). A more appropriate unit of comparison may be based on either structural or thermal performance. The data used for the analysis is based on international manufacturing practices and the Australian fuel mix. These may or may not be representative of the manufacture of the technologies being produced and used in India. A more emissions intensive fuel mix will actually increase the embodied emissions values.

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English Language development in the Village Schools: A Case Study in Assam

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Abstract: *The medium of instruction in village schools plays a pivotal role in the overall development of a student. In most of the village schools, teachers prefer vernacular language as a primary medium of instruction. The use of native language is useful in the sense that it reduces the cognitive load of the students, and they can quickly grasp a new idea/information. Nevertheless, the excessive use of vernacular language prohibits the efficient learning of English in the English language classroom. The influence of the native language in such scenarios overrides the pronunciation of English words. In addition to that, it also affects the English language fluency in higher career life. Such schools have to invest extra time for English learning and speaking for satisfactory performance. 50 students who have completed their undergraduate programme in the humanities participated in the study. The participants were within the age group of 20-25. They were residents of the Kamrup district in Assam. The participants are native Assamese speakers who did their primary and high school from Assamese medium government schools. Recording is done for the purpose of the study. It is found that the Assamese learners of English face three kinds of English pronunciation impediments-i. Challenges with individual sounds-substitution of vowel or consonant sound for other near matching sounds, failure to make distinction between tense and lax vowels ii. Challenges in combining sounds to form words-incorrect pronunciation in words due to the nonlinearity in the orthography and sound system of English language, incorrect pronunciation for inflected words, iii. Challenges with prosodic patterns-either incorrect stress placement or no distinctive stress at word level. Sentence stress was almost flat among the learners.*

Keywords: *Error Analysis, ESL, Phonemic and prosodic errors*

1 Introduction

Assamese belonging to the Indo Aryan language family is the official language of the North Eastern state of “Assam”. The Assamese language is almost phonetically written. There is a consistent representation of nearly every sound by a certain letter. In other words, there is a one to one correspondence between the spoken and the written form in the language. On the other hand, the 44 phonemes of the English language (British RP) are represented merely by the 26 letters or alphabets. English pronunciation is perceived as one of the most challenging skills to acquire (Pourhosein Gilakjani, 2016) in language learning. Intelligible pronunciation is one of the primary requirements of L2 learners' competence (Morley,1991). Second language learners generally face challenges at each linguistic stage viz. phonemic level, word level, phrase level and above. Phonemic level challenges are attributed to the use of native phoneme for the near matching phonemes of the second language, for example, participants uttered the word /romantic/ as /roma:ntik/ instead of / rəʊ'mæntɪk/. It signifies that /æ/ in the given example is replaced by /a:/. Accentual distinction at the word level is very crucial for the effective learning of English as a second language. For example, consider the word /content/ which is a noun as well as a verb. In the case of noun the first syllable is stressed (i.e., 'content) and in the case of verb the second syllable is stressed (i.e., con'tent). Finally, the phrase level, the overall prosodic pattern need to be learnt for effective language use. For example, English declarative sentences have falling pitch pattern unlike the question sentences. Question sentences having rising pitch pattern in English.

English is taught as a compulsory subject even in the Assamese medium schools. However, students generally do not pay much attention to the subject as compared to subjects like Mathematics or Physics. Mostly the students coming from an educated background score good marks in the English test. The theme of literary topics are not grasped by most of the students rather they do rote learning to score good marks in the exams. In contrast to the urban English second language learners, the rural English second language learners are far lacking behind in English language proficiency at every linguistic and communicative aspect in the learning of a language. Teaching and learning of English pronunciation by Assamese native learners is very unsatisfactory in the Assamese medium schools in rural Assam. Kakati's (1972) study is the earliest study which examines the phonemic inventory of the Assamese language. Baishya (2007) studied on the pedagogical implication of vocabulary items for Assamese medium learners in the Kamrup District. In addition to morphological differences, she looks at the differences between English phonology and Assamese phonology. She studied on errors in high school students' vocabulary pronunciation. Baishya (2013) has studied on the rural Assamese ESL learners challenges in producing the English fricative and affricates. Das (2014) has studied on the challenges in the production of central vowels and centering diphthongs by Assamese speakers of English. He has conducted this study in the Dhubri District in Assam.

The present study looks at the errors rural Assamese undergraduate ESL learners of the Kamrup District commit in pronunciation of English words and sentences. The objective of this research is the following.

1. Identification of the characteristics of pronunciation errors by undergraduate native Assamese speakers having primary education in Assamese medium school.
2. Examine the reasons of L2 learners pronunciation errors.
3. Examine the accentual/rhythmic errors at word and sentence level.

2 Theoretical Background

Intelligible pronunciation is very crucial to English language learning (Jesry, 2005). In other words, it is not mandatory to sound like a native English speaker but it is of extreme importance that the English Second language learners have a basic level of English pronunciation competence. Good pronunciation is observed to have a lot of positive effects in the present society. In addition to that, good pronunciation helps in bridging the gap between the speaker and the listener. On the contrary, pronunciation inferior than the basic level in English creates misunderstandings (Gilakjani, 2011). Undoubtedly, phonological system developed out of the native language impacts in the learning of English pronunciation (Huang & Radant, 2009), but effective ways of teaching English as a second language can overcome these challenges. According to Gilakjani (2011) the standardized ways of English should be taught in the ESL classes. Teachers can help ESL learners by developing insights based on the ESL Learner's pronunciation variation. Moreover, they can tweak their pronunciation teaching methodology to help in learning the language efficiently (Charity & Malison, 2011). Several studies have been conducted to observe the pronunciation variations on learners with different native languages - Vietnamese (Nguyen, 2007), Chinese (Zhang, 2009), Arabic (Swan, 2001), Japanese (Ohata, 2004). For instance- Arabic English Second language learners mispronounce words having sounds /p/ and /b/, due to the absence of the voiceless counterpart of /b/ in their native language (Swan, 2001). The mispronunciation of certain sounds like /p/, /b/, /v/, /b/ etc (O'Connor, 2003; Yule, 2003) occurs due to the learners practice of their native language. The pronunciation system of the English language has experienced numerous changes throughout the history of the language but the English orthography has not taken pace with the phonological changes. The sound and the orthography do not correlate exactly. For instance- 'k' is represented by different alphabets in the words 'cat' and 'kite'. Orthographical differences has also been one of the causes of pronunciation errors in ESL learners (O'Connor, 2003).

4 Data Collection

50 students who have completed their undergraduate programme in the humanities participated in the study- 30 are male and 20 are female. The participants were within the age group of 20-25. They were residents of the Kamrup district in Assam. The participants are native Assamese speakers who did their primary and high school from Assamese medium government schools. The participants were asked to read 10 paragraphs from English NCERT (Class XII, Part 1). None of the participants are informed in advance about the objective of the data collection process. The read speech of each participant is recorded using Sony ICD-PX470 Digital Voice Recorder in PCM (i.e., .wav format) at a high resolution sampling rate of 44.1 kHz. Each participant is recorded only once for each paragraph.

5 Data Analysis

The phonemic alignment and word level alignment for these recorded audios are obtained automatically using the help of Kaldi based speech aligner (McAuliffe, et. al., 2017). The automatically aligned files are manually corrected using Praat (Boersma, 2002). The detailed analysis suggests that the following are the main challenges for the learners.

- i. individual sounds i.e., the substitution of vowels or consonants sound for other sounds and failure to make distinction between tense and lax vowels.
- ii. Combining sounds to form words i.e., the incorrect pronunciation in words due to distinction in orthography and sound. Generally words having more than 3 syllables and inflected words are difficult for them to correctly pronounce.
- iii. Incorrect or no proper use of prosodic variations i.e., incorrect or no stress in all the syllables in a word.

Challenges with individual sounds

- a. The Assamese learners found the distinction between very similar sounds difficult to notice and pronounced the phoneme which is present in the native language.
 - (i) /ʃ/ and /s/ in the term 'short' and 'story' as /s/. Since the phoneme /ʃ/, which is a post alveolar voiceless fricative is absent in the native language's phonemic inventory whereas /s/ is present in the learners' L1.
 - (ii) /i/ and /ɪ/ in the terms 'story' and 'into' as /i/. The phoneme /ɪ/ is absent in the learners native language whereas /i/ is present in the learners' L1.
 - (iii) /ʌ/ is produced as /ɔ/ in words like 'covers'. /ɔ/ is present in the learner's native language.
- b. The study shows that the learners have failed to make a distinction between the tense vowels and the lax vowels.
 - (i) /u/ and /u:/ in words 'book' /bʊk/ and 'room' /ru:m/. The learners have preferred the use of the short vowel /u/, which is also called as the back rounded close vowel.
- c. Errors in the production of vowels and consonants is also observed because of the distinction between the English orthography and the sound it represented.
 - (i) /ɪ/ in the word 'limited'/'limitɪd/ is pronounced as /e/ because of the English written text.
 - (ii) /ŋ/ in the word 'length'/'leŋθ/ is pronounced as /n/ because of the English written text.
 - (iii) /z/ in the word 'tragic'/'tregɪk/ is pronounced as /g/ because of the English written text.

Challenges in combining sounds to form words

- a. The learners mispronounced the syllables formed with a fricative and an open-mid back long vowel and inserted the alveolar trill /r/.
 - (i) The word 'thoughts' /θɔ:ts/ was pronounced as /θrɔts/*. [*-refers to error]
 - (ii) The word 'form' /fɔ:m/ was pronounced as /frɔm/*.
- b. The pronunciation of the inflected words were difficult to produce for the learners.
 - (i) The word 'organises'/'ɔ:gənəɪzɪz/ was pronounced as /ɔrzeniz/*
- c. Unfamiliar words are generally pronounced incorrectly by the learners. They also insert intraword pauses for unfamiliar words.
 - (i) The words such as 'tauntness' /'tɔ:tnəs/ , 'satiric'/'sə'tɪrɪk/which were unfamiliar to them were pronounced as /tɔutes/* and /strik/* respectively. More such examples are provided in Table 1.

Words	Correct pronunciation	Incorrect pronunciation by the learners
organises	'ɔ:gənaɪzɪz	ɔrzeniz*
tragic	'trædʒɪk	tregik*
satiric	sə'tɪrɪk	strik*
expensiveness	ɪks'pænsɪvnəs	ekspen-si-venses*

Table1: Examples of words which are difficult to pronounce by the learners

Challenges with prosodic patterns

General stress related errors are shown below in Table 2. Errors are made due to different prosodic patterns in English and Assamese. Sentence stress was almost flat among the learners. The stress in Assamese sentences in some of the dialects of Western Assam viz. Kamrup Dialect is initial. The learners are not able to differentiate the stress patterns in English.

Words	Correct stress pattern	Stress pattern produced by learners
narrative	'nærətɪv	nəre'tɪv*
diversity	daɪ'vɜ:sɪti	'divarsiti*
representing	,reprɪ'zɛntɪŋ	ripel' tɪʃən*

Table2: Example of words showing stress related errors by the learners

6 Conclusion and Future Works

It is found that the Assamese learners of English face three kinds of English pronunciation impediments-i. Challenges with individual sounds -substitution of vowel or consonant sound for other near matching sounds, failure to make distinction between tense and lax vowels, ii. Challenges in combining sounds to form words-incorrect pronunciation in words due to the nonlinearity in the orthography and sound system of English language, incorrect pronunciation for inflected words, iii. Challenges with prosodic patterns-either incorrect stress placement or no distinctive stress at word level. The learners L1 is seen to be one of the sources for the cause of errors in pronunciation. Moreover, errors are made due to the lack on knowledge of difference in prosodic patterns in English and Assamese.

Future works can look into the phonological errors among Assamese ESL learners in the different dialects of Western Assam.

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Heuristic Layout Planning of Eco-Village in Kumbh Mela, India

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Abstract: *Eco-village, being a green, sustainable, and rejuvenating place, is growing and attracting people all across the globe. It offers a unique way to live in close relation and symphony with nature. However, the knowledge system is inadequate, the methodology of layout planning and development guidelines of such eco-villages in the Indian context, especially for spiritual and religious gatherings. This study implements various methodologies of space optimization utilizing the principles of layout planning, activity space design, and optimization for the development of a holistic eco-system using the principles of sustainable construction, architecture, and built environment. The work acts as a real-life case study for the setting up of such an ecosystem in the Jhansi area of Prayagraj, India, at the holy confluence of three rivers (Triveni Sangam) during the Kumbha Mela event attended by over 80 million people. A heuristic approach to layout planning is adopted to optimize the total distance of travel, thus, saving commutation time between various activity spaces in the eco-village. A sustainable approach has been adopted with the incorporation of the best available methods and practices of energy production and conservation, water supply, and wastewater management, providing safety, security, and satisfaction of the occupants. This study provides a roadmap towards adopting a sustainable and energy-efficient approach using heuristic layout approach towards planning and developing an eco-village providing a useful tool for planners, designers, site engineers, and administrators to achieve responsible co-existence of humanity with nature.*

Keywords: *Eco-Village; Energy and Environment; Kumbh Mela, Layout Optimization; Sustainable Built Environment*

1 Introduction

The ideal eco-village, which does not yet exist, is a sustainable human settlement which is in harmony with all aspects of life, including cultural, ecological, and spiritual dimension (GEN 2015; Gilman 2019). Though the eco-villages have been existing for a long time, however, it is not earlier than three decades that it appeared in literature for the first time. The word “eco-village” appeared first in the work of Robert Gilman in his report for Gaia Trust entitled “Eco-villages and Sustainable Communities: A Report for Gaia Trust,” who identified various eco-villages around the world (Gilman 2019). There exists a gap in the knowledge system of the sustainable designing and construction of such eco-villages, including its layout planning in the Indian context where religious faith, traditional practices, and spirituality plays a vital role. This is reflected in the study site with all traditional Vedic elements of layout such as the Yoga center, Meditation hall, Yajna (practice of *hom-hawan* using pious wood ingredients and fire) hall, river deck (ghat) for bath and other areas forms a key role.

The eco-village distribution study that eco-villages are existing across the globe but appears mostly in industrialized nations strongly influenced by Western cultures- such as Europe (34), North America (19), with significant numbers in Australia, New Zealand, South Africa, and India (Leopoldstrasse and Issn 2012). The reason behind a large number of eco-villages identified in Europe is mainly due to extensive research activity by European researchers who have identified this concept as a significant component of achieving the goal of sustainability in the modern built environment.

Thus, there is an intense need for active research-work in the field of an eco-village in Indian sub-continent, where there is a considerable dearth in the body of knowledge dealing with the technical aspects of eco-village such as layout design, and incorporation of available suitable sustainable practices from the knowledge system in the technical community.

2 Eco-tourism

Tourism is a growing economic sector in India. It has huge potential and scope for development (Aguado, Echebarria and Barrutia 2011). It leads to large scale employment and, thus, economic output to the nation's GDP. Development of eco-villages is one of the ways to attract tourists and showcase our rich traditional, cultural, religious, and spiritual heritage (Aguado, Echebarria and Barrutia 2011). Two common eco-villages, namely Sieben Linden eco-village, Bettendorf, Germany (Figure 1.1), and Auroville in Pondicherry, India (Figure 1.2) having a growing community of 2,700 inhabitants from 50 nations are shown. The aerial view of the last *Kumbha Mela* held in 2013 (Figure 1.3) illustrates the complexity involved in proper designing a safe, eco-friendly eco-village that could cater to 120 million pilgrims at the small city of Prayagraj (Figure 1.4) at the confluence of 3 holy rivers.



Figure 2-1: Pictorial view of Auroville, Pondicherry, India

Figure 2-2: Sieben Linden Eco-village, Bettendorf, Germany



Figure 2-3: Aerial View of Kumbh Mela 2013 (Baranwal et al., 2015)

Figure 2-4: The city of Prayagraj at the confluence of three rivers (Tiwari, 2015)

2.1 Eco-village

Eco-villages are traditional or intentional (i.e., planned and engineered) communities whose goal is to become more socially, culturally, economically, and ecologically sustainable. They are consciously designed through a locally owned participatory process to regenerate and restore their social and natural environments (Jackson 2004).

This project envisages the study evolving the development of an eco-village on the bank of river Ganges in Prayagraj, India. It is planned and designed to provide maximum comfort and minimum time spent to commute between the activity spaces in the built environment. Many suitable and appropriately available sustainable practices have been incorporated (Lanka, Ngo, and Foundation 2016).

2.2 Prayagraj City and the Kumbha Mela

The city generates over 500 tons/day of municipal solid waste and is a significant contributor to the river Ganges pollution. This pollution rate increases exponentially during the festivals and significant events in the city and, most importantly, during “The KUMBH”- the largest gathering on earth (Baranwal et al. 2015). These festivities cause an enormous gathering in the small city where the administration and the city authorities are over-burdened. This leads to loopholes in planned layout, waste management, and several issues specific to the site. There is a gap in knowledge system for the layout planning of such an important ecosystem for the specific gathering in the Indian context, celebrated after a long time gap as Kumbh is celebrated at four Indian cities after every 12 years in contrast to any other spiritual gathering celebrated annually. This two

months-long holy festival is celebrated as '*Maha-Kumbh*' (Great Kumbh) after every 12 years and as '*Ardh-Kumbh*' or simply '*Kumbh*' every six years after Maha Kumbh. This festival attracts millions of pilgrims, tourists, and foreign visitors from across the globe to Prayagraj, India bringing in a lot of tourism development opportunities and scope for formulating sustainable built environments such as eco-village. This will not only act as an ideal sustainable built environment for the settlements in this holy city but will also work as a pilot project to evolve and come up with tools, techniques, and methods for sustainable layout, including the management and disposal of wastes generated.

Though the annual average number of visitors is around 0.2 million per day in the city, it increases considerably during festivals such as Kumbh Mela. The number of visitors within 60 days of the gathering of Maha Kumbh 2013 were more than 80 million, and it is expected to be over 120 million in the recently concluded Kumbh Mela 2019 ('Kumbh Mela : The world 's largest religious gathering sets three world records,' 2019).

There exists a significant opportunity for government administration, management and India's scientific and technical community as a whole to provide sustainable waste management techniques, control pollution level in Ganges and showcase a substantial, workable and sustainable built environment model, catering to the visitors' and tourists' needs in order to create sustainable societies within the city. It will not only lead to visitors' satisfaction but will also pave the way for the inspiration and motivation behind the sustainable development and accommodation facility for many ashrams, societies, and organizations in Prayagraj and similar cities of pilgrimage in India.

2.3 Sadguru Sadafaldeo Vihangam Yog Organisation (SSDVY)

This not for profit organization has been involved in constructing and developing such eco-community for a long time, of which the *eco-village of Maha Kumbh in Prayagraj, 2013 and Kumbh Mela in Nasik, 2015* are the notable ones (Sukrit and Singh 2019). The organization has always showcased the genuine Indian culture and tradition to all the visitors and spiritual and social seekers who arrive during gatherings such as Kumbh Mela. For the research work, a pilot project site of Incredible India (Ministry of Tourism, Govt. Of India) to be developed by SSDVY organization has been selected. The development of Built environment with the shelter tents and amenities for the visitors was identified and selected to experiment on the creation of a sustainable society for tourists and visitors, especially during mass gatherings and fests such as Kumbh Mela, Magh Mela, KalpWaas (spiritual stays) as well as for rest of the times. The project is developed in compliance with the Supreme Court's judicial order restricting the construction of permanent structure up to 200 m distance from the river Ganges shore (Kumar 2019).

3 Methodology

In layout planning of such a community, the architectural principles are of great importance. In an architectural layout, an 'optimum solution' does not exist, rather several 'optimized' solutions exist, arrived at by the process of optimization (Bhowmik 1983). Space optimization is vital to saving time and energy, which otherwise, would have been wasted. Additional labor and administrative costs are lowered if space is optimized. Traditionally, space optimization was done using several techniques, such as:

1. Flow and string diagram
2. Process chart
3. A combination of the flow diagram and process chart
4. Using templates for trial layout

5. Models for more sophisticated single and multi-storeyed work
6. Graph theory using paper and pencil or using computer programming such as MS Excel and MATLAB
7. Online computer-based oscilloscope to show data on working of existing buildings

Whitehead and Eldars (1965) used a computer-aided program on the layout optimization of single and multi-storeyed buildings using ALGOL programming, which was based on the principle of minimizing the distance and time of travel between the elements stated as 'activity spaces.' A similar sort of method has been envisaged here to develop the layout of the ecovillage. The researchers also mentioned the transportation model, to minimize the distance traveled, is a primitive solution but has a limitation as it involves making one location fixed concerning all, making calculations overtly dependent on this parameter.

The layout planning in this study has been done by using the architectural principles resulting in a layout taking minimum distance of travel and consuming least commuting time. This also serves the purpose of a layout, putting the busier activity spaces in the center of the site with other higher journey-volume activity spaces adjacent to it and performing an iterative task in a heuristic manner to come up with an optimized layout. The planning, designing, and optimization of such a critical eco-system needs proper attention, care, and expertise in architecture and built environment with sustainability at its prime focus (Cheng and O'Connor 1996).

3.1 Layout Planning

The work has been executed in planned phases, with rigorous research, technical inputs, consultation, and interaction with various researchers, scientists, administrators at local, state and national level and most importantly in synergy with localities as this is the work to show and give a message for sustainable development to the world community. The method adopted includes a preliminary survey of the site camp, followed by a planning space for camp development and calculation of anticipated population followed by outlining of various activity spaces necessary for catering to all requirements of the pilgrims followed by the heuristic layout optimisation (ref Section 4.4) to minimise the average movement of pilgrims and ensure a smooth, organized and sustainable *Kumbha Mela* experience for all attending pilgrims.

3.2 Preliminary Survey

The study site- Kumbh Sukrit camp, on the bank river Ganges, 3 km downstream of *Triveni Sangam*, (the confluence of three rivers) after being identified, was worked upon starting with reconnaissance and a preliminary survey using total station equipment to measure and locate the ground features. Drawings of the plot have been prepared using *AUTOCAD* tool.

Area within the Site 2 (Kumbh Sukrit Camp) = 31,342 m² approx.

Perimeter of the Site 2 (Kumbh Sukrit Camp) = 1,050 m approx.

The area was highly undulated and uneven. It was planned to level the selected space to be developed for setting up shelter tents and not to disturb some of the pre-existing natural landscape in synergy with nature. With the coordinates, distances and the level differences of the points on ground obtained after the survey, planning was done which included the preparation of *Bill of Quantities* to be arranged and consequently, a *work plan schedule was prepared using Microsoft Project Package* for the following six months from the start of the project i.e. July, 2018 to be completed by the December 2018, i.e., before starting of the mega event- Kumbh Mela from 15th Jan 2019.

In master planning, broad work packages were identified, and a plan was formulated to find the best available sustainable processes and methodology. The teams, experts and the contractors to perform the specific operations such as infrastructure facility development, say roads, pathways, shelter tents, plantation and greenery development, water supply, and wastewater management and particular green building and energy-efficient systems to be installed were identified as per the schedule and available budget. The various works executed for the eco-village is provided briefly in figure 2.

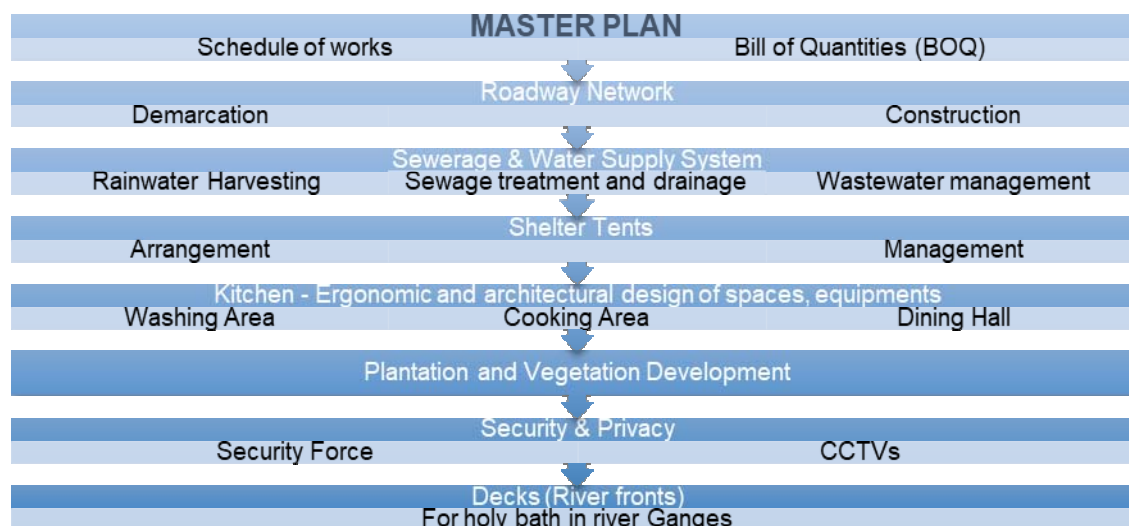


Figure 2: Work packages in the eco-village planning

4 Planning and Space Optimization

4.1 Planned Space for Development

The real site selected for the study, known as Kumbh Sukrit Camp is shown as site 2 in Table 1. It is a scenic place 3 km downstream of Triveni Sangam (The confluence of three rivers), with a developable land area of approximately 10 acres. There are 21 beautiful large trees of *peepal*, *neem*, mango, *jamun* with naturally cultivated farms producing fruits and vegetables. The area caters to a wide variety of fauna species such as peacock, sparrow, parrot, eagle, white Siberian seagull.

Table 1: Site Details for the Eco-village; the selected site for planning and optimization is SITE 2: Kumbh Sukrit Camp

Site No.	Site Details	Area	Distance from Triveni Sangam, Prayagraj(UP)
Site 1	Maharshi Sadafal Deo Ashram, Jhunsi, Prayagraj	10,000 m2 (2.5 acres)	1.5 km by waterways/ 10 km by road
Site 2	Kumbh Sukrit Camp, Prayagraj	40,000 m2 (10 acres)	3 km by waterways/ 13 km by road
Site 3	Near HRI (Harishchandra Research Institute, Gol) Prayagraj	10,000 m2 (2.5 acres)	1.5 km (Waterways) + 1 Km (Roadways)/ 10 km by road
Total		15 acres	

4.2 Anticipated Population- Requirement

In this eco-village, also known as Kumbh Sukrit Camp, Prayagraj, 250 shelter tents are planned.

So, for the planned accommodation of 1 to 3 persons per tent, 750 persons at a time can stay in the eco-village.

Estimated total population days of service = 750 persons x 49 days = 36,750 person-days

$$\text{Total population to be served} = \frac{\text{Total Population-days}}{\text{No. of days of service}} \quad (1)$$

If each person stays for approximately two days,

$$\text{Estimated total population to be served in 49 days} = \frac{36,750 \text{ per-day}}{2 \text{ day}} = 18,375 \text{ persons.}$$

Thus, 16,000 to 20,000 persons approximately were anticipated during the Kumbh festival. This population in the eco-village will decrease gradually as the festival concludes in the holy city. Although the camp developed during the mega event remains for visitors throughout the year.

4.3 Activity Spaces: requirements and existing conditions

As the ecovillage is being developed for the tourists, who are nature lovers and spiritual seekers, it has various specific activities and activity spaces required for optimization than the requirements of an ordinary tourist spot. The primary activity spaces with detailed requirements are designed as per the National Building Code (NBC) of India 2016, Neuferts Standards, and Time-Saver Standards:

4.4 Layout designing and preparation

Architectural method of minimizing the total movement and thus saving time and energy has been the principle behind the layout optimization

1. **Data Collection:** The data of the frequency of movement between each of the activity spaces is collected from the site. This realistic data is obtained as the word of mouth from the past experiences of the experts and parties at the site who have been involved in executing the construction of such mobile eco-villages.
2. **Rough String diagram:** A rough string diagram is drawn with the movements from one activity space to another. A block representation can also be prepared as shown in figure 10.5.
3. **Ordering and Arrangement of Activity Spaces:** The heaviest concentrations of movement shown on the string diagram are analyzed critically and the activity spaces are arranged in decreasing order of their frequency of movements. For convenience, these terminal points are called as 'activities' or 'activity spaces'
4. **Start with most visited:** The arrangement is started with the activity space with the maximum number of journeys to be in the around centre of the layout. It is the sustainable kitchen with dining hall in this case.
5. **Next, with the 2nd most visited:** The next activity space to be located is the one with second largest number of journeys to and from it. It is the cafeteria and block B shelter in this eco-village. They can be located anywhere adjacent to the first activity space located in previous step.
6. **Next, Third activity space:** Then comes the selection of the location for the third activity space. Now, the activity with the maximum relation between the first and second activity is selected and located at a location adjacent to the first and second activity space.

7. **Multiple alternatives of possible layout-empirical and iterative:** A multiple number of possible layout can be drawn, which is empirical and iterative. It will also depend on the site constraints and as per the clients' wish. Here, two possible layout is plotted.
8. **Plotting on Java Coordinate System:** The coordinates of the center point of all the activity spaces in a layout is obtained.
9. **Calculate Movement-Volume(in trip-m):** The number of Standard Journeys (f_{ij}) between each pair of activities is multiplied by the center to center distance (x_{ij}) between corresponding activities on per day basis to obtain the movement volume (in trip-m) as shown in Figure 3 and 4 with product $f_{ij} * x_{ij}$ as obtained.
i.e.,
$$\text{Minimize total movement volume} = \sum_{i=1, j=1}^{i=12, j=12} (f_{ij} * x_{ij}) \quad (i \neq j) \quad (2)$$
10. **Summation of the movement-volumes to obtain total movement-volume:** The sum as the total movement volume is obtained for possible layout and the minimum of the two is the better layout option.

Total movement volume between each Activity Spaces = Frequency of Movement (f_{ij}) * Distance (x_{ij})														
From	Location No., (i)	Location No., (j)	To											
			1	2	3	4	5	6	7	8	9	10	11	12
			Reception	Library	Cafeteria	Block A Shelters	Block B Shelters	Block C Shelters	Sustainable Kitchen-cum Dining	Pond for Water Harvesting	Yagya Shala	Ganga River Ghat	Yoga and Meditation Centre	Riverside Garden
From	1.	Reception		2,250	10,500	25,145	37,259	15,462	12,209	6,865	3,824	13,521	32,757	11,180
	2.	Library			4,000	12,093	16,971	10,050	13,342	-	2,693	10,296	25,145	14,631
	3.	Cafeteria				16,125	20,000	10,050	33,204	-	3,905	24,166	26,196	56,275
	4.	Block A Shelters					3,500	9,000	65,863	-	32,066	31,321	92,770	17,692
	5.	Block B Shelters						9,657	57,706	-	69,147	86,313	1,09,179	36,933
	6.	Block C Shelters							30,373	-	19,405	45,069	21,213	20,471
	7.	Sustainable Kitchen cum Dining								2,795	22,699	37,817	18,507	12,500
	8.	Pond for Water Harvesting									-	-	-	-
	9.	Yagya Shala										5,483	14,080	6,364
	10.	Ganga River Ghat											96,199	5,762
	11.	Yoga and Meditation Centre												45,017
	12.	Riverside Garden												

Figure 3 Total movement volume in trip-m between activity spaces for Layout 1

Total movement volume between each Activity Spaces = Frequency of Movement (f_{ij}) * Distance (x_{ij})														
From	Location No., (i)	Location No., (j)	To											
			1	2	3	4	5	6	7	8	9	10	11	12
			Reception	Library	Cafeteria	Block A Shelters	Block B Shelters	Block C Shelters	Sustainable Kitchen-cum Dining	Pond for Water Harvesting	Yagya Shala	Ganga River Ghat	Yoga and Meditation Centre	Riverside Garden
From	1.	Reception		2,250	10,500	24,739	25,807	37,687	26,927	9,621	26,770	20,594	61,131	38,161
	2.	Library			4,000	12,023	14,329	25,020	36,688	0	17,614	12,500	45,311	36,336
	3.	Cafeteria				16,279	22,023	25,020	1,33,276	0	17,500	21,932	44,762	99,737
	4.	Block A Shelters					3,536	8,504	67,417	0	28,853	28,539	83,706	15,620
	5.	Block B Shelters						9,750	63,285	0	67,546	82,538	1,03,942	35,795
	6.	Block C Shelters							29,774	0	18,916	49,197	17,766	19,801
	7.	Sustainable Kitchen cum Dining								2,000	22,500	41,503	16,971	12,816
	8.	Pond for Water Harvesting									0	0	0	0
	9.	Yagya Shala										6,403	12,816	6,364
	10.	Ganga River Ghat											1,00,245	8,149
	11.	Yoga and Meditation Centre												41,250
	12.	Riverside Garden												

Figure 4 Total movement volume in trip-m between activity spaces for Layout 2

Layout 1 with *minimum journey* volume of 14,95,014 *trip-m* is better than Layout 2 with *minimum journey* volume of 18,74,037 *trip-m* among the two design layouts.

5 The Layout Design outcomes

The design outcomes were applied both quantitatively and qualitatively i.e., as per the principles of layout planning keeping the site data and conditions into consideration with practical requirements (Sukrit, Site and Sukrit 2019):

- A. **Kitchen (I)** with maximum Standard journey is placed in the center,
- B. The kitchen is followed by **cafeteria (II)** near it at the western edge
- C. **Reception (III)** is beside the cafeteria and near the site entrance through gate 2, thus satisfying both the mathematically optimized model and utilizing the site condition as well.
- D. **Yoga and meditation centre (IV)**, although having much denser activities around it, needs to be placed in a peaceful environment at the riverbank, thus placed in block D on the river bank side.
- E. **Yagyashala (V)**, requiring open space and sunshade, is positioned in the dense central tree cover of 18 large trees in the central-west portion.
- F. **Block B shelter (VI)** with second-highest activities/ standard journeys are placed in the rectangular northern plot and in proximity both to the dining hall and the cafeteria.
- G. **Library (VII)** is placed between reception and cafeteria as per the high number of standard journey requirements.
- H. **Riverside garden (VIII)** is placed along the riverside as per the desire of the visitors and tourists and space availability.
- I. **Ganges river ghat (IX) (river-front)** is positioned as per the site condition, as it always needs to be placed on the riverbank for the holy bath obviously.
- J. **Two ponds for rainwater harvesting (X)** are planned as per the natural slope in the eastern and north-eastern sides.

So, the given ecovillage is to be designed both qualitatively and quantitatively, i.e., taking both the mathematical computations and the real site constraints into consideration. Thus, one can achieve the desired optimum goals and, thus, make the planning suitable to a given problem statement keeping the site constraints in mind.

6 Conclusion

Thus, the above eco-village is designed both qualitatively as well as quantitatively using the available suitable tools, for an optimized layout. The ecovillage development is a holistic approach incorporating the awareness, management, and responsible concern for nature, the next generation, biodiversity, and humanity as a whole. It builds with little caring steps and leads to a giant leap for humanity in its form. It is still an evolving community as an ideal ecovillage nowhere exists. However, it can be developed for a community with proper integration and holistic approach of planners, Architects, site engineers and technicians, experts' guidance, and from the learnings of the past. Awareness is an essential element in the development and progress of the concept and the community, which can be spread online as well as offline through social media, newspapers, interactions with the society, administration, and the government.

Thus, with a similar note, an ecovillage project with 100 % green, i.e., net-zero or even net negative energy society can be developed, which has been proposed in this study. It can be seen by the physical exposure and real-life experience of the project site only that how a sustainable society can be developed with support and collaboration of different people from academia, civil society, local community, and the administration. It is a conducive environment developed to provide minimal or no problem to the gatherers.

This project was an attempt for a mood change of the government and the people towards responsibility, cleanliness, and positivity. It is an appeal for green building and green society, expected to give a message to all nearby societies, working organisations, ashrams, camps and societies for sustainable development with all its elements and functionalities in compliance with green rating system such as LEED, GRIHA, Green Star, developed by the SSDVYS Centre of Excellence in energy and environment conservation and protection with international collaboration and partnership of DFAT, Australia-India Council (AIC).

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ACCESSIBLE RESPONSIVE COMMUNITY SIMULATIONS FOR SMART VILLAGES IN ASSAM

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Abstract: *The economic climate in Assam has in recent years improved. Great disparity still exists, however, between the wealth and living standards of rural and urban citizens. One factor contributing to this relative and absolute rural disadvantage is the deficiency of data available in useful form to the public and within levels of government, in terms of completeness, breadth, and reliability, and the consequent shortfall of actionable insights that impedes satisfaction of development goals and rural needs. A qualitative lack of citizen participation in data gathering processes is recognised in policy framework goals adopted by the Government of Assam, which set forth it is essential to promote bottom-up engagement and to identify all stakeholders, understand their motivations, and support building of their capacity.*

This paper explicates the utility of emerging and novel 'gamification' technologies, that apply computer game design principles to solve problems, to involve rural citizens as responsive agents in decisions affecting the communities within which they live. Using this approach, environment simulations are implemented as light-weight apps that provide domains of citizen interaction including consensus building, illustrative modelling for community awareness, and garnering apparent and latent attitudes and preferences. A kit-of-parts approach is proposed so to be flexible and applicable across a range of scenarios and suitable for development and deployment in rural and developing contexts with relatively limited access to latest computational and communications technology and education. In the face of incomplete rural data, this gamified approach provides an innovative way for decision makers and designers to ascertain citizen intents, desires, and preferences to facilitate an evolving, responsive policy and action framework.

Keywords: *built environment simulation, gamification, volunteered geographic information, smart villages, public participatory planning.*

1 Introduction

Smart villages have a role in promoting concordant and cohesive rural communities in which people lead fulfilling lives as best they choose; however, to do so it is essential these smart villages can respond nimbly to the needs of their members. Concomitantly, citizens benefit from being responsive not passive participants in change, such that government, private industry, designers and planners, non-governmental organizations, and wider society itself may better contribute to meeting the wants and needs of all community members through participation in the creation and management of smart villages.

The global need for new approaches is pressing as rural societies seek to deal with challenges including population growth and migration, climate change, consequences of the encroachment of mechanical and digital machines on the domain of human work, counterintuitive tribalising effects of modern communication networks, and a climate of border tensions and uncertain security.

A governmental and decision-making need for such smart villages solutions is implicitly recognised as present within Assam by the State Government's 2016 endorsement of the policy framework *Assam 2030: Our Dream, Our Commitment* (Government of Assam 2016). *Assam 2030* adopts and adapts the United Nations Development Programme's Sustainable Development Goals (SDG) for the Assamese context to improve the living standards of rural citizens and reduce the rural-urban divide. The framework identifies 'critical challenges' that point to the need for greater self-determination of rural dwellers in the development of their villages (Government of Assam 2016), and highlight:

- A. Positioning communication as integral to promoting harmonious development that includes stakeholder from all sections of society;
- B. Reinventing governmental systems and exploiting rapidly changing technology so to better predict and shape the future;
- C. Promoting sub-state level governance that devolves decision making and engagement to promote bottom-up engagement;
- D. Recognising it is essential to identify all stakeholders, understand their motivation, and support building of their capacity;
- E. Compensating for a 'dearth of credible and adequate data, and weak internal monitoring & evaluation systems'.

The need in Assam for new solutions is particularly pressing, as evidenced by development statistics. Although the economic outlook for Assam overall has improved in recent years, great disparity still exists between the wealth and living standards of rural and urban citizens (Government of Assam 2018). Certain statistics of disadvantage in Assam both illustrate further this need and demonstrate the social and technological impediments to implementation. Assam ranks only 26th in literacy among the states of India; in rural areas it is at 69.34%, and only 60.05% for rural females, compared to much greater literacy in urban areas at 88.47%. There is a significant lack of communications access in rural areas of Assam with only 39.18 telephones per 100 people, compared to 132.26 per 100 in urban areas and a national average for rural areas of 48.04 per 100. Rural provision of electricity is greatly below that in urban areas: although 84.10% of urban households use electricity for lighting, only 28% of rural households do so (Government of Assam 2017).

Doloi, Green, and Donovan (2019:189) note that “central government generally devises a single policy for all the rural communities under their jurisdiction which can be hundreds or even thousands of villages with differing cultural traditions, religious beliefs, employment opportunities and standards of living.” To ameliorate this, novel methods are needed for bottom-up engagement with local communities, and to uncover unorthodox solutions, new information, and latently-held issues and attitudes. Further, the knowledge of communities must be captured not only on an individual level, but also in a process of ‘swarm ideation’ in which users participating with each other collaborate – perhaps not with explicit awareness they are doing so – to find solutions to problems.

While surveying citizen opinion, perspectives and attitudes is not, in itself, a new concept (Lazarsfeld 1957), citizen participation through the essentially static approach of paper-based forms has been carried over to the information technology space through use of close digital facsimiles of the analogue undertaking. The emergence of non-deterministic, responsive information technology systems present opportunities for people to participate as responsive citizens within responsive communities and can be applied to smart villages in Assam in response to the needs identified in Assam 2030 and elsewhere.

Gamification – the application of computer game technology and cultures to problems that would not normally be tackled by that route – can be applied to participatory built environment modelling to provide an innovative process for eliciting responses from citizens to issues affecting themselves and their communities. These issues can be relatively trivial from matters of minor nuisance to grand challenges such as climate change.

This paper sets out a proof-of-concept app and framework for accessible responsive community simulations (ARCS) to address the identified objectives of Assam 2030 and data capture in developing rural contexts. The work aims to engender citizen participation through engagement with playable simulations of real-world smart village issues and to generate actionable insights with a focus on a kit-of-parts of base, extensible simulation and gameplay patterns. Specifically, the framework sets out how to model a smart villages issue, in both literal and figurative modes, in a simulation, how to invite citizen engagement in these simulations to promote community participation in decision making and planning, and to exploit this engagement and data captured to bootstrap further data collection, data creation, and participation.

2 Accessible Responsive Community Simulations

Gamification is given by Deterding et al (2011), in a widely accepted definition, as “the use of game design elements in non-game contexts” and uses elements of game design and interaction to achieve a particular outcome (Groh 2012). Marczewski (2014) notes the utilitarian nature of the gamification process, in contrast to games development, and observes its design workflow is in aspects the reverse of game design workflow; whereas game design may begin with a ‘fun’ idea and game play outline proceeding to definition of performance metrics, gamification design begins with a business objective and definition of supporting assessment metrics proceeding to a subordinate game play outline.

This power of gamification to engage users in pursuit of pragmatic, real-world outcomes has been used in diverse fields. Sailer et al (2013) note gamification arose in marketing contexts and from there spread to business and education applications. More recently, the idea of gamification has been applied to digital built environment modelling and

community engagement to address the crucial need of integration of citizens in urban planning and other participatory processes (Poplin 2012). Two notable precedents of platforms for gamified simulation in urban participation are SuperBARRIO and CityScope.

The SuperBARRIO smartphone app, Institute for Advanced Architecture of Catalonia, provides a navigable, interactive 3d environment of a local neighbourhood (IAAC 2017). Citizens, working within the app's urban model, may place modules from categories of culture, ecology, energy and mobility, such as a basketball court, tree, solar panel, or bike rack. Each module may positively or negatively affect a running tally of one or more of those categories, with the goal to build a neighbourhood balanced across categories.

The creators note the mechanics of the SuperBARRIO app have potential applications to collect and visualise data to understand and analyse the needs and preferences of citizens; to educate and make aware citizens to facilitate the understanding of collective and individual decisions on the public space; and to communicate and disseminate to citizens urban plans and operations to show proposed or planned changes.

CityScope by MIT Media Lab's City Science Group provides a Tangible User Interface simulation of an urban environment that "aims to reduce much of the coordination and collaboration challenges associated with traditional planning methodologies" (Alonso et al. 2018). It, like SuperBARRIO, provides three engagement components of environment representation, user interaction, and feedback. These are implemented as a tabletop physical 3d urban scale model, reconfigurable and tagged parts that may be positioned by hand that are recognised by computer-vision enabled cameras, and a real-time projected computational analysis overlay. CityScope has three stated key objectives: "to visualize complex urban data and the inter-relationships between urban systems", "to simulate the impact of urban interventions", and "to support decision making in a dynamic, iterative, evidence-based process using a tangible interface."

Gamified built environment simulations, such as SuperBARRIO and CityScope, are composed of individual, interleaved game elements. A common typology of these elements is given by Bedwell et al. (2012) as a list, synthesised from literature review, of 19 attributes such as conflict, control, or progress, with each element having a nature and associated theory. Although each such game element is useful in itself, and any one may be essential to a particular purpose of gamified simulation, such near-atomic, building-block classification is not conducive to rapid, inexpensive development of gamified built environment simulations apps.

We extend the approach of gamified built environment simulations, demonstrated in SuperBARRIO and CityScope, to propose defining base simulation and gameplay patterns that create explanatory value, generate reportable and actionable data, and provide engaging interaction. We refer to this methodology as accessible responsive community simulations (ARCS). These patterns or modes, which sit above base game play elements such as described by Bedwell et al., are intended to form a non-exhaustive conceptual kit-of-parts for designing apps to be deployed in the community to create engaging play targeted to promote citizen participation in civic processes.

Three gameplay modes of sandbox play and rivalrous parameters, consensus building through interactive simulation, and illustrative modelling for community awareness were illustrated in a research-demonstrator smartphone app developed by one of the authors for community participation in understanding and deciding upon issues of urban densification.

The graphical environment of the app, shown below in this paper, is presented with a deliberately simplified and consistent style of textureless voxel-art for three reasons. First, to reduce computational load so to allow a wide distribution and use on even relatively low-end phones and tablets. Second, to avoid the disruption to engagement that may occur, in an effect reminiscent of the uncanny valley phenomena and human simulacra, when a level of detail and visual verisimilitude approaches real-life and prompts user nit-picking of detail and disadvantageous comparison to own experiences (Hopson 2019). Third, research by Howard (2017) shows that simulations have greatest learning outcomes and user reactions when levels of detail of both environment (observations) and control (interactions) are in concordance, hence visualisation is here kept to a level comparable with the freedom of interaction which, within this app as a demonstrator, is limited by design.

2.1 Sandbox play and rivalrous parameters

Sandbox play and rivalrous parameters allows users to explore without prescriptive goals the possibilities of a built environment simulation with the restriction that many decisions in one area will degrade the outcome in another area.

The demonstrator uses in this gameplay mode a scenario of an eroding foreshore reserve that requires revegetation (Figure 1). Users are able to allocate a council budget to place trees and bushes throughout the reserve, and receive feedback on the effect on stabilisation of the new planting. This budget is deliberately limited; there are funds sufficient to either adequately stabilise the whole reserve with uniform planting or to create more considered, detailed planting designs with lesser stabilisation; hence, users must order rivalrous priorities to emphasise what is important to themselves. Further, users may choose to exceed the allocated budget to achieve an outcome they desire, and are warned that prioritising this project will take funding from other community park projects.



Figure 1: Urban densification app demonstrating sandbox play and rivalrous parameters play mode

A feedback process of parametrised modelling incorporating reactive scripting is established within the simulation. It provides to players direct guidance on the nature of their decisions and on what factors are contributing to certain outcomes, and to prompt them for a choice when the simulation detects a significant decision point (Burry, Cruz, &

Kimm 2019). In Figure 1 is seen two examples: in the centre of the foreshore reserve a user has created a tree thicket and in response the thicket is highlighted to warn such dense vegetation will reduce passive surveillance and hence public safety; and in the mid-right of the foreshore reserve the user is prompted to plant in a bare area that has not yet been stabilised through planting.

The response to these prompts is left to the player – the intent is to offer choices when the system has reached a significant decision branch, not to dictate to the player what decision they should make (and to do so would indeed undermine the purpose of the engagement).

2.2 Consensus building through interactive simulation

Consensus building through interactive simulation allows users to apply accurate simulation to visualise, test, and comment on the effects of community plans and decisions.

The demonstrator uses for this play mode a scenario of a proposed brownfield apartment development on an inner-suburban high street typical of a Western country (Figure 2). Users may explore the impact on the urban context in two key ways.



Figure 2: Urban densification app demonstrating consensus building through interactive simulation play mode

First, users can view the proposed apartment development within its context. They may ascertain the appearance and visual massing of the proposed tower. They may visualise overshadowing for any time of any day of year using day-of-year and time-of-day UI sliders that control an accurate sun position model. For each of these selected street view positions on surrounding streets and freely-positionable view cameras are provided within the UI.

Second, users can also adjust the development proposal, using a simplified building kit of parts, to give detailed feedback on the proposal (“no more than six storeys!”). Further, users may from scratch build their own indicative proposal to illustrate their feedback or suggest guidelines (“I’d like to see all new buildings tapered back for better sun access.”).

2.3 Illustrative modelling for community awareness

Illustrative modelling for community awareness allows users to see the impacts of decisions through adjusting the parameters of descriptive simulation. This mode is distinct from 'consensus building through interactive simulation' above: the simulation in this mode is indicative and only core relationships need be embodied in support of a narrative that explains a built environments issue or local government policy.

The demonstrator uses for this gameplay mode a scenario of increasing densification as population grows and the future effect of current decisions on supporting mixed mode transport (Figure 3). Specifically, it addresses changes to local government rules such as removal of minimum off-street parking planning requirements that may be unpopular and seen as counterintuitive (Topsfield 2019). Although such policies may be unpopular with citizens, taking difficult decisions now on parking requirements can produce better urban futures (Forinash et al. 2003, Weinberger 2012).



Figure 3: Urban densification app illustrative modelling for community awareness play mode

In particular, users may play with densification levels, represented by an apartment building of customisable height and floor area, and choices such as provision of off-street parking and public transport. The decisions a user makes within the app affect an agent-based traffic simulation model of cars, buses, and pedestrians. Ultimately, users may compare highly-densified urban futures that, according to their choices, are gridlocked with cars or have peaceful, pedestrian-friendly streets.

3 Smart Villages ARCS in Assam

Previous research by the authors presented a self-help parametric digital-workbench prototype for Assam village development (Kimm & Burry 2018). This computational participatory tool encapsulates and expounds the relationships and conditions affecting the design and use of the physical environments of village life in locations of rural development (Figure 4). The digital-workbench is designed to uncover and communicate decision-making criteria and evaluation objectives, and elicit villagers' predilections, to support bottom-up, participative community engagement in smart villages.



Figure 4: a self-help parametric digital-workbench prototype for Assam village development

We extend this research to propose the implementation in Assam of ARCS for smart villages (SV-ARCS). In this framework, GIS and other data is used to increase engagement with the app, such as through an enticing game mechanic in a 3d simulation, and through that engagement increase participation in a broader civic dialogue. The use of GIS is twofold. First, crowdsourced GIS data is accessed from the cloud and processed to contribute to the simulation. Second, Volunteered Geographic Information (VGI) methods, in which spatial and other information is contributed for free by volunteers (Goodchild 2007), is used to elicit information from users to further inform the simulation, to share with other users, and to provide feedback and data to the implementing agency. As this volunteered information goes beyond purely geographic qualities, for example capturing of sentiment, we use in this work a more general term of ‘volunteered community information’.

An SV-ARCS demonstrator prototype was developed in the Unity™ game environment software development engine. The demonstrator provides a 3d, state-level overview of Assam through which a user may freely move. Terrain information and location services are provided in the prototype by the Mapbox™ mapping platform for custom designed maps, and information on placement of roads and settlements is provided by the OpenStreetMap™ (OSM) crowdsourced mapping platform. The OSM data is incomplete, particularly so for smaller settlements, and hence a user in the demonstrator can insert a missing settlement. This could work at other scales; in 3d simulation at village level a family could add their own house and those of neighbours.

As a demonstration of illustrative modelling for community awareness, the road network in the prototype is interactive and users may select and configure road elements and cities to better understand road network accessibility and the need for potential projects. For example, in Figure 5 is shown the road accessibility catchment from Jorhat under existing conditions and if National Highway 715 underwent an extensive upgrade; thereby allowing government to explain why such a project may be prioritised over others and citizens to compare for themselves the proposal against less-advantageous alternatives. The actions a user takes on that road network is harvested, and such preference and interest data, if captured and analysed in a real-world context, can inform policy and community-government engagement decision making.

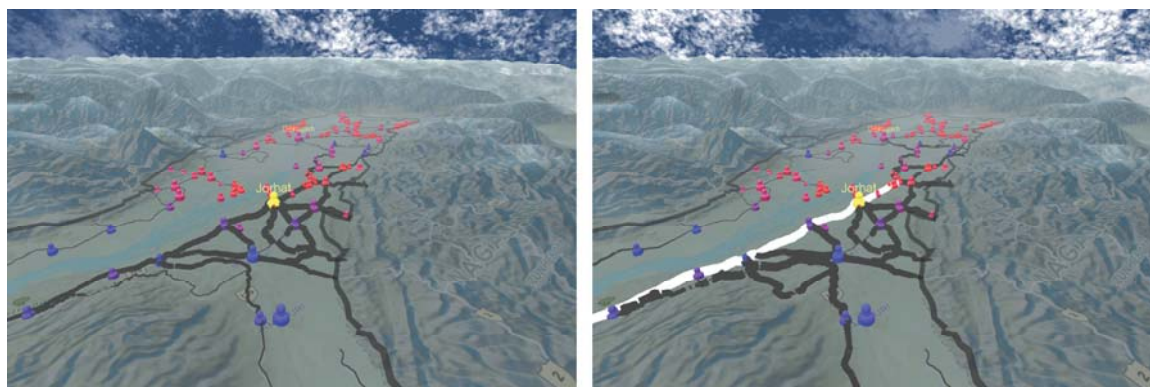


Figure 5: SV-ARCS illustrating road network accessibility for Jorhat, Assam, for National Highway 715 under existing and, shown in white, upgraded conditions

Further work on this demonstrator prototype is underway at time of writing to extend it to include the below overlays.

- Community consensus for placement of mesh networking nodes for smart village internet access including socio-political considerations, such as community status and signal strength, and technical consideration, such as topography, complemented with reactive-scripted artificial intelligence for optimisation of node placement.
- Modelling with uncertain or incomplete data using, as a testbed, community resource and infrastructure placement with accessibly illustrated by display of land-use-aware desire paths.
- Analysis of user-supplied data with embedded GIS tools.

The SV-ARCS framework is developed on three key principles:

1. Broad, consistent low-level data is gathered that, in general, can be of more initial use than scattered, heterogeneous detailed data.
2. Data collection can be bottom-up and self-sustaining.
3. Citizens are engaged as the best first asset for collecting data in developing communities.

An SV-ARCS app can rapidly collect broad, consistent low-level data that, in general, can be of more initial use than scattered, heterogeneous detailed data that may have been, or currently is, collected by other means. There are inherent impediments to comparison of diverse rural communities for decision making; Doloi et al (2019:189) note “every rural community is different, and it will take unique insider knowledge of the region's assets and customs to determine the most effective combination of policies”.

Deployment of an SV-ARCS app can facilitate gathering of this unique insider knowledge. The app can have broad reach; it may be deployed via existing IT infrastructure, such as Google Play™ or the Apple App Store™, throughout a governance or program area, and targeted to all members of communities or representative facilitators within communities.

The app can ensure comparability of data collected; whereas crowdsourced GIS and other data may suffer from mismatched levels of detail that hinder actionable use, as can occur in GIS platforms such as OSM (Girres & Touya 2010, Touya & Brando-Escobar 2013), the demographic and feedback data collection processes are embedded within the app and hence homogenise data granularity and structure.

The inherent digital nature of the SV-ARCS framework addresses potential gaps in governance overview and surveying processes by facilitating the generation in, and insertion directly into, IT systems of data rather than requiring the manual integration of data collected through paper based and other analogue processes.

Data collection and participation through an SV-ARCS app can be bottom-up and self-sustaining. Information collected in the above approach may also be used to leverage self-sustaining data collection through use of machine learning to bootstrap cycles of new data generation. The use of machine learning in smart village demographic survey in Assam, through classification on standardised house photos and corresponding household demographic data, to yield swift and low-cost initial analyses of villages that can guide further surveying or funding allocation has already been identified (Kimm & Doloi 2018). The SV-ARCS framework may extend this to broader GIS applications; for example, house position and holdings data collected through the app can create datasets of labelled aerial images, and these datasets could be used in machine learning processes to classify land use in aerial images (Hagenauer & Helbich 2012).

Data collected in an initial implementation of an SV-ARCS app may also help identify what other data is needed to be collected in a later iteration. This can be facilitated by providing an SV-ARCS framework as a software as a service (SaaS) cloud platform that allows rapid configuration of simulation and data capture elements and access permissions for users. Such a SaaS solution would distribute technology costs across governments and programs whilst allowing local knowledge to be applied to implementations as experienced by users in the community. To illustrate, using as an example the developing mesh networking extension to the SV-ARCS demonstrator prototype, a community which in initial collection of data reveals a dearth of communication access may have added to their SV-ARCS app access the mesh networking module to begin to design for themselves where they would like mesh networking access nodes to be placed.

Citizens are engaged as the best first asset for collecting data in developing communities, and this engagement leads to greater participation. Citizens whose engagement is sought in participatory urban and other planning processes may choose to be 'rationally ignorant' (Poplin 2012); they may decide that the cost of entering such a process, e.g. the time investment to understand the process, outweighs the benefits, e.g. the potentially-minor chance to make a difference. The gamified simulations embedded within an SV-ARCS app can engage users in the process of collecting data by concomitantly offering feedback of immediate interest. For example, Doloi et al (2019:190) note the potential in smart villages for resource flows between complementary businesses; in SV-ARCS apps such support for circular economy solutions can be gamified to, in response to business and resource information entered by users, identify opportunities for new businesses and connections between existing ones.

The need for greater participation in local decision making in developing rural contexts is increasingly recognised. In Assam it has been found that a top-down model is not conducive to either effective nor timely rural road maintenance; instead is proposed a model of a local overseeing committee controlling public and private funding for, and ensuring quality of, road maintenance in its local jurisdiction (Doloi et al 2019:143). The SV-ARCS framework can assist in such situations by both identifying issues of importance to local communities, including those missed due to limitations of oversight from afar that is removed for peculiarities of a local context, and coordinate responses.

The SV-ARCS framework, through engagement with citizens, provides an alternative to IoT sensor networks which, if implemented in a developing rural context, are expensive to procure and emplace, difficult to maintain, cannot directly assesses individual's needs or preferences, may only provide scattered coverage, and may be slow to respond in configuration, placement and capabilities to changing demands. By contrast, crowdsourced community data in the SV-ARCS framework through VGI methods can potentially offer rapid and flexible implementation and results.

4 Discussion and Further Work

The research presented in this paper, part of an ongoing project, builds on a previous self-help parametric digital-workbench prototype for Assam village uplift. This new extension focuses on user experience and an informed social science perspective on how best to engage with a rural community through interactive simulation. The goal is to provide digital tools to allow citizens a better say in how their community might expand and develop with collective prosperity. Accessible responsive community simulation, supported with a kit-of-parts of simulation and gameplay patterns, is an innovative extension to gamified built environment simulation that can enable community participation through encapsulating the mechanics of complex smart village issues in a community-friendly digital form. The research suggests several further areas, which are beyond the scope of this initial paper, to be investigated towards implementation of accessible responsive community simulations in smart villages.

The SV-ARCS model relies on community information being elicited from volunteer users to inform the simulation itself as well as community and government decision making. While geographical data entered within tight-knit community contexts might be verified through a natural processes of shared oversight interleaved with the social communication in the village itself, and while other contexts such as preference capture produce data that is a matter of opinion and not objective truth that may be corrected, data entered in other contexts may require a level of verification. This verification should insofar as possible be embedded within the SV-ARCS process. Miller et al. (2015) summarise three approaches that may be of use. The *crowd solution* relies on enough users viewing information that for most items of information at least some users will have knowledge sufficient to accurately correct errors. Miller et al note that this solution might fail for certain edge cases of obscure or remote locations for which the crowd might have little interest or ability to correct errors. We suggest the overall benefit of volunteered information is not diminished by these edge cases: data may be marked with a level of confidence based on SV-ARCS usage in that area, there are potential automated means with which to flag certain types of errors, and the administering body may have access to alternative data against which to verify. The *social solution* relies on a hierarchical structure of moderators as may be found in Wikipedia. Miller et al. note this process introduces delay in the release of data; we note that such gatekeeping is against the bottom-up goals of SV-ARCS. The *knowledge solution* relies on checking if submitted data is logically consistent; for example, a building located in wet padi and marked as pucca construction is likely incorrectly labelled. This solution may utilise automated detection processes such as machine learning and can potentially be applied to the edge cases of the crowd solution.

The engagement by users with the SV-ARCS demonstrator – both here presented and described as in development – beyond an enjoyment of play is predicated on the self-interest of users in the opportunity to provide bottom-up commentary on conditions in

ones own village and the use of the encapsulated simulations to see the effect of current and future conditions on ones own welfare. There is hence an opportunity for further research into modes of engagement. Game mechanics including scores, quests, or competitions may be used to increase engagement, as could integration with social networking platforms such as tweeting of defined solutions or embedding of SV-ARCS apps within Facebook. Real-world reward systems may also be integrated; for example, a village that successfully geolocates a certain percentage of its houses may win a small community reward.

A gamified simulation under this SV-ARCS approach is extensible to different levels of veracity or levels of detail as a participatory civic process might require for audiences across the gamut of a community. The potential of different levels of detail has been shown in the state-level road network model of the demonstrator SV-ARCS app and the outlined in-progress village level extensions, and the potential of different levels of veracity is inherent in the three gameplay modes of sandbox play and rivalrous parameters, consensus building through interactive simulation, and illustrative modelling for community awareness. Fine-tuning of the use of different levels of veracity or levels of detail for different applications, and the potential derivation of a matrix of uses, would significantly further the effective implementation of SV-ARCS.

Further, thus far this work has focussed on simulations that are recognisably of a real-world environment. This need not be the case. The crux of the approach to simulation in this gamified context is that there is embedded within the simulation the essence of the relational structure of the smart villages issue on which actionable insight is being sought, so that the participating citizen may respond in such a way as to provoke meaningful change within the system. These simulations may exist on a spectrum from tending to a more literal presentation of a smart villages issue, such as in the work herein described, to tending to a more figurative presentation of a smart villages issue, for example a decision-based simulation to test hypothetical smart villages service provision scenarios that might be exposed as a puzzle game.

SV-ARCS apps are a nexus for open data: they can draw from sources such as GIS databases from within a host agency and across agencies, as well as from public cloud-based sources, and the results captured by an app may become an open source repository or feed in themselves. The specifics of how such data generation might feedback into such platforms is beyond the scope of this paper, however the context of developing rural communities and associated NGO and government agencies suggests a uniform SaaS solution, with embedded external knowledge and process, that spans multiple agencies and even countries is required. The use of a SaaS or like solution has its own considerations that must be determined and responded to; for example, how may a solution be rolled across different governments with different priorities, and how can it be ensured local knowledge in design of apps is captured in an easy-to-use app specification and administration environment?

The selection of target groups for particular SV-ARCS purposes, and conversely the selection of SV-ARCS methods for particular target groups, need further investigation. Schlossberg et al. (2005) propose matrices of *domain of participation* against *domain of public*; this approach could be extended to further refine the relationship between SV-ARCS gameplay patterns and particular real-world scenarios and goals. There are many potential ways to raise awareness of an SV-ARCS app within a rural community, both targeting the community overall or selected groups within the community, such as advertising or mention within existing communications, and these may be tied into engagement tactics discussed above. There is potential for facilitator roles in which

persons with additional training at panchayat or village level guide users through the app engagements and host community discussion of the issues of participation in civic processes uncovered in that engagement. The outcomes of any engagement process are intended to be part of a feedback cycle to allow government responses that are nuanced at a local level and support for policy that evolves alongside changing community needs. A model for smart rural governance using information communication technology for development (ICT4D) with defined relationships of government-to-government, government-to-citizen, citizen-to-government, and citizen-to-citizen is a potential framework within which to insert bottom-up survey tools for responsive policy outcomes (Kimm & Doloi 2018).

Crucial to the ICT4D for smart governance of rural development approach above is the citizen-to-citizen relationship. We have mentioned above in this paper the potential for supporting circular economy solutions through identifying opportunities for new businesses and forging connections between existing ones, and there is in developing rural communities evidence in support of such synergistic collaborations through technology. In a survey of e-retailing in Chinese villages Leong et al (2016) identified a process of birth, expansion, and renewal leading from early adopters of e-commerce engendering community interest to government redefining its role in an increasingly autonomous community (Leong et al 2016). There is further research to be done in identifying how smart governance interventions with SV-ARCS apps might leverage the mechanisms villagers have for self-sufficiency.

Finally, use of the SV-ARCS framework could have ethical considerations and create unintended consequences as an outcome of the very reason they would be used. By capturing and publicising data that might previously have only been available locally, there is a potential that conflict might be fomented. To illustrate with a general scenario, displaced persons illegally camping on remote public land might previously have only attracted local and governmental notice, whereas such information could be widely disseminated, including to strongly opposed vigilante groups, if entered as GIS data within an SV-ARCS app.

5 Conclusion

Accessible responsive community simulation applied to smart villages (SV-ARCS), in presenting encapsulated smart villages issues in simplified gaming interfaces comprehensible to the wider community, offers benefit by directly addressing what can be a great challenge for governance: encouraging community participation in decision-making processes and developing consensus for decisions made. They help overcome 'rational ignorance' – the process by which citizens withdraw from participation in civic processes by prioritising short-term gain – and can help develop community understanding of the interplay of constraints under which governments and other authorities must make decisions. Through this, gamified simulations support an approach to smart communities that prioritises citizens over sensors as the responsive agents in responsive villages; as a generator of data they assist uncovering from the community novel solutions, new information, and latently-held issues and attitudes; and they assist integration of complex domains of knowledge under constraints of imperfect data. Overall, they are of benefit across the range of social, environmental and economic outcomes that may be improved through streamlining decision-making processes, offering fewer false starts, and responding to what people really need or want.

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UTILIZATION OF WASTE PLASTIC IN CONCRETE

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Abstract: Development of villages as smart villages in terms of sustainable development is one of the new trends in developing countries. There are different aspects of smart villages such as water supply, sanitation, indoor air quality, solid waste management and renewable energy etc., which are taken care of. Solid waste management is one of the most vital problems in today's world. In this context study on various construction materials or components where solid waste can be used as a core part considering engineering properties as well as economic aspects becomes very much relevant to the present world. The study deals with the use of solid waste such as waste plastics in concrete to improve the quality of concrete as well as reduced the cost. Concrete is strong in compression and weak in tension. The main objective of this study is to investigate the proper way of producing solid waste into construction materials. Solid waste management is one of the major environmental concerns in the world. This paper describes the performance of plastic fiber reinforced concrete (M25). Similar kind of experiment can also be performed for lower target strength such as M20, M15. It is inevitable that all these concrete construction have better strength and durability properties as compare to the traditional concrete. Experimental work has been carried out and different mixes were taken with 0.5%, 1%, 1.5%, 1.75% and 2% replacement of cement with plastic fibers. Cubical and cylindrical specimen were cast with 0.5% to 2% replacement of cement with plastic fiber. The test results shows that inclusion of fiber will reduced slump and workability but it was good enough workable up to 2% addition of fiber. Test results indicates that 1.5% of plastic fiber will shows maximum compressive strength and split tensile strength, but after that there is a drop of compressive strength, which indicates air entrapment in the concrete due to incorporation of high fiber fraction. Regression analysis also been carried out. From the regression analysis data it is observed that regression analysis gives good predicted value which is almost nearer to the experimental data.

Keywords: Compressive strength; Split tensile strength; Bulk density; Improvement factor; Regression analysis

1. INTRODUCTION

Concrete is such a material which can be developed to fulfil the requirements of the community viz can be developed as a high performance concrete, traditional one, geo polymer concrete, fiber reinforced concrete. Concrete is a basic material for construction and the ingredients of concrete are natural. But the properties of concrete can be change by adding some amount of admixtures. Concrete has many advantageous properties such as good compressive strength, durability and fire resistance but tensile strength of the concrete is very much low. But this tensile strength of the concrete can be increase by addition of fiber. Research conducted by using plastic fiber which are extracted from waste plastic bottles by taking constant aspect ratio. Use of plastic in concrete increases sustainability as well as it reduces large quantities of plastic based wastes all over the world.

2. OBJECTIVE OF WORK

The main objective of this research were proposed,

- (a) To investigate the mechanical behaviour of the cubical and cylindrical blocks when fiber is use as a core part of the block.
 - (b) To determine the percentage of fibre which gives maximum improvement factor when compared with control concrete.
 - (c) To count as one of the foundation for green project through reduce environmental pollution.
 - (d) To study the variation in the bulk densities for different % of fibres.
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3. MATERIALS AND METHODOLOGY

(a) Cement: Ordinary Portland Cement (OPC 43) Dalmia brand is used in this work.

(b) Fine Aggregate: Locally available river sand which is free from organic impurities is used in this work. The fine aggregate having size 4.75mm down with specific gravity 2.65 were used in the work.

(c) Coarse Aggregate: Locally available crushed angular coarse aggregate having maximum size of 20mm with specific gravity 2.7 was used in this work.

(d) Water: Water is used for both mixing and curing of cubes specimens should be free from organic impurities of any type. Potable, colourless and odourless water is generally considered satisfactory for mixing and curing of concrete. In the present work potable tap water was used. The used water is free from oil and other chemical substances.

(e) PET bottle: PET bottles are waste materials observed from restaurant as well industries. PET bottles are collected from various restaurant of jorhat town. After removing the top and bottom of the bottle the length of PET fibres was kept as 20 mm and the breadth was 2 mm. Aspect ratio of these fiber is 10.



Fig1 PET fiber

(f) Mix Design: Mix design has been perform by IS 10262:2009. Mix proportion is 1:1.466:2524, having water-cement ratio 0.45. Chemical admixtures are not used in this work.

(g) Compressive Strength: The steel mould of size 150 × 150 × 150 mm is well tightened and oiled thoroughly, then tested in 7, 28, 56, 90 days.

(h) Split Tensile Strength: The cylindrical specimens for routine testing and comparison of results, unless otherwise specified the specimens shall be cylinder 150 mm in diameter and 300 mm long.

(i) Curing: Curing of concrete is the process of maintaining the moisture and temperature conditions of concrete for hydration reaction so that concrete gets harden over time. The main component which needs to be taken care are moisture, heat and time during curing process.



Fig 2 Curing of cube specimen

4. EXPERIMENTAL OBSERVATION

The experimental observation of various test conducted on the laboratory are presented.

(A) Physical Properties of Cement

The various physical properties of cement are tested as per relevant IS codes in the laboratory and the results are listed in Table 1

Table 1 Physical Properties of OPC-43 Grade Cement

Sl No.	Tests	Reference	Value
1	Consistency of Cement	IS 8112:2013	32.5%
2	Initial Setting Time		95 min
3	Final Setting Time		560 min
4	Fineness	IS 4031:1996 (Part-1)	96%
5	Avg. Specific Gravity	IS 2720:1980 (Part-3)	3.12
6	Colour		Grey

(B) Physical Properties of Fine Aggregate and Coarse Aggregate

The various physical properties of FA and CA are tested as per relevant IS codes in the laboratory and the results are given in Table 2

Table 2 Physical properties of FA and CA

Tests	Reference	Fine Aggregates	Coarse Aggregate
Avg. Water Absorption	IS 2386: 1963 (Part-3)	1.12	0.53
Avg. Specific Gravity	IS 2720: 1980 (Part-3)	2.65	2.7
Zone of Sand	IS383:1970	Zone II	-
Aggregate Impact Value	IS 2386: 1963 (Part-4)	-	The aggregate impact value is 20 % < 21.506 % < 30 % Therefore, this sample can be used for road surfacing.
Grain Size Analysis	IS 460:1962	$C_u=3.535$, $C_c=0.796$ Since C_u is less than 4, Therefore our sample is uniformly graded.	-
Size in mm	-	4.75 down	20 down

(C) Physical Properties of Concrete

The various physical properties of concrete are tabulated in Table 3.

Table 3 Slump value and Bulk Density

SI No	Sample	Slump Value (mm)	Avg. Bulk Density($\frac{\text{kg}}{\text{m}^3}$) at 28 days
1	NC	52	2519.50
2	PF1 (0.5%)	46	2478.02
3	PF2 (1%)	41	2462.22
4	PF3 (1.5%)	36	2454.30
5	PF4 (1.75%)	33	2434.57
6	PF5 (2%)	31	2403.95

(D) Compressive Strength Test of Concrete

The cubes with a different proportion having w/c 0.45 are tested for compressive strength at 7, 28, 56, 90 days of curing as per IS 516:1959 are given below. Mix proportion of the specimen is 1:1.466:2.524. Six types of specimens were prepared with plastic fiber and designated as NC, PF1, PF2, PF3, PF4 and PF5 plastic fiber to the weight of the cement.

Table 4 Compressive strength test (7 day) for cube using plastic fibers

SI No.	Types	Compressive Strength (MPa)	Avg. Compressive Strength (MPa)	Improvement Factor at 7 days	Bulk Density ($\frac{\text{kg}}{\text{m}^3}$)
1	NC (0%)	28.22	27.62	1.000	2494.81
2		27.11			2506.67
3		27.33			2488.89
4	PF1 (0.5%)	23.55	23.70	0.858	2474.07
5		23.11			2474.07
6		24.44			2477.03
7	PF2 (1%)	25.77	25.55	0.925	2468.14
8		24.66			2465.19
9		26.22			2465.19
10	PF3 (1.5%)	28.88	28.59	1.035	2462.22
11		29.11			2459.26
12		27.78			2456.29
13	PF4 (1.75%)	27.11	27.25	0.987	2441.48
14		26.44			2432.59
15		28.22			2435.56
16	PF5 (2%)	25.77	26.29	0.951	2429.62
17		26.88			2426.67
18		26.22			2423.70

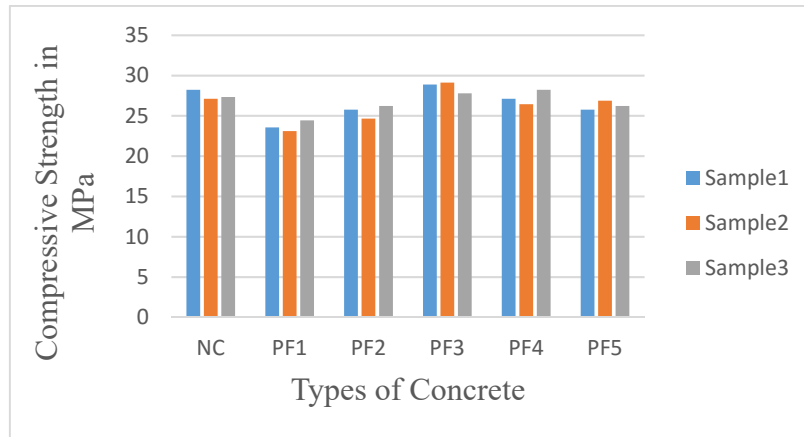


Fig3 Compressive strength of cube specimen (7 day) when plastic fiber is use as admixture

Table 5 Compressive strength test (28 day) for cube using plastic fibers

Sl No.	Types	Compressive Strength (MPa)	Avg. Compressive Strength (MPa)	Improvement Factor at 28 days	Bulk Density ($\frac{kg}{m^3}$)
1	NC (0%)	39.11	39.33	1.000	2518.51
2		39.55			2521.48
3		39.33			2518.51
4	PF1 (0.5%)	33.56	33.93	0.863	2474.07
5		34			2477.03
6		34.22			2482.96
7	PF2 (1%)	36	36.37	0.924	2459.26
8		36.67			2465.19
9		36.44			2462.22
10	PF3 (1.5%)	40.22	40.51	1.030	2453.33
11		40.88			2456.29
12		40.44			2453.29
13	PF4 (1.75%)	38.89	38.67	0.983	2438.52
14		38.44			2435.56
15		38.67			2429.62
16	PF5 (2%)	37.78	37.85	0.962	2402.96
17		38.22			2408.89
18		37.56			2400.00

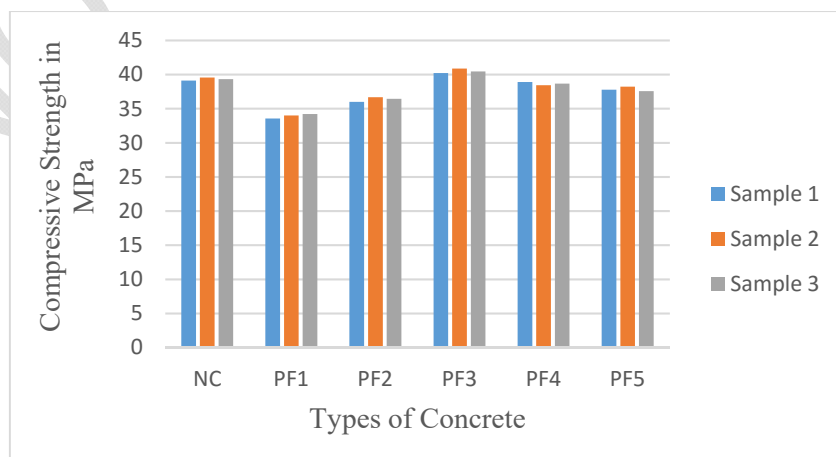
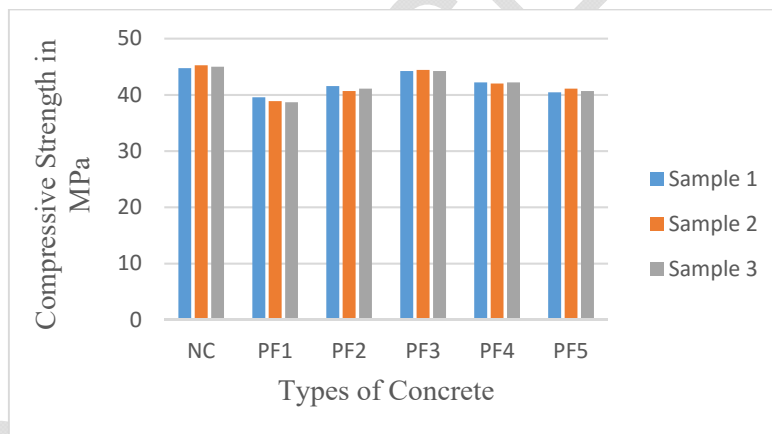


Fig4 Compressive strength of cube specimen (28 day) when plastic fiber is use as admixture

Table 6 Compressive strength test (56 day) for cube using plastic fibers

Sl No.	Types	Compressive Strength (MPa)	Avg. Compressive Strength (MPa)	Improvement Factor at 56 days	Bulk Density ($\frac{kg}{m^3}$)
1	NC (0%)	44.75	45.00	1.000	2520.00
2		45.25			2520.00
3		45.00			2510.00
4	PF1 (0.5%)	39.55	39.03	0.867	2494.81
5		38.89			2488.89
6		38.67			2485.93
7	PF2 (1%)	41.55	41.11	0.913	2474.07
8		40.67			2465.19
9		41.11			2468.15
10	PF3 (1.5%)	44.22	44.29	0.984	2456.29
11		44.44			2459.26
12		44.22			2453.33
13	PF4 (1.75%)	42.22	42.15	0.937	2438.51
14		42.00			2444.44
15		42.22			2444.44
16	PF5 (2%)	40.44	40.74	0.905	2426.67
17		41.11			2429.63
18		40.67			2426.67

**Fig 5** Compressive strength of cube specimen (56 day) when plastic fiber is use as admixture**Table 7** Compressive strength test (90 day) for cube using plastic fibers

Sl No.	Types	Compressive Strength (MPa)	Avg. Compressive Strength (MPa)	Improvement Factor at 90 days	Bulk Density ($\frac{kg}{m^3}$)
1	NC (0%)	46.75	46.00	1.000	2530.00
2		45.50			2520.00
3		45.75			2530.00
4	PF1 (0.5%)	40.44	40.14	0.872	2503.71
5		39.77			2494.81
6		40.22			2497.78
7	PF2 (1%)	41.77	42.21	0.917	2477.03
8		42.66			2482.96
9		42.22			2474.07
10		45.11			2462.22

11	PF3	44.66	45.11	0.981	2459.26
12	(1.5%)	45.56			2465.19
13	PF4 (1.75%)	43.55	43.55	0.947	2450.37
14		44.00			2453.33
15		43.11			2447.41
16	PF5 (2%)	41.33	41.70	0.907	2426.67
17		42.00			2432.59
18		41.78			2429.63

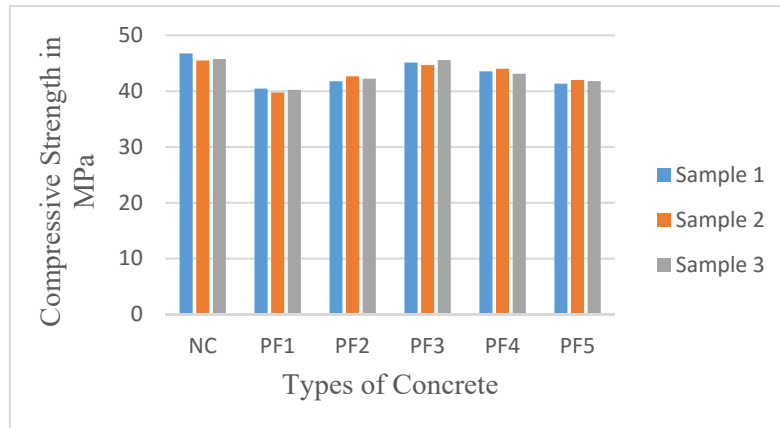


Fig 6 Compressive strength of cube specimen (90 day) when plastic fiber is use as admixture

(E) Split Tensile Strength Test of Concrete

As per clause 8.1 of IS 5816:1999

$$\text{Split tensile strength, } f_{ct} = \frac{2P}{\pi DL}$$

Where, P = Compressive load on cylinder, L = Length of the cylinder, D = Diameter of the cylinder

Split tensile strength of different cylindrical specimen with various proportion are tabulated at table 8

Table 8 Split tensile strength test of cylindrical specimen

SI No.	Sample	Split Tensile Strength at 28 days	Avg. Split Tensile Strength	Improvement Factor at 28 days
1	NC (0%)	2.829	2.829	1.000
2		2.900		
3		2.759		
4	PF1 (0.50%)	2.546	2.565	0.907
5		2.532		
6		2.617		
7	PF2 (1.00%)	2.794	2.746	0.970
8		2.687		
9		2.758		
10	PF3 (1.50%)	3.112	3.053	1.079
11		3.041		
12		3.006		
13	PF4 (1.75%)	2.900	2.936	1.037
14		2.971		
15		2.936		
16	PF5	2.758	2.793	0.987
17		2.829		

(F) Graphical representation of Compressive Strength Test and Split Tensile Strength Test Result

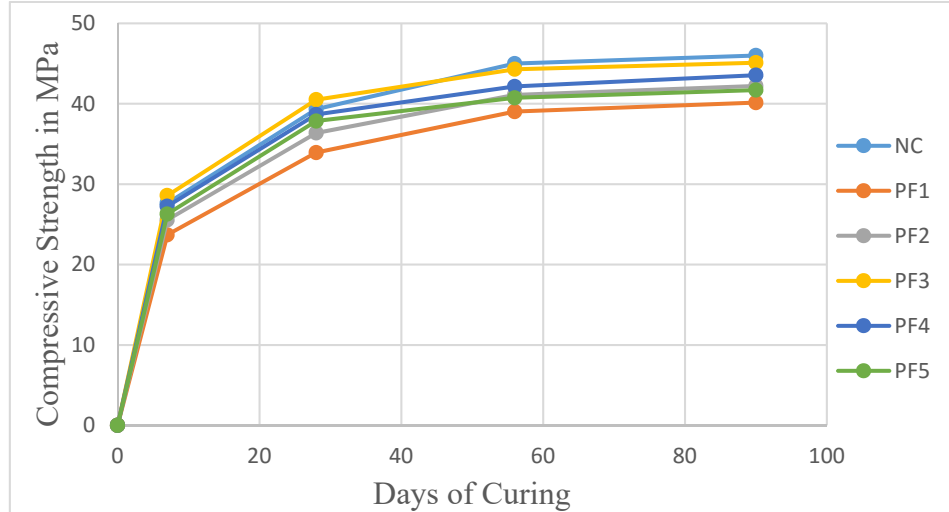


Fig 7 Compressive Strength test when plastic fiber used as an admixture

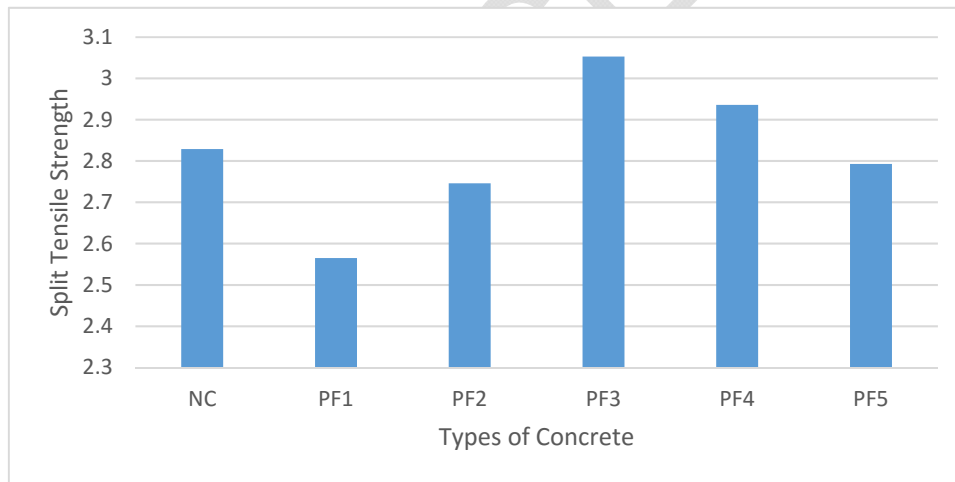


Fig 8 Split Tensile Strength test when plastic Fiber used as an admixture

From the above figure 7, it can be concluded that PF3 (i.e. partial replacement of 1.5% of plastic fiber with cement) shows maximum compressive strength at 7 days and 28 days of curing than all other samples but at 56 days and 90 days of curing it shows slightly lower compressive strength than that of normal concrete but in acceptable limit. Similarly in figure 8, it is observed that that PF3 (i.e. partial replacement of 1.5% of plastic fiber with cement) shows maximum split tensile strength at 28 days of curing than all other samples.

5 REGRESSION ANALYSIS

Predicted compressive strength at 7 days = $-79.410 + 0.090 \times \text{cement content} - 2.073 \times \text{PF1} - 0.683 \times \text{PF2} + 0.167 \times \text{PF3} - 0.047 \times \text{PF4} - 0.152 \times \text{PF5} + 1.218 \times \text{SF1} + 0.156 \times \text{SF2} + 0.298 \times \text{SF3} + 0.097 \times \text{SF4} - 39.814 \times \text{JF1} + 4.215 \times \text{JF2} + 0.580 \times \text{JF3} - 0.687 \times \text{JF4} + 0.106 \times \text{FA1} +$

$$0.036 \times \text{FA2} - 0.006 \times \text{FA3} + 16.774 \times \text{CF1} + 3.571 \times \text{CF2} + 1.744 \times \text{CF3} + 0.419 \times \text{CF4} + 40.975 \times \text{HSF1} + 40.570 \times \text{HSF2} + 0.607 \times \text{HSF3} + 0.268 \times \text{HSF4}$$

The experimental and predicted compressive strength at 7 days of curing period are given in the table 9

Table 9 Experimental and predicted compressive strength at 7 days of curing

SI No.	Sample	Experimental Compressive Strength N/mm ² at 7 days	Predicted Compressive Strength N/mm ² at 7 days
1	NC	27.62	28.29
2	PF1	23.70	24.67
3	PF2	25.55	25.63
4	PF3	28.59	28.67
5	PF4	27.25	27.33
6	PF5	26.29	26.36

$$\text{Predicted compressive strength at 28 days} = -197.68 + 0.055 \times \text{cement content} - 2.680 \times \text{PF1} - 0.481 \times \text{PF2} + 0.474 \times \text{PF3} + 0.129 \times \text{PF4} + 0.013 \times \text{PF5} + 1.969 \times \text{SF1} + 1.503 \times \text{SF2} + 0.994 \times \text{SF3} + 0.212 \times \text{SF4} - 99.29 \times \text{JF1} + 11.012 \times \text{JF2} + 1.733 \times \text{JF3} + 0.015 \times \text{JF4} + 0.072 \times \text{FA1} - 0.022 \times \text{FA2} - 0.014 \times \text{FA3} + 73.527 \times \text{CF1} + 10.414 \times \text{CF2} + 4.769 \times \text{CF3} + 2.420 \times \text{CF4} + 102.38 \times \text{HSF1} + 100.83 \times \text{HSF2} + 1.194 \times \text{HSF3} + 0.559 \times \text{HSF4}$$

The experimental and predicted compressive strength at 28 days of curing period are given in the table 10

Table 10 Experimental and predicted compressive strength at 28 days of curing

SI No.	Sample	Experimental Compressive Strength N/mm ² at 28 days	Predicted Compressive Strength N/mm ² at 28 days
1	NC	39.33	37.86
2	PF1	33.93	34.82
3	PF2	36.37	36.26
4	PF3	40.51	40.41
5	PF4	38.67	38.57
6	PF5	37.85	37.74

$$\text{Predicted compressive strength at 56 days} = -154.35 + 0.053 \times \text{cement content} - 2.931 \times \text{PF1} - 0.628 \times \text{PF2} + 0.211 \times \text{PF3} - 0.136 \times \text{PF4} - 0.291 \times \text{PF5} + 1.413 \times \text{SF1} + 1.312 \times \text{SF2} + 0.902 \times \text{SF3} + 0.097 \times \text{SF4} - 92.057 \times \text{JF1} + 9.056 \times \text{JF2} + 0.416 \times \text{JF3} - 0.910 \times \text{JF4} + 0.092 \times \text{FA1} - 0.012 \times \text{FA2} - 0.014 \times \text{FA3} + 52.753 \times \text{CF1} + 9.276 \times \text{CF2} + 3.983 \times \text{CF3} + 1.864 \times \text{CF4} + 95.147 \times \text{HSF1} + 93.539 \times \text{HSF2} + 1.159 \times \text{HSF3} + 0.543 \times \text{HSF4}$$

The experimental and predicted compressive strength at 56 days of curing period are given in the table 11

Table 11 Experimental and predicted compressive strength at 56 days of curing

SI No.	Sample	Experimental Compressive Strength N/mm ² at 56 days	Predicted Compressive Strength N/mm ² at 56 days
1	NC	45.00	43.64
2	PF1	39.03	40.03
3	PF2	41.11	41.28
4	PF3	44.29	44.46
5	PF4	42.15	42.32
6	PF5	40.74	40.92

Predicted compressive strength at 90 days = $-154.76 + 0.053 \times \text{cement content} - 2.869 \times \text{PF1} - 0.593 \times \text{PF2} + 0.182 \times \text{PF3} - 0.073 \times \text{PF4} - 0.294 \times \text{PF5} + 1.541 \times \text{SF1} + 1.262 \times \text{SF2} + 0.902 \times \text{SF3} + 0.098 \times \text{SF4} - 92.906 \times \text{JF1} + 9.290 \times \text{JF2} + 0.475 \times \text{JF3} - 0.835 \times \text{JF4} + 0.101 \times \text{FA1} - 0.010 \times \text{FA2} - 0.011 \times \text{FA3} + 52.046 \times \text{CF1} + 9.240 \times \text{CF2} + 4.091 \times \text{CF3} + 2.021 \times \text{CF4} + 96.076 \times \text{HSF1} + 94.446 \times \text{HSF2} + 1.168 \times \text{HSF3} + 0.524 \times \text{HSF4}$

The experimental and predicted compressive strength at 90 days of curing period are given in the table 12

Table 12 Experimental and predicted compressive strength at 90 days of curing

SI No.	Sample	Experimental Compressive Strength N/mm ² at 90 days	Predicted Compressive Strength N/mm ² at 90 days
1	NC	46.00	44.31
2	PF1	40.14	40.79
3	PF2	42.21	42.08
4	PF3	45.11	44.97
5	PF4	43.55	43.42
6	PF5	41.70	41.57

From the regression analysis it is observed that the regression analysis gives good predicted value which is almost nearer to the experimental data.

6. CONCLUSION

Following conclusion can be drawn,

- Compressive Strength at 1.5% plastic fiber at 7 days, 28 days, 56 days and 90 days curing period are 28.59 N/mm², 40.51 N/mm², 44.29 N/mm² and 45.11 N/mm².
- Test results indicate that inclusion of 2.0% steel fiber to the weight of the cement shows maximum compressive strength at 7 days, 28 days, 56 days and 90 days curing period. Observed Improvement Factor at 7 days, 28 days, 56 days and 90 days are 1.179, 1.203, 1.136 and 1.131 respectively and increase 0.073% of cost per cubic meter of concrete work.
- Test results indicate that inclusion of 1.5% plastic fiber to the weight of the cement shows the maximum split tensile strength compare to all other admixtures at 28 days curing period. Observed split tensile strength at 28 days curing period is 3.053 and improvement factor is 1.079
- After optimum level, there is drop in compressive strength which indicates air entrapment in the concrete due to incorporation of high fiber fraction.
- Cracks occur in microstructure of concrete and fibers reduce the crack formation and propagation.
- Workability decreases with increase in fibre content.
- From the experiment it was observed that the FRC specimens did not break suddenly and failure was ductile compare to the normal concrete.

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BAMBOO REINFORCED CONCRETE-A SOLUTION FOR AFFORDABLE RURAL HOUSING

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Abstract: *The best, quickest and most efficient way to build up a nation is to build up from the root and this can only be achieved by providing affordable housing with sanitation system, education, health and proper transport and communication system to all. Every village has to become self-sufficient which requires an intelligent and proper investment. In today's world construction industry is the highest consumer of the available natural resources there by making sustainable development a major issue of concern in order to satisfy the ever increasing housing demand of the world's inflated population. One of the most commonly accepted definitions of affordability refers to housing affordability which is taken as a measure of expenditure on housing to income of the household. There is high need for designing and building Smart Villages which are independent in providing the services and employment and well connected to the rest of the world. A conventional building is constructed in accordance with the traditional construction practices and regular building code (if available) in a specific country. The most common kind of housing in villages of north-east India are traditional bamboo-mud-thatch kind of housing. The durability aspect of these traditional housing is not up to the mark though convenient from sustainability and economic point of view. But a smart housing type also takes into consideration of strength, safety and durability aspect as a matter of concern. On the other hand classical RCC buildings though serve the strength, safety and durability aspect, the performance is poor while analysed from economic and sustainable point of view. The high cost in case of a traditional RCC building is normally due to high cost associated with steel reinforcement. The study aims at exploring the various aspects of bamboo reinforced concrete beams which are simple, efficient and economical for rural construction. The study was broadly divided in three steps and attempt has been made to investigate the feasibility of locally available species. Four common species Bamboosa Tulda (Jati Bah), Bamboosa Balcoa (Bhaluka Bah), Bamboosa Nutans (Mokal Bah) and Dendro Calamus Hamiltonii (Kako Bah) were taken for the study. The properly sized splints were supplied by RFRI (Rain Forest Research Institute), Sotai Jorhat. Treated bamboo splints were tested in UTM and were used in RCC beams as a full and partial replacement of steel reinforcement. In the second phase, the bonding of bamboo splints with concrete were evaluated with the help of pull out test. Different techniques such as coir wrapped, tar coated and sand roll,*

G.I. wire are wrapped etc has been attempted. The bonding in case of G.I. rolled, CCB treated splints was found to be highest from the pull out test. In the final phase the flexural strength of bamboo reinforced beam were compared with unreinforced as well as steel reinforced beams. BRC beams performed well and showed more than 30% of the capacity of a traditional steel reinforced beam. Thus the present study encourages use of bamboo as a good potential reinforcement as partial or full scale replacement of steel for low cost housing thereby saving natural resources to a considerable extend.

Keywords: *BRC, affordable housing, CCB*

1 Introduction

Shelter is the basic human requirement and even after 72 years of Independence the country is still grappling with the growing shelter problem especially for the poor. Particularly there is a severe housing shortage in the urban area with demand supply gap increasing day by day. Housing for all by 2022 is a new urban housing mission which has been approved by union cabinet with the goal of constructing about two crores houses in all 4041 statutory towns and cities of the country by the end of 2022 coinciding with the historic occasion of 75yrs of independence of the country. Similarly, smart village is a concept adopted by national, state and local governments of India as an initiative focussed on holistic rural development derived from Mahatma Gandhi's vision of Adarsha Gram and Swaraj. An attempt has been made to introduce low cost houses which are durable, safe, sustainable and economic by using locally available construction materials.

One natural material which has great appeal in terms of availability and ease of use in the rural areas with causing minimum harm to the environment is bamboo. Bamboos occur mostly in tropical and subtropical areas and even in temperate regions, in altitude varying from sea level to snow-capped mountain peaks. They are most abundant in south-eastern Asia, with some species in the America and Africa and none in Australia. It is estimated that there are about 1200 species of bamboo in the world. A single bamboo grows in clumps can produce up to 15km useable pole in its lifetime. It is estimated that about one billion people have been living in bamboo houses. For ages bamboo has been used in construction and currently they are used as props, foundations, framing, scaffolding flooring, walls, roofs and trusses. Bamboo has been used in a wide variety of applications such as recreation like to construct a variety of musical instruments in addition to the fact that bamboo can be used in the arts and crafts. It can also be used to make furniture, can be fashioned into many shapes leading to artistic freedom : home decoration, dishware, dolls, toys, jewelry etc. It has the highest carbon dioxide absorption. Quick harvest is possible which can be also continuous harvest and it sustains green cover.

2 Literature Review

Brink and Rush (1966), provided a study giving a set of instructions on how to properly construct a variety of structures and structural elements using bamboo. They suggested not to use green, unseasoned Bamboo for general construction, nor to use un waterproofed bamboo in concrete. Concerning Bamboo reinforced concrete, it was found that the concrete mix designs may be the same as that used with steel, with a slump as low as workability will allow. It was advised that the amount of bamboo reinforcement in concrete be 3-4% of the concrete's cross-sectional area as the optimum amount. It concludes that BRC is a potential alternative in building construction.

Khare (2005) on her M.S research explored the feasibility of the use of bamboo as a potential reinforcement in concrete structural members. A series

of tensile tests on three types of bamboo were conducted. Four-point bend tests on concrete beams reinforced with bamboo were also performed to identify their behavior compared to steel reinforced concrete members.

Ghavami (2005) studied the mechanical properties of six different types of Bamboo, proper treatments that should be applied to bamboo, and the methods that should be employed when utilizing bamboo as concrete reinforcement. The properties of bamboo were found to be based upon a functionally graded construction with its most important property being that its ratio of strength to specific weight is six times greater than steel. Test results showed the ideal value for the percentage of bamboo in concrete to be 3% of the cross-sectional area of concrete beam, allowing for the highest applied load, and the necessity for drying and water repellant treatments. This study concluded that bamboo can substitute steel satisfactorily, and that there is a need to establish the characteristic strength of Bamboo for design purposes.

Bamboo Reinforced Concrete being a simple, efficient and cost-effective construction technique is a suitable way for proceeding civil engineering construction towards sustainable development. **Mark and Russell (2013)** tested sixteen BRC beam to failure under four-point bend test. The beams were provided with shear reinforcements of three different types such as bamboo stirrups, steel stirrups and cane stirrups. On testing it has been found that BRC beams with steel stirrups performed better as compared to beams with bamboo and cane stirrups. Also, cost effectiveness of steel stirrups is more as compared to bamboo and cane stirrups. **Mary and Tensing (2013)** discussed the advantages of bamboo which proves to be a strong natural fiber, highly flexible, light-weight and heavy shock absorber. Several other properties were also put into light such as low bond stress with concrete and high-water absorption capacity, which should be taken care of before bamboo is being put to use. **Kankam and Odum-Ewuakye (2006)** carried out laboratory test on two-way slabs that had been reinforced with babadua bars by applying point loads on them. Test results concluded that the average monotonic and cyclic failure loads were approximately 133 % and 270% of the theoretical flexural strength respectively, and 148% and 198% of the theoretical punching shear strength of the unreinforced concrete section. The results of the investigation also show that the stems of bahaduagiants are structurally suitable and durable as reinforcing bars in concrete slabs. Along with the above results and discussion one major recommendation is the generation of a finite element model which would help to get an idea of how a bamboo reinforced concrete member behaves under the action of certain applied loads.

3 Affordable housing

Affordable housing refers to any housing which meets some of the forms of affordability criterion, which can be income level, size of the dwelling, affordably in terms of EMI size or ratio of price to annual income. A natural material which is available in bulk and easy to use possess the full potential to be used in large extent in construction

industry. Bamboo has been historically used as a building material due to its inherent properties, being regenerating, biodegradable, with high tensile strength and light weight, being an eco-friendly alternative to many construction materials. But conventionally it has been preferred as a material only for the poor or for temporary construction and still unpopular in construction due to low durability, lack of structural design data etc. Bamboo is an integral part of the cultural, social and economic traditions of India. Many people still depend on it for their livelihood, and for household and functional uses.

There are many who are homeless eg. the people living on footpaths, slums, temporary shelter, unsafe homes alongwith children/old aged people living in unfavourable conditions. House/shelter is fundamental need to human being however owning a shelter is not. Thus affordable housing is important. Government of India has also taken initiative about “affordable housing” keeping in mind the economy and need of people to fulfill the target of 2022. For the last several decades, efforts have been made to provide quality housing to poor households in rural India. Pradhan Mantri Awaas Yojana Gramin (PMAY-G) holds potential as a turning point in this journey. It is a flagship programme of the Ministry of Rural Development, that aims to fulfill the vision of providing “Housing for All” with a strong focus on providing credible assistance and support to the beneficiaries in making informed choices with regard to the construction of his/her house.

As a major step in this direction, the Ministry, in partnership with United Nations Development programme (UNDP) and Indian Institute of Technology (IIT) Delhi, has undertaken detailed exercise of 18 states so far to provide a menu of technically validated options for design, construction material and technologies.



Fig 1 Proposed housing zones for Assam

Assam contains three physiographic divisions (out of the six in India)- The Northern Himalayas (Eastern Hills), The Northern Plains (Brahmaputra plain) and Deccan Plateau (Karbi Anglong). Plains in the 20-120 metre elevation range occupy most of the upper and lower Assam valley, covering almost 72% of the state's total area and constituting the most flood prone regions of Assam. The chief criteria for these designs are the geographical constraints – namely plains, hilly areas and flood affected areas – and consequently, the availability of building materials for house construction. Vulnerability to

natural hazards, Physiographic and access to building materials, Cultural Compatibility are the three main criteria for design of PMAY-G houses for Assam and the state has been divided in to five housing zones –

Zone A

High vulnerability to floods- 50-75% flood hazard area and likelihood of flood inundation for more than 24 hours almost every year. Marigaon, Nalbari and Darang are most vulnerable, Medium vulnerability to cyclonic storms, and mostly low vulnerability to river bank erosion. This zone lies entirely in the alluvial plains of the Brahmaputra valley, with the average elevation in the range of 25m-50m with negligible forest cover. Fig 2



Fig 2 Proposed housing type in zone A

Zone B

High vulnerability to floods- 50-75% flood hazard area and likelihood of flood inundation for more than 24 hours almost every year, Medium to high vulnerability to cyclonic storms, Medium to high vulnerability to river bank erosion. Housing in the river island areas such as Majuli are highly vulnerable to river bank erosion, high incidence of post flood silt deposition. This zone lies entirely in the alluvial plains of the Brahmaputra valley, with the average elevation in the range of 75m-125m with negligible forest cover .



Fig 3 Proposed housing type in zone B

Zone C

Low vulnerability to flooding and erosion, medium to high vulnerability to cyclonic wind storms, High vulnerability to landslides with highest forest cover in the state, with more than 3/4th of the zone covered with a mix of moist semi-evergreen, mixed deciduous and bamboo forests. Access to bricks for house construction is difficult in the zone.



Fig4 Proposed housing type in zone C

Zone D

Majority of the zone has low to medium vulnerability to flood with threat of severe floods once in about 10 years. High vulnerability to the northern part of the zone to flash floods in rivers flowing from Bhutan. High vulnerability to cyclonic wind storms with wind speeds reaching above 50 m/s in many parts of the zone. High vulnerability to river bank erosion and loss of land to erosion in Char areas are present in many parts of this zone Goalpara, Kamrup, Darrang, Bongaigaon, Barpeta, Tinsukia, Golaghat. This is a predominantly plain zone with the average elevation of 25-50 metres for the most part. The northern part of the zone has pockets of higher elevation of 125-150m. Bricks are easily available in most parts of the zone.



Fig 5 Proposed housing type in zone D

Zone E

Low vulnerability to floods – about 25% of the zone area is vulnerable to floods with a frequency of about 1 or 2 floods in 10 years. High vulnerability to cyclonic wind storms due to proximity to the Bay of Bengal. Predominantly plains and wetlands with an elevation of 25-50m, interspersed with hills. Karimganj has about 30% forest area Bricks, sand, aggregate are easily available in most parts of the zone. The zone is rich in bamboo- with a good stock of species suitable for good quality bamboo construction.



Fig 6 Proposed housing type in zone E

5. Characteristics of Bamboo

Traditionally steel is used as reinforcement in concrete structure. But because of cost and unaffordability, replacement of steel with some other suitable materials as reinforcement for low cost housing is now a major concern. In the present study, an attempt has been made to study the performance of four very common bamboo specimen found in North Eastern region as reinforcement in BRC(Bamboo Reinforced Beams) beams. The load displacement characteristics of these beams were obtained and comparative study reveals that *Bambusa Tulda (Jati baah)* performs the best as a flexural member. To get a better insight an analytical approach has also been tried. This study aims to develop bamboo as a structural element for its use in bamboo reinforced concrete beams which can be used in rural construction ..Since bamboo is a natural, cheap and also readily available material, it can be a substitute of steel in the field of low cost housing. .Bamboo has some constraints which does not allow it to be a very good option for the complete construction material .Firstly, untreated bamboo is susceptible to insects and fungi attack. So advisable to go for treated bamboo always for any kind of construction works. Secondly lack of knowledge and awareness among the public and even engineers even though provided with proper codes of practices. Another important point has been proved that bamboo has a tensile strength like steel but lower percentage of elongation as compared to steel. This is the reason of not providing the bamboo as reinforcement in multi-storeyed building as ductility is a prime factor of consideration in such type of buildings. .Northeast region of India is very rich in bamboo diversity. Approximately 50% of the total bamboo species of India are from this region. Out of about 130 bamboo species available in India, 34 species available in Assam, while Manipur and Arunachal Pradesh are richest in diversity of Bamboo with 53 and 50 species respectively. Table 1 lists the different available species in NE, hosted by RFRI.

Table .1Bamboo found in RFRI(Rain forest Research Institute, Jorhat)

Sl no	Species	Sl no	species	Sl no	species
1	Bambusa alemtenshii	15	Bambusa tulda	29	Melocanna baccifera
2	Bambusa Balcooa	16	Bambusa tulda var. gathia	30	Ochlandra scriptoria
3	Bambusa bambos	17	Bambusa vulgaris	31	Ochlandra travancorica
4	Bambusa bambos var. Gigantean	18	Bambusa vulgaris var. Striata	32	Ochlandra ebracteata
5	Bambusa beeheyana	19	Bambusa wamin	33	Oxytenanthera abyssinica
6	Bambusa cacharensis	20	Dendrocalamus asper	34	Oxytenanthera parviflora
7	Bambusa garuchakua	21	Dendrocalamus strictus	35	Phyllostachys mannii
8	Bambusa glaucescens	22	Dendrocalamus calostychus	36	Phyllostachys pubscens
9	Bambusa khasiana	23	Dendrocalamus giganteus	37	Pseudosasa japonica
10	Bambusa multiplex	24	Dendrocalamus giganteus (Mota kako)	38	Sassa fortune
11	Bambusa nutans	25	Dendrocalamus hamiltonni	39	Schizostachyum dullooia
12	Bambusa pallida	26	Dendrocalamus longispathus	40	Schizostachyum Fushsianum
13	Bambusa pallida (big)	27	Dinochloa compactiflora	41	Schizostachyum pergracile
14	Bambusa pseudopallida	28	Gigantochloa albociliata	42	Schizostachyum polymorphum

Considering the various positive aspects such as availability, strength, economy, sustainability etc, a study was performed to assess the performance of bamboo reinforced concrete members at least for the purpose of low cost housing. The study was broadly divided into three steps. Locally available species were taken for testing. Tensile strengths of four available species were experimentally found out. The species taken for consideration were a *Bambusa tulda* (Jati bah), *Bambusa balcooa* (Bholuka bah), *D.hamiltoni* (Kako bah), *Bambusa nutans* (Mokal bah). The samples were collected from RFRI(Rain Forest Research Institute), Jorhat, an institution under ICFRE (Indian Council of Forest Research and Education). The properly sized and cut splints were then treated with CCB (Copper Chrome Boron) in RFRI to protect it from insect and fungi attack. The chemical composition of CCB treatment solution is as follows:

Boric acid (H_3BO_3) / Copper Sulphate($CuSO_4$) / Sodium Dichromate ($Na_2Cr_2O_7$) in the ratio 1.5: 3: 4.

The CCB treated splints were then tested in UTM and yield strength, ultimate strength and percentage elongation were found out. Figure 9, UTM.

Figure 6 and 7 shows *Bambusa tulda* in RFRI and CCB Treatment respectively.



Fig 6 Bamboos Tulda



Fig 7 CCB treated splints

Beams were cast with reinforcement cages prepared with bamboo as longitudinal reinforcement and steel stirrups. Various methods have been adopted for increasing the bond strength in CCB treated bamboo splints. Some of the bamboo splints were tar

coated and sand rolled whereas some were epoxy coated and GI rolled. Figure 8 and 9 showing tar coated sand rolled BRC sections.

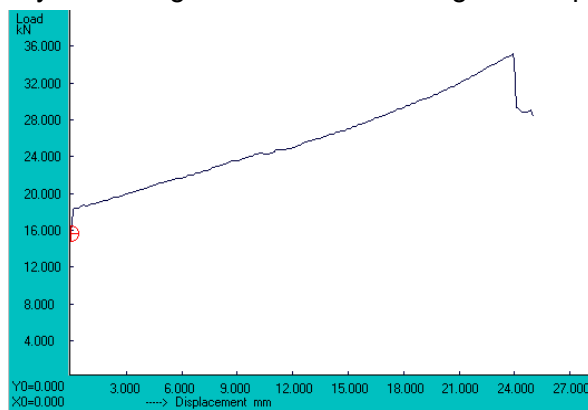


Fig 8 tar coated sand rolled splints

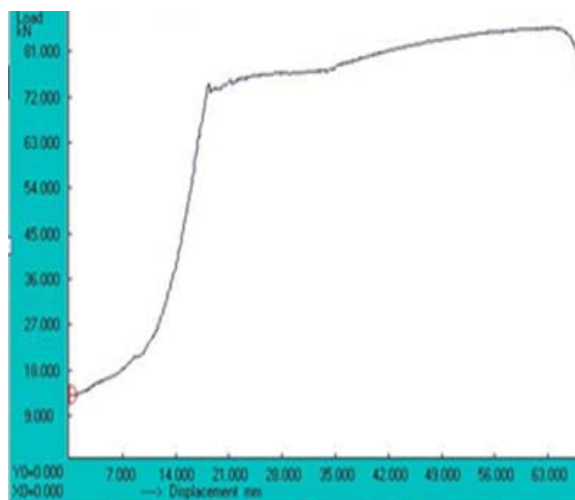


Fig 9 Epoxy coated GI wire rolled splints

The CCB treated splints were tested in UTM . Fig 10 a and b shows the comparative values of yield strength and ultimate strengths for splints and steel.



Maximum Force (Fm)	35.200 kN
Disp. at Fm	24.000 mm
Max. Disp.	24.800 mm
c/s Area (So)	80.000 mm ²
Tensile Strength (Rm)	0.440 kN/mm ²
Elongation	6.200 %



Maximum Force (Fm)	85.600 kN
Disp. at Fm	63.900 mm
Max Disp	69.700 mm
c/s Area (So)	113.143 mm ²
Tensile Strength (Rm)	0.757 kN/mm ²
Elongation	8.730 %
Reduction in Area (Z)	65.972 %
Yield Load	76.500 kN
Yield Stress	0.676 kN/mm ²
YS/UTS Ratio	0.894

Fig 10.a,b UTM Results for bamboo splint, 16mm size, Jati Bah and Steel

The no of main reinforcements were different for different specimen. The test result of flexural strength of 7, 28, 45 days were taken into consideration for comparison purposes. Better performance was observed in beams with more area of reinforcement and shear reinforcements. The frictional properties(bond strength) of BRC splints have been achieved by rolling the bamboo reinforcements with sand, GI wire and coir. The web material in all cases essentially consists of steel stirrups which help in resisting shear of reinforced concrete beams. Frictional properties were assessed with the help of series of pull out tests and highest bond strength were for epoxy coated GI wire rolled bamboo splints. For all specimen of CCB treated bamboo splints a coat of epoxy was applied.



Fig11a,b beams ready for curing and testing

6. Test Results

Continuous load v/s deflection graphs were obtained for different specimen when tested in the laboratory of NEIST (CSIR). At failure it was observed that beam subjected to higher curing period and reinforcement size perform better. Fig 12 shows load Vs displacement graph for BRC beams with 16 mm splints , cured for 45 days. Similarly Fig 13 shows load Vs displacement graph for BRC beams with 16 mm splints , cured for 60 days. Similar kind of performance graph is also shown Fig 14 and Fig 15 for beams with 20 mm size splints for 45 days as well as 60 days.

The experimental results obtained were also verified by modelling it in finite element software, ANSYS.

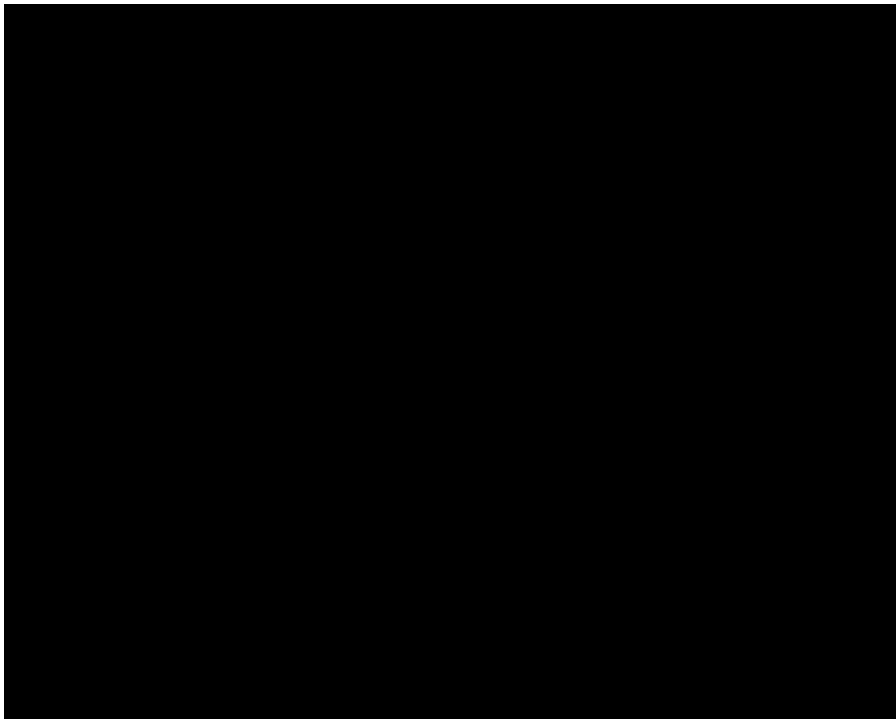


Fig 12 Comparative performance of BRC beams with different splints, 45 days

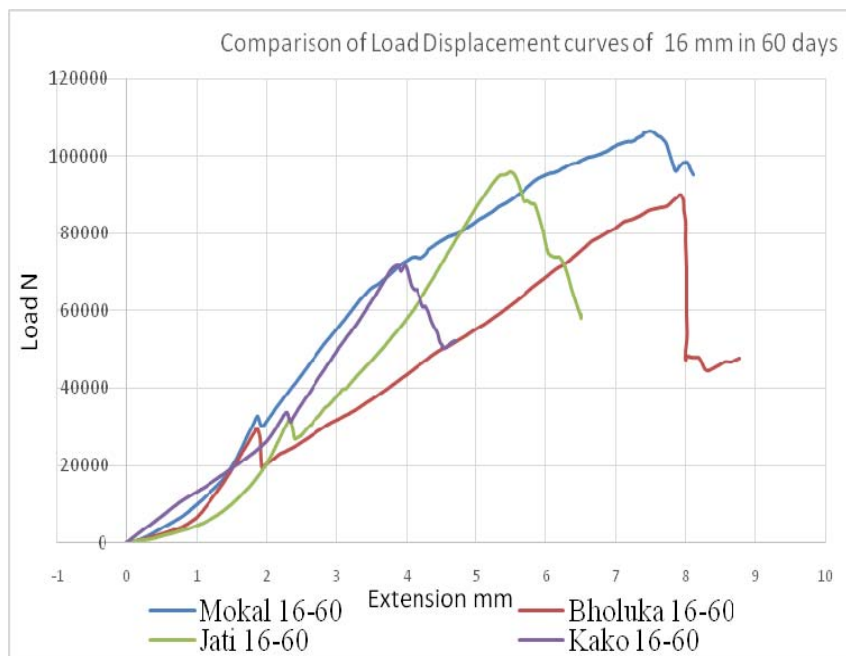


Fig 13 Comparative performance of BRC beams with different splints, 60 days

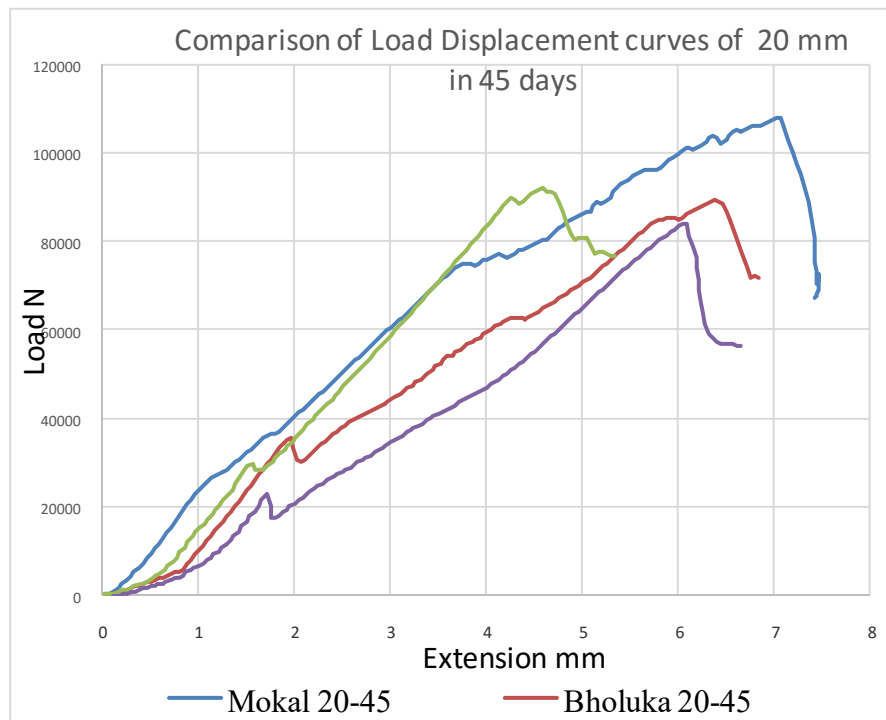


Fig 14 Comparative performance of BRC beams with different splints, 45 days

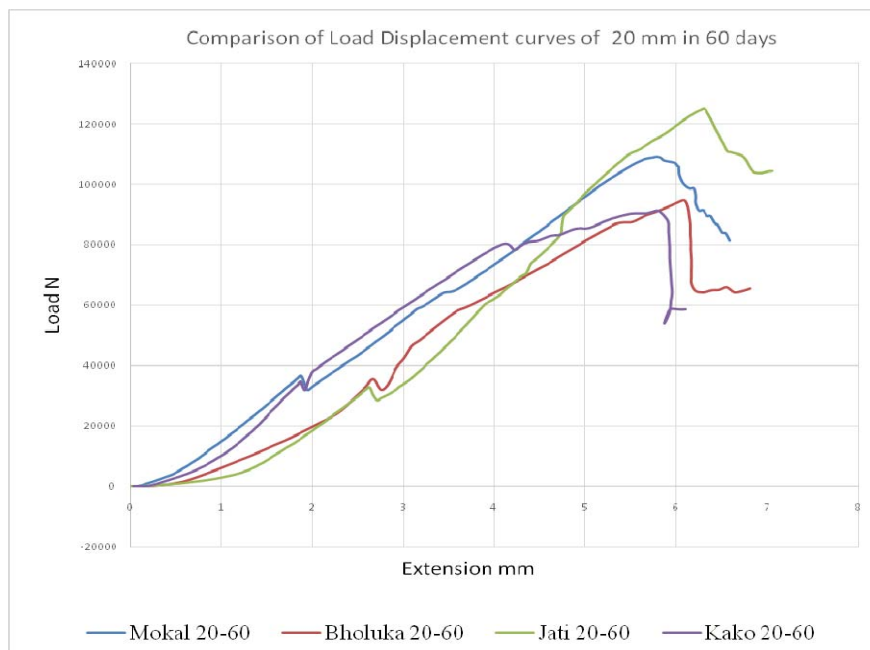


Fig 15 Comparative performance of BRC beams with different splints, 60 days

Stresses were found out and contours were located. Close approximation was observed between experimental and analytical results .Fig 16 shows the model of the referred beam in finite element software.

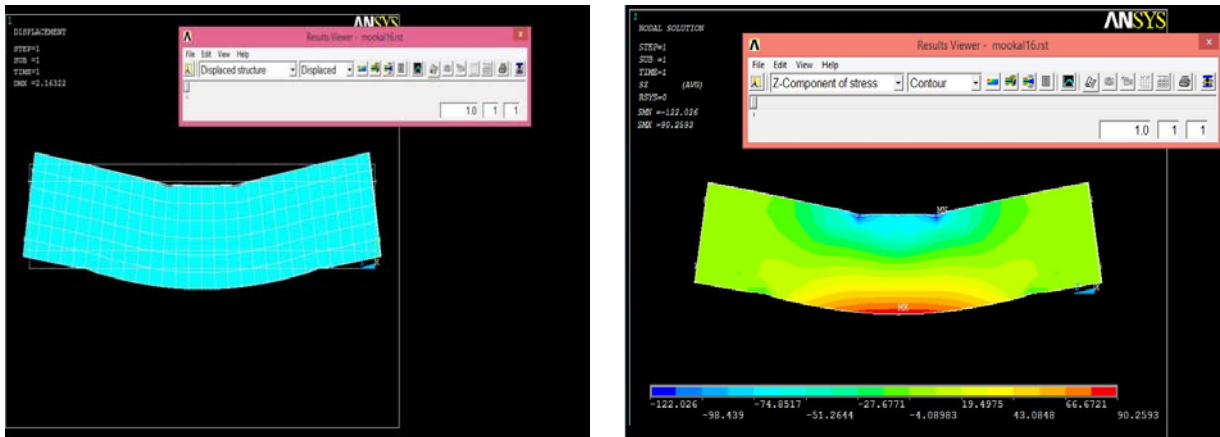


Fig 16. BRC beam modelled in Finite element software.

7.Conclusion

This study evaluated the feasibility of the use of bamboo as a potential reinforcement in concrete structural members. To achieve this objective four-point bending tests were conducted on four types of bamboo reinforced concrete beams. An overview of bamboo as a construction material, its characteristics, problems, treatments . are also addressed

From the experimental work, it can be concluded that flexural strength of bamboo actually depends on the type of species and cross-sectional area. An improved flexural performance of BRC beam has been observed with the increase in number of days of curing period and increase in the size of bamboo rebar. The aim of the study is to compare the flexural strength between different bamboo species. It has been found that the strength in flexure varies from species to species. In our case of study, the Jati Bamboo (*Bambusa tulda*) and Bholuka Bamboo (*Bambusa balcooa*) gave the best results, while Mokal bamboo (*Bambusa nutans*) showed moderate strength. The Kako Bamboo(*Dendrocalamus hamiltonii*) exhibited the lowest strength. From the FEM modelling a validation of experimental output of BRC beams with plain rebar has been made which gives us a suitable idea of the behavior of BRC beams.

To conclude the use of bamboo has the potential and can act as a substitute material for construction in India which will be a bold step toward building a sustainable environment. With the abundance of bamboo in our region, further research should be conducted to find out detailed characteristic and properties of the species and their various attributes. Due to the great advantages bamboo yield to the environment bamboo can be a substituted material for both wood and steel in construction. With adequate government input into policy measure, bamboo can be a very resourceful material, thereby contributing highly to mitigate the negative impacts of environmental degradation due to use of natural resources, militate against climate change, protect the biodiversity and promote sustainable construction development. Also, the government should encourage the use of bamboo in construction such as affordable housing scheme and also partner with governing bodies and also building industries.

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Cold formed steel buildings: An affordable housing solution for rural India

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Abstract

"Housing for all by 2022" is a slogan of the government, realizing the importance of providing roof for every household in the country. Conventional methods of constructing multi-family dwellings with concrete/masonry are time-consuming, wet in nature, labour and material intensive, causes environmental degradation and also cannot meet ever increasing demand for housing in the country. Limited availability and high price of raw materials for concrete, and pressure from environmental groups to preserve nature has forced engineers and researchers to look for other alternative materials and construction technology which is fast, sustainable and also cost effective to meet the shortage in housing sector. This paper reviews the merits and shortcomings of various affordable housing technologies adopted in the country and propose Cold Formed Steel (CFS) wall panel housing system as a viable alternative to meet the housing shortage and build sustainable rural infrastructure in the country.

The main objectives of the paper are (a) to present the various suitable construction techniques for single and multi-family CFS dwellings which facilitates fast track construction; (b) to provide brief introduction on the integration of essential services, acoustic and thermal insulation in CFS building system; (c) to present the current state of art review in CFS housing under vulnerable loading and put forward the research needs for next generation codes of practice emphasizing Performance Based Seismic Design (PBSD) philosophies.

Keywords: Cold Formed Steel housing, mass housing, housing shortage, affordable house and Performance Based Seismic Design.

Introduction

Housing is a basic need that provides a place of home to every individual. Developing countries like India face severe shortage, particularly among the economically weaker sections (EWS) and lower income groups (LIG) in urban and rural areas. The shortage of urban housing in the country is estimated to be nearly 18.78 million households in 2012 (Kundu, 2011). The working group on rural housing for the Twelfth Five Year plan estimated the number of households and housing stock as around 173.73 million and 169.63 million respectively in 2012, that leads to a shortage of 4.15 million. Apart from this, shortages due to temporary houses, obsolescent houses, and congestion were 20.21, 7.47, and 11.30 million respectively (WGRH-12). So the overall total housing shortage is estimated to be 43.13 million in 2012. In the estimated shortage, nearly 90 percent of the population lives below poverty line. The country faces severe shortage of housing both in urban and rural areas. Rapid pace of increase in population over the recent decades also imparted pressure on the availability of land and housing shortage, deteriorated the housing conditions of the weaker section of society resulted in increased number of slums in the country. Even though, there is a considerable investment in the housing infrastructure by the government, the demand is continuously outreaching the supply causing increase in the housing shortage.

The Government of India proposed Pradhan Mantri Awas Yojana (PMAY) under the slogan “Housing for all” in year 2015, realizing the importance of providing roof over every household to enable the family to be productive. Conventional method of construction with concrete or masonry are time-consuming, labour and material intensive, cannot scale up to meet the demand and also cause environmental degradation. It is clear that the housing problem calls for alternate housing technology, which can facilitate fast track construction. Since the housing shortage is severe in LIG and EWS, the proposed housing solution should meet the economy and living conditions of the household. Hence, the main aim of the affordable housing techniques should be a cost effective housing solution with not any sacrifice in living conditions, safety or serviceability over the life cycle of the structure. To meet the requirement in the housing sector, BMTPC have identified various housing technologies to meet the demand in the country (BMTPC, 2018).

The paper reviews the various affordable housing technologies being adopted in the country and proposes Cold Formed Steel (CFS) wall panel system as an attractive alternative to build smart infrastructure. The modular framing and dry form of construction facilitates fast track construction that could potentially address the housing shortage in the country. The CFS system is structurally stiff, absorbs energy and dampen vibration which can be used to construct multi-family dwelling in earthquake prone areas.

Emerging Technologies for mass housing

The Building Materials & Technology Promotion Council (BMTPC, 2018) proposed various alternate housing construction technologies for rapid and cost effective housing systems. This paper gives a brief overview of the range of housing solutions proposed by BMTPC (Compendium of Prospective Emerging Technologies for Mass Housing, 2018). Various housing technologies identified by BMTPC are found to be mostly wall panel / shear wall building system as compared to conventional RC framed construction with brick masonry infill. The various housing technologies are introduced along with its advantages and the same is summarized in (Table 1).

In addition to above systems, in the authors view confined masonry buildings (Brzev, 2007) with fly-ash bricks (instead of burnt clay bricks) could also be efficient, ecofriendly structural system for 3-4 storied building even in seismically active zones of the country. As an example in Gujarat, IIT Gandhinagar has built around six G+3 (four-storey) residential building for students, faculty and staff.

Table 1: Emerging technology for mass housing in India (BMTPC, 2018)

S. No	Housing technology	Building system	Advantages
1	Precast large panel system	- Concrete wall and floor units are pre-casted and assembled at site. - Individual elements are inter-connected through dowel bars and grouted at site.	- Speed in erection - Elements can be factory made or site fabricated.
2	Glass Fiber reinforced gypsum (GFRG) building	GFRG wall panel: Cavities can be partially or fully filled with plain/ reinforced concrete.	- Ecofriendly: Industrial byproduct (gypsum) as building material. - It can be build up to 8 storey even in seismic zones - No plastering - Concrete usage is less
4	Monolithic Concrete Construction	Wall and floor elements are casted monolithically with engineered formwork system made of Aluminium, Plastic and Composite formwork or combination.	Predesigned formwork enables cost effective and rapid construction of multiple units with repetitions
3	Expanded polystyrene (EPS) Core Panel System (CSIR-CBRI Report, 2017)	- EPS panel is used as a structural element for floors, walls, partitions, roof and stairs. - Panel consists of EPS core reinforced with high strength wire and finished with shotcreting on both sides.	- Light weight system & attracts less amount of lateral forces. - Adequate thermal and sound insulation. - Essential services can be integrated.
5	Light gauge / Cold formed steel (CFS) wall panel system (NASFA, 2000)	- CFS framing attached with sheathing material on both faces to form wall and floor system. - Sheathed wall and diaphragm enhances the lateral strength.	- High strength to weight ratio - Materials used are recyclable & reusable

Most of the proposed housing methodologies (except CFS building system) rely on usage of concrete which is material intensive, demands skilled field labors, wet in nature, construction methods are slow and cannot keep pace with the demand. The supply of raw materials such as sand, stone, clay and wood is unable to keep pace with the increasing demand, particularly under the strict environmental regulations. This has led to increase in the cost of such inputs. The speculative and the shortage driven push is rapidly increasing the housing costs, making housing less and less affordable to a larger segment of the society, particularly EWS's and LIG's. In this paper, CFS wall panel

building system is proposed as an affordable and sustainable alternative technology to meet the housing shortage and to build sustainable rural infrastructure.

Why CFS wall panel housing system

The advantages of the proposed CFS housing is summarized below:

- steel framed construction will have lower life cycle cost
- it is green
 - o more than 25% of steel is from recycled material and 100% of it is recyclable
 - o the wall boards can also be made from recycled or waste material such as gypsum, calcium silicate, or natural fibres in cement/resins etc.
- High strength to weight ratio,
 - o attracts less earthquake forces and have the ability to span longer
 - o stiff, ductile and could dissipate energy under earthquake loading
 - o easy to handle during transportation and erection
 - o does not require special material handling equipment at site
- Components of CFS wall panel system are prefabricated at shop to the desired level, field work can be considerably reduced, erection and installation would be easily done on site at a higher speed.
- well tied together to resist wind uplift forces and lateral loads
- slim construction and hence larger carpet area
- dry construction and hence amenable for fast track completion
- Mechanical, electrical & plumbing elements can be easily embedded into the framing.

Cold Formed Steel (CFS) Wall Panel System

The present generation of steel framed house construction systems has been derived from traditional timber framed house construction systems without any significant change in either the architecture or the interior and exterior finishing materials. Only the wood

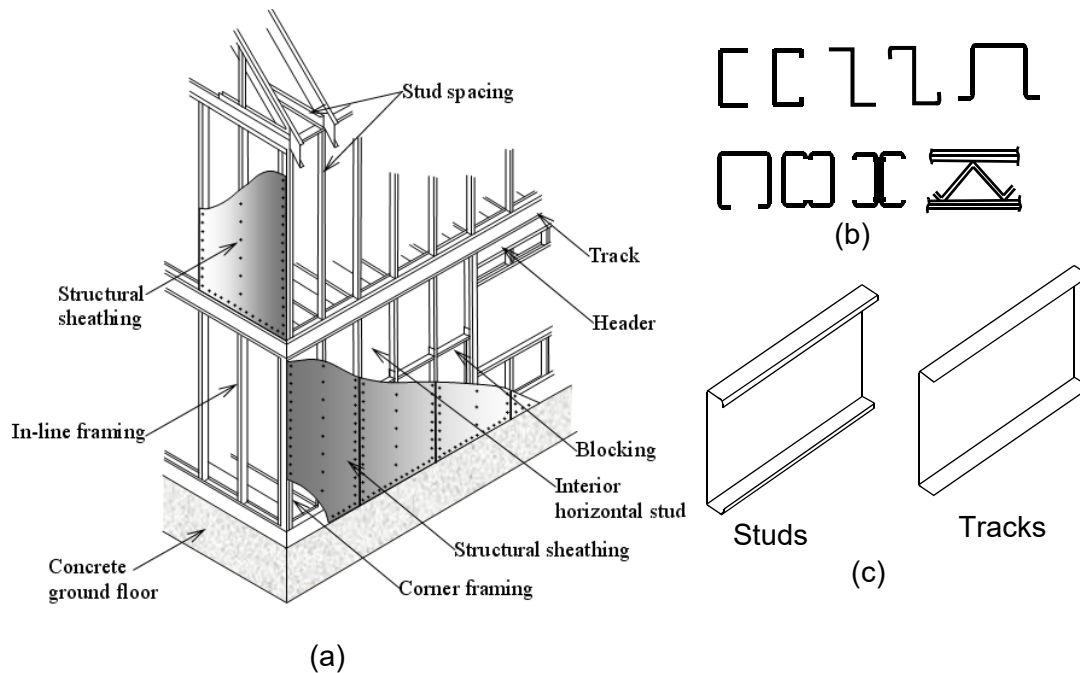


Figure 1: (a) 3D view of CFS system (b) Possible CFS section (c) Members used in CFS framing

structural members have been replaced with the CFS member. A view of CFS building is shown in (Figure 1a).

The possible range of CFS sections used in the system is shown in (Figure 1b). The CFS sections are generally of yield strength between 280 - 350 N/mm² and with thinness of member ranging from 0.9 to 3.2 mm thick. The various elements of the building system are discussed below.

Foundation: Foundation for CFS system normally slab on grade for single family dwelling and continuous strip footing or poured concrete wall for multi-family dwelling. The poured concrete wall footing consists of a crawl space which is essential in cold climates. Probably this is the only wet form of construction in the entire CFS wall panel system.

Walls: The typical CFS wall panel consists of CFS framing member's clad with sheathing material on exterior and interior faces with self-tapping screws. The CFS framing in the wall panel consists of vertical studs made of channel sections with lips (C section), top and bottom horizontal tracks made of channel without lips (U Section) as shown in (Figure 1c). The web depth of the tracks are slightly larger, where studs are inserted and in turn connected through self-drilling screws. The track at the ground floor is anchored to the foundation using concrete (chemical/adhesive) anchors. The typical spacing between the studs is 600mm (NASFA, 2000) and blockings made of C-sections are provided at mid height between the studs.

Sheathing Material: The cladding is usually a single skin sheathing material made of plaster board, gypsum board, Cement Particle board (CP), Oriented Strand Board (OSB) or plain/profiled steel sheathing and calcium silicate boards. It is recommended to use cement based boards as external cladding to prevent moisture penetration along with gypsum or plasterboards as internal cladding in the wall panels (Landolfo, 2019).

Floors: Floors at higher stories are constructed by framing CFS joists (channel with lips) between the wall panel with sheathing material attached on top of it. Normally, roofs are constructed using CFS roof trusses overlaid with plain/profile metal sheets or composite sheathing material, when the habitat space is not essential for the occupants in the upper storey.

Connections: Connections include steel to steel, steel to sheathing material and bottom track to concrete foundations. The connections are generally made with self-drilling screws for steel-steel connections & self-tapping screws for steel-sheathing connections. Typically, spacing of screws in the wall panel for perimeter studs is around 150 mm and field studs it is 300mm (intermediate members and blockings) (NASFA, 2000). Concrete anchors are used to establish connection between the continuous bottom track to foundation. They are normally cast in place anchors and post installed or drilled in anchors.

Various Bracing system

Bracings are essential elements in the system which resists lateral forces due to earthquake loading. Three common types are a) Integral Bracing b) X-Bracing and c) sheathing material acting as bracing as shown in (Figure 2).

Integral bracing uses C-sections placed diagonally in between the studs and the connection between the studs and diagonal members must be ensured correctly to resist the forces in tension and compression. X-bracing with flat straps of thin steel is fixed to the external face of the stud to resist the horizontal loads. These straps are capable of carrying only tension because of their high slenderness. Under in-plane shear loading, the CFS framing in wall panel behaves as a rigid parallelogram transferring the entire shear to the sheathing which is stiff in its plane via screw connection. Shear deformation in the framing member and the rotation of the sheathing causes differential demands in

the screw connection that forms screw connection as the primary lateral resisting mechanism (Madsen et al., 2016)

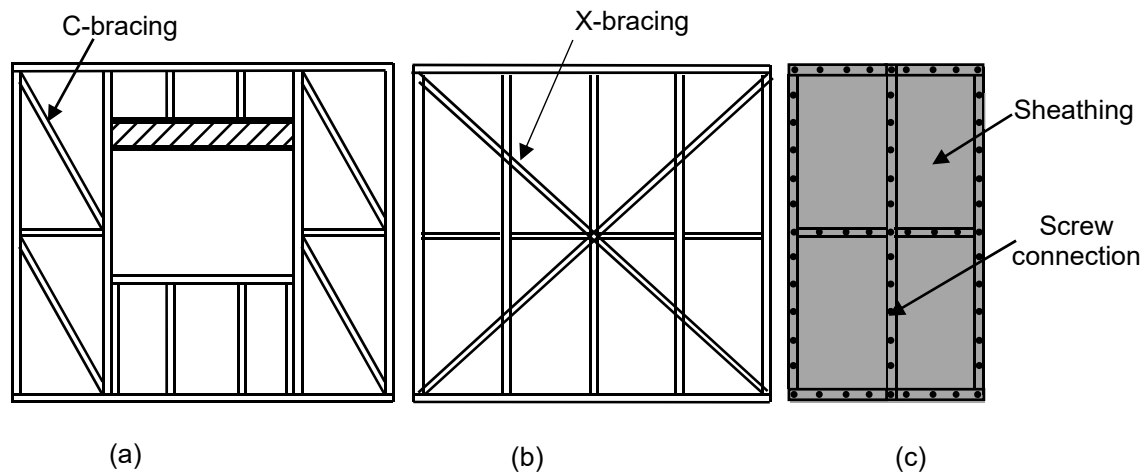


Figure 2: (a) Integral Bracing (b) X bracing (c) Sheathing as bracing

Behaviour of CFS building under gravity and earthquake loading

Under gravity load acting on the floors, the floor sheathing acting as a one-way slab between the joists, transfers the load to the joists. The joists in turn transfer the load to the supporting tracks at the ends, causing axial compression on the wall panels. Major portion of the axial load is transferred to the sheathed studs. Under in-plane shear loading, the chord studs in the wall panel experiences high cyclic tensile/compressive forces under in-plane racking and hence it is recommended to provide boxed, back-to-back studs (AISI S230-15, 2015). Sheathing attached to walls and floors acts as

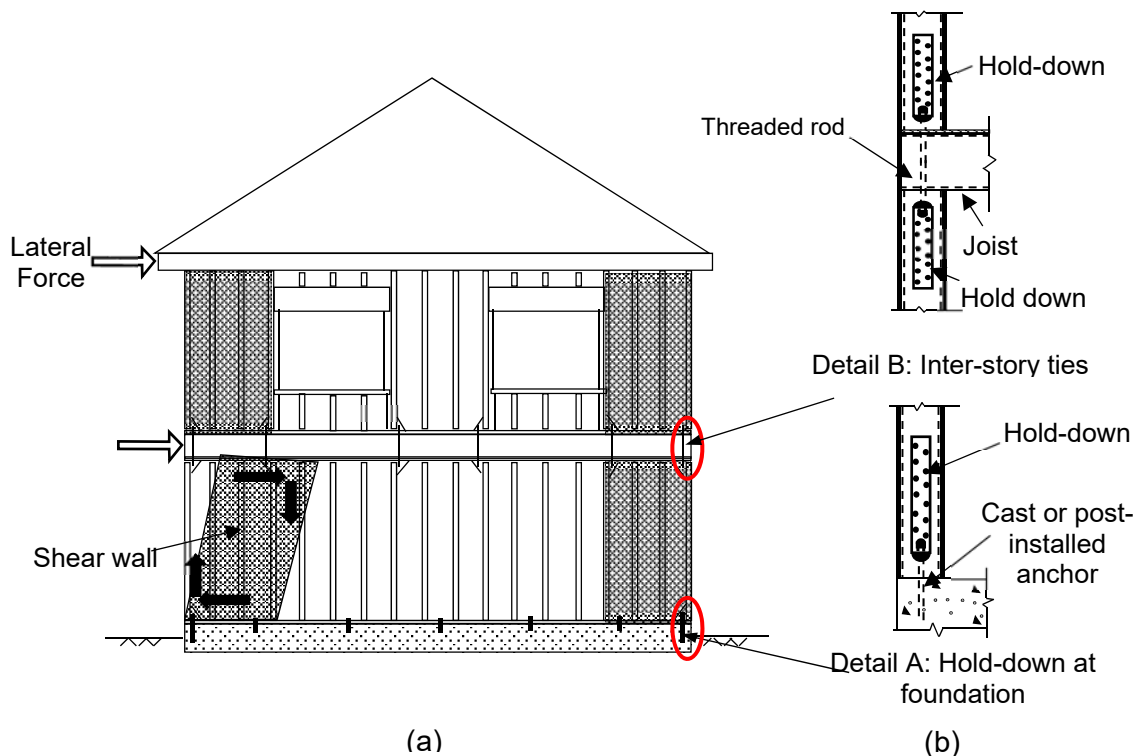


Figure 3: (a) Wall actions for resisting lateral loads (b) Hold down and Inter-storey ties

cantilever and horizontal diaphragm respectively that can resist lateral loads (Grubb et al., 2001). Lateral loads are transferred via floor diaphragm to the shear wall system as in plane shear loading and to foundation. The typical load transfer mechanism in the CFS building with shear wall is shown in (Figure 3a).

Hold downs and interstorey tie downs are key elements in transferring the earthquake forces safely to the sub structure. Hold downs are installed at end studs of the shear wall panel to transfer the chord forces caused by the lateral loads to the foundation. Hold-downs are bolted or screwed to the end stud and anchored to the foundation through bottom track. Interstorey tie downs are used to connect walls above and below the floor level that comes in pairs. It is connected to end stud and the uplift forces gets transferred from the wall above to the wall below through the threaded rod. Typical hold down and inter-storey tie down detail in platform framed building system (Madsen et al., 2016 and FEMA 232-2006) are shown in (Figure 3b). Details on inter-storey tie connections for ledger framing as reported in (Peterman et.al. 2016) is shown in (Figure 3b).

Construction Methods:

The CFS wall panel construction can be (a) stick form, (b) panel form or (c) modular form, depending upon the facility for shop fabrication, transportation, erection and the desired speed of construction at site. In the stick form of construction, the studs, joists and connection elements are transported individually and assembled at site to form the panels, which are attached to one another and subsequently cladded after inserting all the services. In the panel form, entire panel of framing along with or without cladding and functional inserts, is fabricated at shop and transported to the site and joined at site to form the desired space. In the modular form an entire module of a room or unit is fabricated in shop along with all the services and simply erected adjacent to each other or on top of one another. Modular construction has the ability to reduce the construction time and cost to a greater extent and increase the quality of construction because of its systematic and controlled process at factory level. Construction of mass housing can be achieved using this technology with affordable cost. It is one of the solutions to housing shortage that provides affordable and eco-friendly housing with minimal waste in the construction process. Enforcing this construction method in a large scale leads to an industrialization in housing sector that reduces cost of dwelling (make it affordable) and also could address housing shortage with fast track construction. Recently, there is a rapid increase in the modular construction worldwide and some of the recently completed projects are documented in (Kim, 2019 and Lawson & Ogden, 2008).

Basic Framing systems

Basic framing systems that are being followed in the construction of CFS wall panel building system are (a) Platform Framing, (b) Ledger framing.

Platform framing is raised by building walls and floors of one level followed by other floor levels. Walls are not continuous that transfers the loads from walls of the above floors to the walls below through floor joists. This framing refers to the discontinuous wall system where joists are connected to the stud and track intersection interrupting the studs to cross the floor. Floor system can be of CFS joists attached with either sheathing material (flexible diaphragm) or metal decking with concrete (rigid diaphragm) supported by truss structure underneath it. Typical view of platform framing is shown in (Figure 4a).

Ledger Framing is similar to the balloon framing, gaining importance when compared to platform framing in which floor or roof joists are embedded into the interior flange of the CFS stud via a ledger track clip angles connection. The studs are broken at the top of each floor level and capped with a track. Walls above are stacked on the lower wall top track. (Figure 4b) clearly describes the ledger framing connection in a CFS building. The load distribution from the floor or roof joist is transferred to the ledger track which is connected to the studs completing the load path. Studs above bear the load directly over

the studs below. The advantage of ledger framing over platform framing is that it increases the stiffness and moment rotation behavior of joint and also contributes to lateral strength is described by (Ayhan et al., 2015).

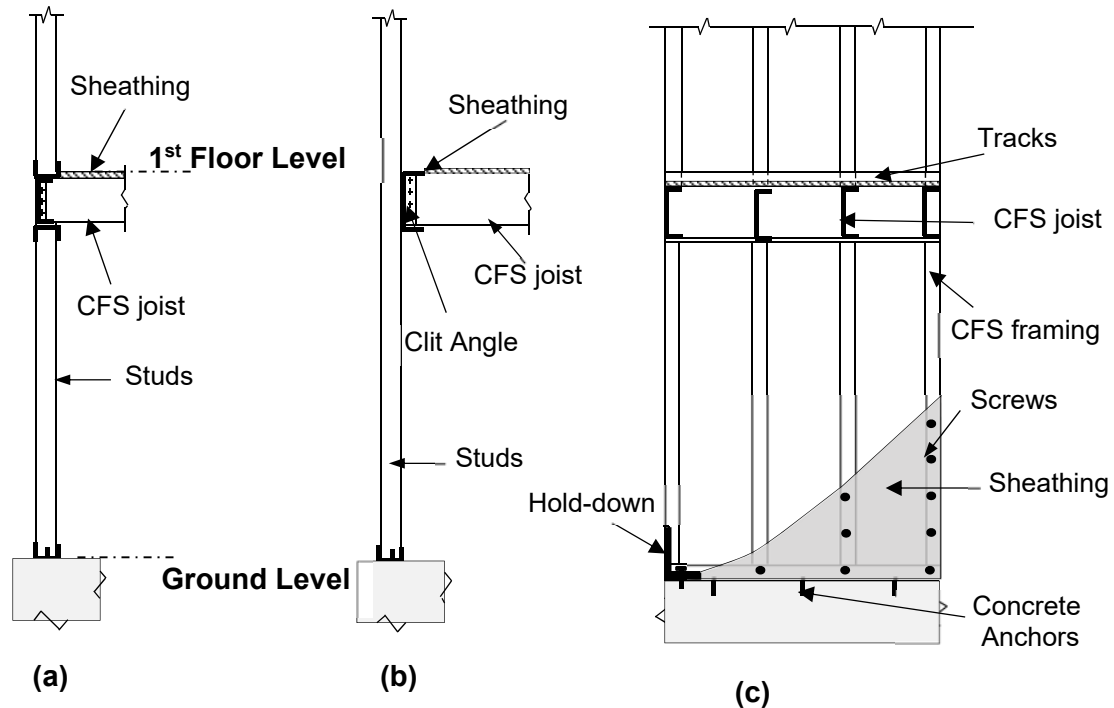


Figure 4: (a) Platform framing (b) Ledger framing (c) sectional view

Essential Services in CFS building system

In CFS system, the acoustic, fire and thermal performance are enhanced by providing double layer of sheathing board on either side of the panel with resilient bars attached to floors or walls (Yu, 2016).

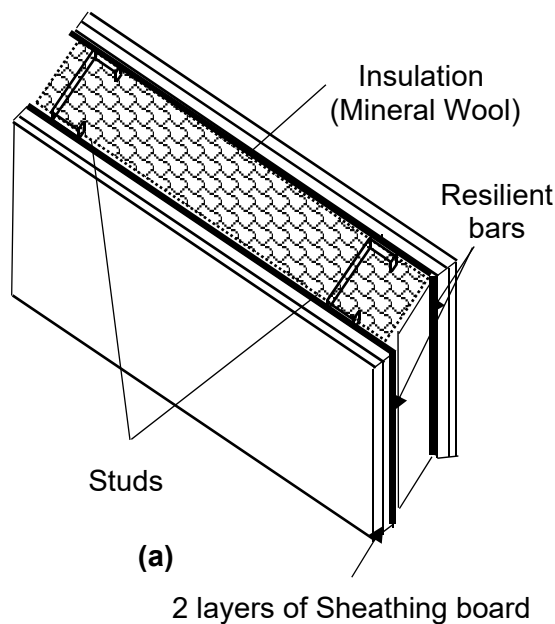


Figure 5: (a) Insulation (b) Essential services (Schafer et al., 2015)

Various insulation materials used in CFS system are glass fibre, rock fibre, dry blown cellulose, mineral wool, aluminum silicate wool etc (Kodur and Sultan., 2006; Ye et al., 2015 and Grubb et al., 2001).

CFS slotted sections are employed in joists and studs to provide electrical, mechanical and plumbing fittings essential for a building. However, care should be taken in providing openings, since large openings may influence the strength of the member. Hence the member may require reinforcing at the location of opening by addition of extra steel plate or stiffener.

Design of CFS system

Gravity Loading

Behaviour of CFS building system under gravity loading is well understood. Design of CFS framing elements under the influence of geometric imperfections, residual stress, independent buckling modes and their interaction, screw connection between steel to steel is well established (AISI-S100-16,2016). The reference can be made to (ACI 318-14, 2014) for designing the concrete anchors between track and foundation.

Earthquake Loading

The current design standards (ASCE 7, 2010 and AISI S400-15, 2015) adopts the capacity based design approach to design CFS building under seismic loading. In capacity based design, the system is designed to have an adequate capacity/strength to resist a particular earthquake ground motion (EQGM) and checked for serviceability. Force based design approach has its own limitations that the design is carried out for a particular EQGM without directly addressing the limit states of deformation and serviceability. In addition, (AISI S230-15, 2015) provides only a prescriptive method and comprehensive construction details for one and two-family CFS dwellings limiting its application to only mid-rise (3-4 storeys) buildings. The knowledge on behaviour of CFS system for high rise building under different EQ intensities is limited. The current research in CFS building system is moving towards Performance Based Seismic Design (PBSD) approaches, as more rational seismic resistant structural design method (Fiorino et al., 2012 and Wang et al., 2010).

Performance Based Seismic Design (PBSD)

The PBSD approach (Bozorgnia and Bertero 2004) is based on coupling of multiple performance levels and ground motion intensities for a desired performance objective (PO) to be satisfied. The performance levels are Operational (O), Immediate Occupancy (IO), Life safety (LS) and Collapse prevention (CP) under varying intensities of EQGM. PO's are expressed in terms of acceptable levels of damages under different ground motion intensities. The quantum of damage is generally associated with global drift of the structure. (Figure 6) shows the various damage states in a pushover curve of a building. Reliable analytical and numerical analysis at different level of model abstraction for identifying the damage levels and relating them to performance objectives are essential for the development of PBSD approach (Bertero & Bertero, 2002). The necessary analysis are:

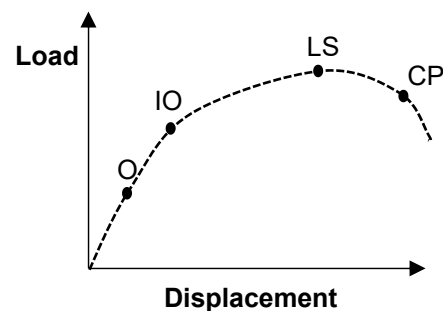


Figure 6: PBSD, Load vs Displacement Curve

- Nonlinear (NL) static pushover analysis validating experimental static response
- Nonlinear response history analysis capable of modelling actual seismic response

Research towards PBSD in CFS system

In CFS building, wall panels and floors are the main subsystems that attracts the lateral forces from wind and earthquake loading. Each subsystem consists CFS framing attached with sheathing, connected through self-drilling screws. Such subsystems are repetitively assembled together to form the entire building system based on the architectural drawing (plan and no. of stories).

The analysis model can be at the highest level of abstraction, with elements of the subsystem being modelled with intrinsic details to represent the nonlinear behaviour observed from experimental studies. For example, CFS framing members can be modelled with shell element, sheathing with plane stress element, screw connection between steel to steel, steel to sheathing, concrete anchors between track and foundation and inter-storey ties with spring elements. Initially, an experimental investigation on individual members is to be carried to evaluate their constitutive properties and failure criteria. The constitutive model should include strength, stiffness degradation and cumulative damage observed under cyclic loading. The constitutive relationship of each element is embedded into the numerical model of the subsystem and the response is validated with experimental response. The reference can be made for the experimentally validated subsystem i.e., wall panel under cyclic loading attached with corrugated metal sheathing (Fulup and Dubina, 2004), gypsum or OSB (Buonopane et al., 2015), steel sheathing (Shamim et al., 2013), fiber cement board (Badr et al., 2019) and under gravity loading when attached with plasterboard (Telue and Mahendran, 2004). Experimental studies on wood sheathed CFS floor, roof diaphragm under cyclic loading by (Nikolaidou et al., 2018) revealed that unsheathed CFS floor and roof diaphragms do not contribute to the strength and stiffness.

At the low level of abstraction, individual subsystems are modelled as equivalent truss elements with the entire nonlinearity being represented with spring elements. The constitutive property obtained from the numerical model of subsystem at high level of abstraction is used to represent the nonlinear spring behaviour in entire full scale model of building system. Full scale dynamic studies of CFS building is essential to validate the response of the numerical model which is essential to develop PBSD guidelines.

Very limited shake table studies on full scale CFS building are reported in literature. A dynamic testing on G+1 storey CFS building was tested at John Hopkins University, USA as part the CFS-NEES building project (Peterman et al, 2016). This study includes investigation of CFS framing with shear walls alone and with inclusion of non-structural elements such as partition walls, gravity walls and ceilings. The major observation made from the experimental study are: (a) sheathing at the interior faces contributed significantly to the lateral response (b) building experienced only superficial damage with interstorey drift significantly less than allowed drift (2.5% as per ASCE 7-05, 2005) (c) shear wall performance was enhanced by the presence of additional track to connect ledger framing. The experimental dynamic response was validated by (Leng et al. 2017) in modelling the entire system in OpenSEES with low level of abstraction. Recently, full scale six storey CFS wall braced building was conducted and was subjected to seven earthquake motions followed by fire tests in University of California, San Diego (UCSD). Under earthquake loading, sheet steel on corridor shear walls undergone buckling leading to damage. Fire tests resulted in loss of rigidity in floor sheathing due to degradation of cement board (Wang et al., 2016)

Also acoustic insulation and thermal protection are provided through prescriptive design (AISI S-230-15, 2015) in CFS building, since their performance under sound and fire behaviour of CFS members, sub element and system is not known. Few experimental studies on floor assemblies (Baleshan and Mahendran, 2010) and load bearing CFS wall

panel (Batista et. al 2014, Chen et.al 2014) at elevated temperature has been carried out dictates the necessity of research to enhance the performance of the CFS system

In India, CBRI have initiated a research on "CFS wall panels with improved structural performance and fire resistance" to support national initiative on mass housing shortage. IIT Tirupati initiated the research on developing PBSD guidelines for mid to high rise CFS buildings under earthquake type loading and it is in progress.

Future directions

- Efficient numerical framework for simulating seismic response of system and its subsystem under range of earthquake loading.
- Development of Reliability based design standards and guidelines for PBSD.
- Progressive collapse analysis to investigate the redundant load path transfer and robustness of single & multifamily dwellings.
- Experimental and numerical studies on acoustic and thermal performance of sub system to prescribe strict codal regulations compatible with national building regulations.
- Recommendations to reduce the human induced reduce floor vibration.
- Further research to upgrade Indian standards for the design of CFS members under static and earthquake loading.
- Advanced connection details for mid-rise modular construction

Summary

Various emerging housing technologies for mass housing are reviewed, finding that CFS housing system is an attractive and competitive solution, sustainable, cost effective and fast track solution to address the housing shortage and also build sustainable rural infrastructure. CFS housing with modular form of construction could bring industrialization in mass housing that addresses the housing shortage. In order to fully exploit the potential of CFS framing, the design practice should move towards performance based design approach instead of current strength based design approach. It is seen that, although many research efforts in the past one decade could contribute towards the development of the PBSD of CFS panel building systems, considerable consistent and coordinated research efforts by institutions would be needed before the profession can comfortably move towards PBSD of CFS panel building system.

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EFFECT OF SUSTAINABLE MATERIAL INCORPORATION ALONG WITH RAP IN BITUMINOUS PAVEMENT

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Abstract: Road infrastructure plays a vital role in the development of the country. Road infrastructure increases the accessibility to the desired destination. Most of the road surface is constructed using bituminous material. The construction of new roads and maintenance of existing roads requires more amount of natural aggregates. Aggregate constitutes more percentage (more than 90%) in construction of bituminous pavement. Depletion of aggregate takes place during the construction of the road, it has an impact on cost and also to the environment. Hence there is a need for reducing the usage of virgin aggregate for bituminous pavement construction. It can be achieved by utilizing sustainable material like marble waste, along with reclaimed asphalt pavement (RAP) in the bituminous pavement. The main objective of this study is to find the effect of sustainable material incorporation along with RAP in the bituminous pavement. The marble waste is used in the bituminous mix as a replacement of fines. The proportion of RAP in the bituminous mix is fixed as 10%, 20%, 30%, and 40%. In this study, Marshall stability test, Indirect Tensile strength test on various bituminous mix were carried out. The test results were compared with the control specimen prepared using virgin materials. The test results show a better value compared to the control specimen values. This method of mix proportion in the bituminous pavement reduces the utilization of virgin materials and also less impact on the cost of construction and environment.

Keywords: Sustainable Material, RAP, Marshall Stability of Sustainable pavement.

1 Introduction

Road infrastructure plays a vital role in the development of the country. India has the largest road network in the world about 59 lakhs km as on January 2019. Rural roads share about 70% of the total length of the road. (1). Rural Roads Connectivity is one of the key components for rural development, as it promotes access to economic and social services, generating increased agricultural income and productive employment (Lokesha 2016). Most of the road surface is constructed using bituminous material. The construction of new roads and maintenance of existing roads requires more amount of natural aggregates. Road infrastructure increases the accessibility to the desired destination. The mineral aggregate, including coarse and fine particles in asphalt paving mixtures, contributes to the volume of hot mix asphalt (HMA) by approximately 90%. The rural road in India forms a substantial portion of the Indian road network (Moghadas Nejad 2013).

In India, about 6 million tonnes of waste from marble industries is being released from marble cutting, polishing, processing and grinding. The marble dust is usually dumped on the riverbeds and possesses a major environmental concern. Attempts are being made to utilize marble dust in different applications like road construction, concrete and bituminous concrete aggregates, cement and other building materials. Attempts are being made to utilize marble dust in different applications like road construction, concrete and bituminous concrete aggregates, cement and other building materials (George Mohan 2016). Depletion of aggregate takes place during the construction of the road, it has an impact on cost and also to the environment.

Due to economical reasons and the need for environmental conservatism, there has been an increasing shift towards the use of Recycled Asphalt Pavement (RAP) materials in the pavement construction industry (Elmohr 2015). Hence there is a need for reducing the usage of virgin aggregate for bituminous pavement construction. It can be achieved by utilizing sustainable material like marble waste, along with reclaimed asphalt pavement (RAP) in the bituminous pavement. The main objective of this study is to find the effect of sustainable material incorporation along with RAP in the bituminous pavement.

2 Literature Review

Nejad et. al (2013) assessed the use of recycled marble aggregate (RMA) as a replacement for virgin aggregate in HMA for roads with medium traffic volume. Five asphalt concrete mixes were investigated with the first mixture containing 100 % virgin aggregate, which is the control mix. In other mixes, RMA was used as a portion of aggregate at rates of 15, 25, 40 and 60 %. Various tests like resilient modulus, dynamic creep, and indirect tensile strength ratio tests were performed on the mixes. The results showed that the resilient modulus and fatigue life for the mixtures containing RMA are slightly lower than that of the control mix. Use of RMA increased optimum binder content because of the porous surface of RMA and increased binder absorption. Substitution of virgin aggregate with RMA up to 60 % decreases the permanent deformation in roads under medium traffic volume.

Shekhawat et. al (2017) evaluated the effects of marble dust as filler in Dense Bituminous Macadam (DBM) layers of asphalt pavement. The marble dust used in this study is collected during the cutting and polishing of marble blocks. The bituminous mix of varying bitumen content 4.5%, 5%, 5.5% and 6% are used for specimen preparation. The marshall stability test was performed for all the specimen and the optimum binder content was found out using the basic formula. The marshall graphical plots are drawn to find out the optimum binder content and marshall stability value of the bituminous mix. The test results show the marble dust can be used as effective filler material in DBM layer of bituminous pavement. This also improves the safe disposal of marble waste from the environment.

Mohan et. al (2016) investigated the effect of marble dust and coir fibre on the indirect tensile strength of bituminous concrete mixtures. The bitumen of grade S90 and bituminous mix grade I were used in this study as per MoRTH specification. The specific gravity test, ductility test and penetration test are carried out for the bituminous materials. In this study marble dust and coir fibre was used for the preparation of bituminous mix specimen. The test conducted in this study is marshall stability test and indirect tensile strength test for the bituminous mix. The optimum marble content for the bituminous mix is obtained from the ITS test result. Indirect Tensile test was conducted on the bituminous mix prepared with optimum marble content and varying coir fibre content to determine the optimum fibre content of the mix. The test result shows that optimum bitumen content, optimum marble content and optimum fibre content about 6.4%, 8% and 0.5% respectively. The cracking resistance of bituminous mix can be increased by adding marble to the bituminous mix. It is due to the good adhesion property between the aggregate and bitumen.

Jashanjot Singh et. al (2015) conducted an experimental study on reclaimed asphalt pavement In bituminous concrete. This study gives the optimal use of recycled asphalt pavement in bituminous concrete. The optimum percentage of recycled asphalt pavement depends on the binder content of RAP and availability of RAP, the extent deterioration of recycled asphalt pavement. The bituminous mix prepared using RAP of different percentage varies from 25% to 40%. The marshall stability test was conducted for the bituminous mix. The test result of modified bituminous specimen prepared using recycled asphalt pavement is compared with the control specimen. The test result shows that 35% of RAP content matches the marshall stability value of control specimen. The test result shows that the project cost reduced approximately by 50%.

3 Materials and Methodology

In this study, the bituminous concrete (BC) mix was prepared as per the specification in the Ministry of Road Transport and Highways (MoRTH). Initially, the basic tests of materials were conducted to find the properties of materials. The materials used in this study are Bitumen, Coarse Aggregate 12 mm & 6 mm, Fine aggregate i.e., dust, Recycled Asphalt Pavement (RAP), Marble waste. The RAP material used in this study was collected from MC Road near Venjaramoodu, Thiruvananthapuram. The marble was used bought from the rockmins. The basic tests include specific gravity of materials, penetration test on bitumen, softening point test on bitumen, ductility test on bitumen. The gradation of aggregate was carried out to find the proportion of aggregate used for the bituminous mixture. The gradation of aggregate is important for the bituminous mix and also for RAP material. The gradation of the aggregate and the RAP is shown in Table 1 and Table 2 respectively. The gradation chart of the aggregate and the RAP is shown in Figure 1 and Figure 2 respectively.

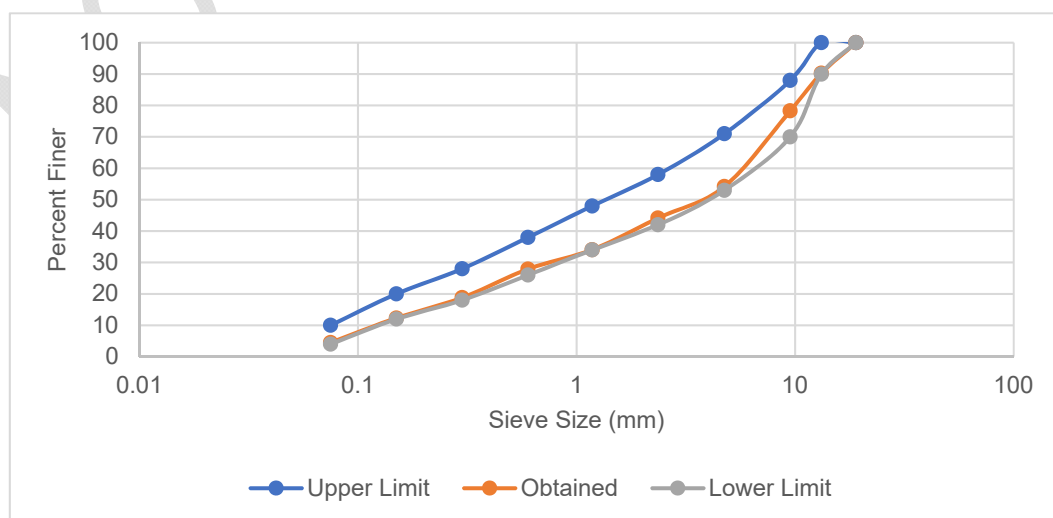


Figure 1: Gradation of the aggregate
Table 1: Gradation of the aggregate

Sieve Size (mm)	12 mm Aggregate	6 mm Aggregate	Fine Aggregate	Obtained Gradation	Required Gradation
	20 %	30 %	50 %		
19	100	100	100	100	100
13.2	51.33	100	100	90.27	90 – 100
9.5	2.67	92.58	100	78.31	70 – 88
4.75	0	14.04	100	54.21	53 – 71
2.36	0	0	88.30	44.15	42 – 58
1.18	0	0	68.16	34.08	34 – 48
0.6	0	0	55.82	27.91	26 – 38
0.3	0	0	37.62	18.81	18 – 28
0.15	0	0	24.63	12.31	12 – 20
0.075	0	0	9.03	4.52	4 – 10

Table 2: Gradation of the RAP

Sieve Size (mm)	Obtained Gradation	Required Gradation
19	100	100
13.2	94	90 – 100
9.5	80	70 – 88
4.75	58	53 – 71
2.36	50	42 – 58
1.18	42	34 – 48
0.6	35	26 – 38
0.3	23	18 – 28
0.15	13	12 – 20
0.075	6	4 – 10

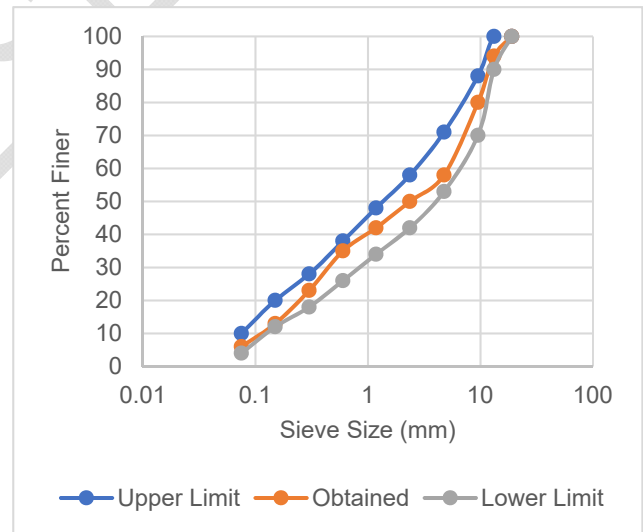


Figure 2: Gradation of the RAP

Initially, the control specimen was prepared as per the procedure (i.e.) the aggregate and the filler material is heated to a temperature of 175°C – 190°C. The required quantity of bitumen is heated to a temperature of 120°C – 165°C. The heated aggregate and bitumen are mixed thoroughly at a temperature of about 154°C - 160°C. The mix is then placed in a preheated mould having 10.16 cm diameter and 6.35 cm height and is compacted by a rammer with 75 blows on either side. In order to find the optimum binder content, the control specimen was prepared at different bituminous percentage 4.5%, 5%, 5.5%, and 6%. Using the Optimum Binder content, bituminous specimens using RAP material is prepared based the optimum binder content by changing percentage of RAP content. The proportion of RAP in the bituminous mix is fixed as 10%, 20%, 30%, and 40%. The procedure for preparation of RAP specimen is same as for control specimen. In this study the marble waste was used as a replacement of fines in bituminous mix, to reduce

the usage of virgin materials. The percentage of replacement of fines in bituminous mix varies from 25% to 100%.

The Marshall test, Indirect tensile strength (ITS) test was conducted for the prepared bituminous mix. The marshall test was carried out to find the stability and flow value of the bituminous mix. Marshall Stability is the maximum load carried by the specimen at a standard test temperature of 60°C when the load is applied under specified test conditions. Flow value gives the total deformation undergone by the test specimen at the maximum load. The ITS test was carried out to find the moisture susceptibility of the mix. Moisture susceptibility can be analysed by the Tensile Strength Ratio (TSR) value of the sample. The TSR value can be determined by using the formula given in Equation 1. The bituminous mix proportion of materials for the control specimen and RAP specimen is shown in Table 3. Determination of optimum binder content for the mix by taking the average value of (i) Binder content corresponding to maximum stability (ii) Binder content corresponding to maximum unit weight (iii) Binder content corresponding to 4 percentage air voids in the total mix.

$$TSR = \frac{ITS \text{ CONDITIONED}}{ITS \text{ UNCONDITIONED}} \times 100 \quad (\text{Equation 1})$$

where,

TSR = Tensile Strength Ratio (%)

ITS Conditioned = Indirect Tensile Strength of the conditioned specimen

ITS Unconditioned = Indirect Tensile Strength of the unconditioned specimen

Table 3: Bituminous mix proportion of materials

Material	Mix 1 (Control)	Mix 2 (10% RAP)	Mix 3 (20% RAP)	Mix 4 (30% RAP)	Mix 5 (40% RAP)	Mix 6 (25% Marble)	Mix 7 (50% Marble)	Mix 8 (75% Marble)	Mix 9 (100% Marble)
12 mm aggregate	240	216	192	168	144	168	168	168	168
6 mm aggregate	360	324	288	252	216	252	252	252	252
Fines	600	540	480	420	360	315	210	105	0
RAP	0	120	240	360	480	360	360	360	360
Marble	0	0	0	0	0	105	210	315	420
Virgin Bitumen	66	61	56	52	47	52	52	52	52
RAP Bitumen	0	5	10	14	19	14	14	14	14

*material quantity – in gm

4 Results

4.1. Test on materials

The basic tests were conducted on various materials used for the bituminous mix is to evaluate the properties of the materials. The specific gravity test on aggregates, RAP, Marble, Bitumen was determined. The Penetration value of bitumen, ductility value, and softening point of the bitumen were tested. The specific gravity value is important to evaluate the properties of the bituminous mix. The material properties of bituminous mix are shown in Table 4.

Table 4: Material properties of bituminous mix

Sl. No.	Name of the Test	Obtained Result	Required Result
1	Specific gravity test on 12 mm aggregate	2.67	-
2	Specific gravity test on 6 mm aggregate	2.68	-
3	Specific gravity test on dust	2.60	-
4	Specific gravity test on marble waste	2.65	-
5	Specific gravity test on RAP	2.68	-
6	Specific gravity test on bitumen	1	0.99 minimum
7	Penetration test on bitumen	67	65 – 90
8	Softening point test on bitumen	52 °C	40°C – 50°C
9	Ductility test on bitumen	77 cm	75cm minimum

4.2. Marshall Stability Test

The marshall stability test was conducted for the control specimen initially. The bitumen content varies from 4.5%, 5%, 5.5%, and 6%. The marshall stability value and flow value is recorded for each control specimen. The marshall stability test results of the control specimen are shown in Table 5. The marshall graphical plots of control specimen are shown in Figure 3. The stability value is maximum for bitumen content of 5.5% about 12.43 KN.

Table 5: Marshall test result (Control specimen)

Sl. No.	Parameter	Result
1	Marshall Stability Value (KN)	12.42
2	Optimum Binder Content (%)	5.5

4.3. Bituminous mix using RAP

The optimum RAP content for the bituminous mix is obtained from the marshall test on different RAP specimen using the optimum binder content from the control specimen. The RAP content varies from 10%, 20%, 30%, and 40%. The maximum stability value of the bituminous mix with RAP and optimum RAP content is shown in Table 6.

Table 6: Marshall test result (RAP specimen)

Sl. No.	Parameter	Result
1	Marshall Stability Value (KN)	12.13
2	Optimum RAP Content (%)	30

4.4. Bituminous mix using RAP along with Marble

The bituminous mix proportion of 70% virgin material and 30% RAP was selected. In the selected bituminous mix the fines are replaced by marble waste. Four different specimens prepared of the varying percentage of marble content as 25%, 50%, 75% and 100%. The marshall stability test was carried out for each specimen. The marshall stability value is shown in Table 7.

Table 7: Marshall test result (Marble)

Sl. No.	Parameter	Mix 6	Mix 7	Mix 8	Mix 9
1	Marshall Stability Value (KN)	10.41	10.91	11.46	12.09

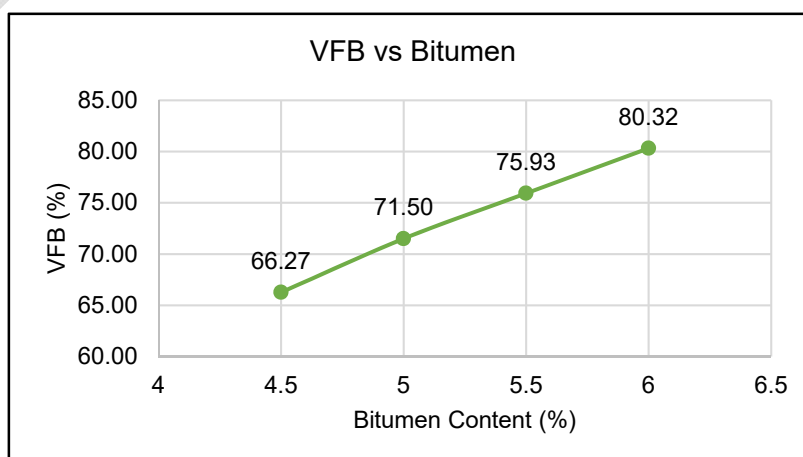
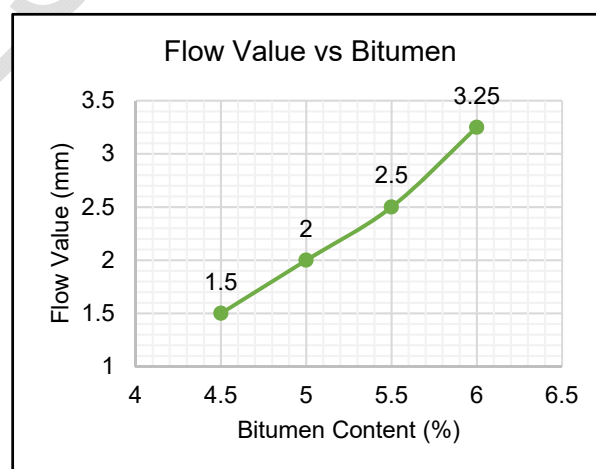
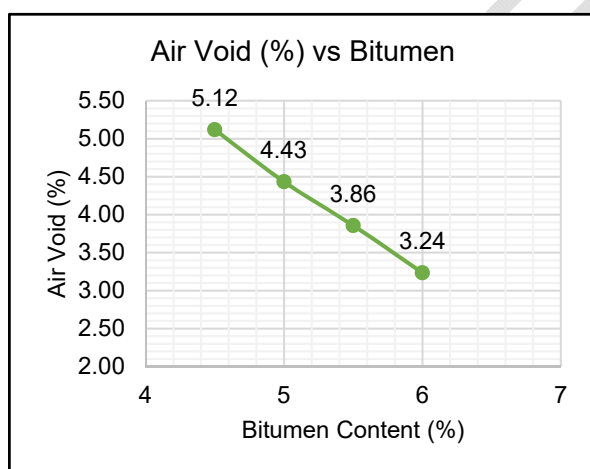
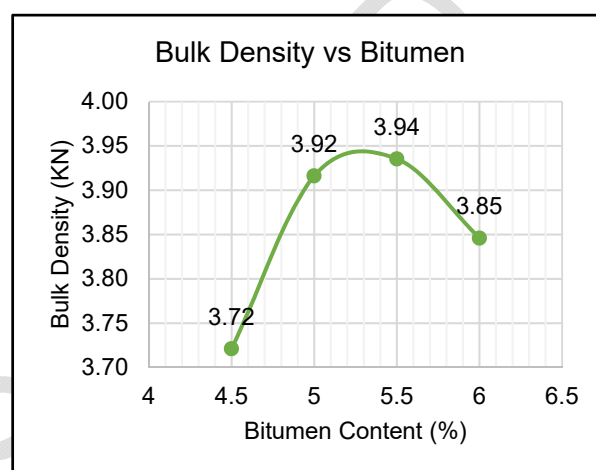
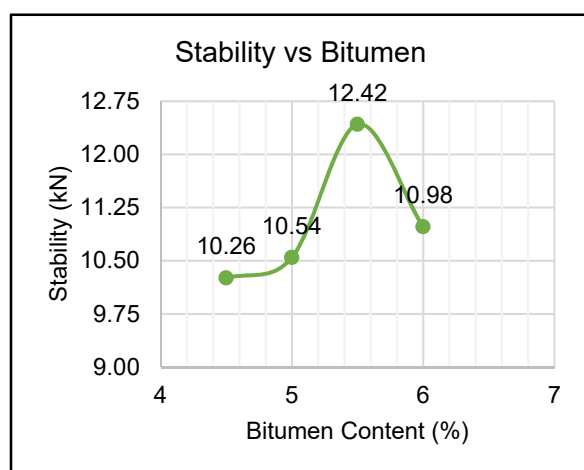


Figure 3: Graphical plots of the control specimen
4.5. Tensile Strength Ratio

The tensile strength ratio (TSR) value is obtained from the Indirect tensile strength test. TSR value is a measure of water sensitivity of the bituminous mix. Higher TSR value indicates more resistance to water damage. The TSR value is higher for bituminous mix using RAP and also for marble waste added specimen compared to control specimen. The TSR value for different condition is shown in Figure 4.

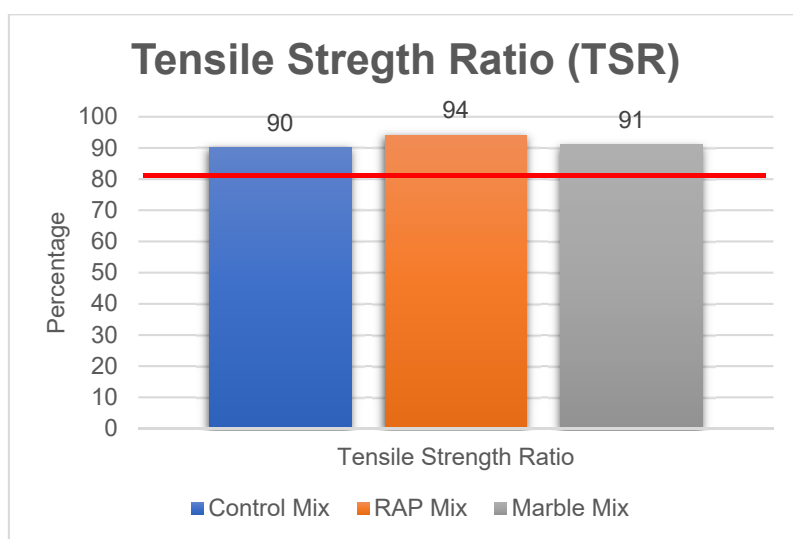


Figure 4: Tensile Strength Ratio (TSR)

5 Conclusion

Based on the test results the following conclusion was obtained. The marshall stability value of control specimen is about 12.43 KN, satisfy the minimum stability value of 9.82 KN. Optimum binder content of the control specimen is about 5.5% also satisfies the minimum requirement as per MoRTH specification. The optimum RAP content is 30% and stability value is about 12.13 KN. The stability value of bituminous mix using RAP along with marble waste is about 12.09 KN. These values satisfy the minimum requirement of 9.82 KN as per MoRTH specification. Tensile strength ratio for RAP as well as marble waste specimen gives better value about 94% and 91% respectively compared to control specimen value of 90%. Better value shows that the bituminous mixture has more resistance to moisture, it can be most suitable for regions having high rainfall. The main factor for rural development is providing new connectivity in rural areas by means of constructing new roads. The maintenance of road in all areas delayed due to lack of availability of materials. The study results show that the usage of waste material and recycling of existing material reduces the usage of virgin material about 60%. This method of construction reduces the utilization of virgin materials and also less impact on the cost of construction and environment.

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DOMESTIC WASTEWATER TREATMENT FOR RECYCLING WASTEWATER SAFELY TO ENVIRONMENT

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Abstract: *Domestic wastewater treatment is given less importance while designing a building in areas where water is available in abundance. Unknowingly, this has been a cause of most of the water borne diseases and environmental damage. Also the increasing use of man-made products has caused significant anthropogenic impact to damage the environment. A feasible and cost-effective method of treating used water added to the existing design can help to contribute in lowering the risk to the environment. The paper therefore aims at presenting a methodology to recycle used water safely to the environment. Also the feasibility and cost analysis of the proposed method is discussed with reference to the rural environment.*

Keywords: *Wastewater, anthropogenic impact, rural environment*

1 Introduction

Pollution is one of the major reasons of environmental damage and it has reached an alarming level (Nawarkar 2019, Soni 2019, Sonune 2004). Different types of pollution like air pollution, water pollution, soil pollution, noise pollution etc. are caused by various reasons. One of the causes is the human activities which has most effects and can be controlled to maintain a clean and safe environment. Life is impossible without water and therefore the paper focuses on wastewater which is a cause of water pollution and how it can be controlled.

Ground water or surface water is collected and consumed for various uses like drinking, cleaning, agriculture and industries. The water after being used is called as wastewater. Such water is not suitable for use. Mostly the wastewater is released to the environment into the lakes and rivers without being treated and hence causes pollution and harm the environment.

Wastewater can be classified into three categories based on the source of generation of wastewater:

- i. Domestic or municipal wastewater
- ii. Industrial wastewater
- iii. Agricultural wastewater.

Domestic or municipal wastewater generates from household and commercial buildings where water is mainly used for drinking and cleaning purpose. It includes substances like food wastes, chemicals present in soaps and detergent and human waste. In terms of nutrients, the domestic wastewater has high concentrations of nitrogen (N) and phosphate (P) and small amounts of other nutrients like iron (Fe), Manganese (Mn), bicarbonates (HCO_3^-) and salts like Sodium chloride (NaCl) (Bixio 2005, Ichinari 2008). Industrial wastewater is the water that is produced by some particular process from industries and is not suitable for further use. It is a combination of different nutrients in very large amount and depend on the type of industry which is the source of wastewater. The main pollutants are oils, metals, acids, phenols, organic chemicals, heavy metals suspended solids, BOD, COD etc (Hanchang 2009, Gao 2014).

Agricultural wastewater is generated from farms and poultry houses. It contains harvest waste, fertilizer and pesticide runoff from fields which are used in agricultural activities. In terms of nutrient, it is has high nitrate and phosphorous content (Ayres 1996).

Wastewater treatment is very much needed to keep the environment clean and pollution free. Most of the municipal wastewater is treated at some distance from the wastewater generation where the municipal wastewater treatment plant is located. The time duration taken for the wastewater to travel from the source to the treatment plant increases the unwanted and harmful nutrients of wastewater. If the treatment is done at source, this can be minimized. Also the treated water can be reused for watering the plants in the household or similar purpose.

Major constituents of weak, medium and strong polluted wastewater contents is compared in table1 (Pescod 1992, Almeida 1999).

Table 1. Constituents of domestic wastewater.

Constituent	Concentration (weak) (mg/l)	Concentration (medium) (mg/l)	Concentration (strong) (mg/l)
Nitrogen (as N)	85	40	20
Phosphorous (as P)	20	10	6
Suspended Solids	350	200	100
Chloride	100	50	30
Alkalinity (as CaCO_3)	200	100	50
BOD	300	200	100
Grease	150	100	50

2 Wastewater treatment technologies

Wastewater treatment conventionally uses the aerobic-anaerobic treatment technology and is classified into the following types (Sikosana 2019):

- i. Aerated stabilization ponds
- ii. Aerated and non-aerated lagoons
- iii. Natural and artificial wetland systems

Aerated stabilization ponds are man-made earthen structures which treats the wastewater naturally. It can be a single pond or a series of ponds where wastewater known as influent enters from one end and the treated water known as effluent exits from the other end. The time taken for such kind of treatment is very large because of the slow removal rates. The time duration for which the wastewater remains in the pond is known as the hydraulic retention time (HRT) which is large for aerated stabilization ponds (Adhikari 2019). Such ponds also require large area to facilitate natural aeration.

To decrease the HRT, the aerated and non-aerated lagoons are designed where the structures are man-made and supplied with aeration facility. This requires some external energy but the area required for such treatment technique is less as compared to the traditional technique of aerated stabilization ponds. The time required for such treatment is also less (Adhikari 2019).

Natural and artificial wetlands are engineered systems that use natural vegetation, soil and organisms to treat wastewater (Juwarkar 1995). The vegetation of such wetland depends on the type of wastewater that is to be treated. Again such wetlands require a large area (Gopal 1999).

However, the general methodology of all types of wastewater treatment is similar which can be represented as figure 1 (Daverey 2019, Strazzabosco 2019, Munusami 2014).



Figure 1. Block diagram representation of the three stages of wastewater treatment.

The wastewater treatment may be classified into three main stages (Tchobanoglous 1991):

- i. Primary treatment
- ii. Secondary treatment
- iii. Tertiary treatment.

Primary treatment is the physical treatment where wastewater is temporarily retained in a settling tank so that the heavy solids and light solids are separated. The heavier solids are collected at the bottom after settling, the lighter solids are collected at the surface and the remaining liquid moves to the secondary treatment. These tanks are supplied with mechanical scrapers to aid in the removal of solids.

Secondary treatment is the biological treatment and can be done using biofiltration or aeration or oxidation ponds. Biofiltration uses filters like sand filters to remove additional pollutants present. Aeration uses external air to breed more microorganisms and remove the pollutants effectively (Daverey 2019). Oxidation ponds use natural

water bodies or artificial bodies to retain water for a longer duration to be treated before releasing it to the next stage. The wastewater after passing through the secondary stage moves to the tertiary stage.

Tertiary treatment refers to the treatment using chemical or biological unit processes or both to raise the treated water quality as per pollution board standards.

3 Proposed design for house hold wastewater treatment

The per capita use of water in India is approximately 90-100 litres per day which is consumed in the daily household activities in addition to drinking. Activity like bathing consumes the highest amount of water (around 28% of the total water consumed) followed by use in toilets, washing clothes, and washing utensils (Singh 2013, Shaban 2007).

Assuming a family of five members, the total amount of water consumed
= 100 litres per capita per day × 5
= 500 litres per day

So, the freshwater supplied is 500 litres. Again, as cited by (Kaur, 2012) about 70-80 % of the supplied freshwater is generated as wastewater.

Therefore, wastewater generated
= 80% × 500 litres
= 400 litres

The wastewater treatment plant design should be able to retain 400 litres of wastewater treatment in the primary settler used for physical treatment for one day.

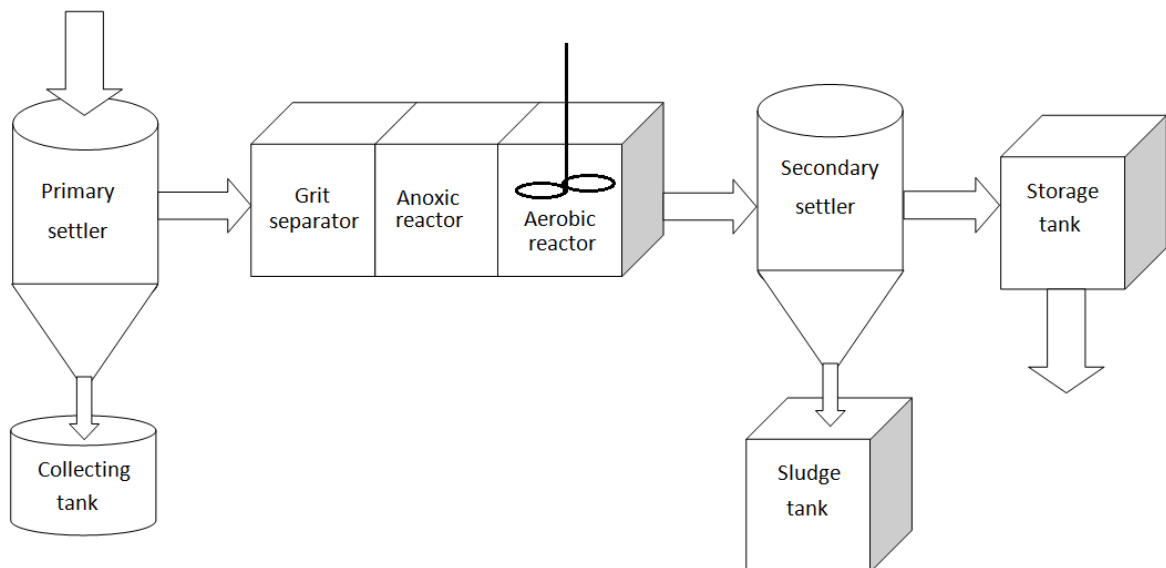


Figure 2. Proposed household treatment block diagram.

The block diagram of the proposed structure is given in figure 2. It consists of the following (Spellman 2013):

- i. Primary settler
- ii. Grit separator
- iii. Anoxic reactor
- iv. Aerobic reactor
- v. Secondary Settler

- vi. Collecting tank
- vii. Sludge tank
- viii. Storage tank

Primary settler collects the wastewater from the household and separates the large sized solid pollutants. Grit separator separates the sand like particles present in the wastewater. Anoxic reactor treats the wastewater in presence of microorganisms in anoxic environment which is again treated in presence of oxygen in the following aerobic reactor. Secondary settler separates the sludge from the treated wastewater and collects the water that can be recycled in the storage tank. The sludge is collected in the sludge tank and solids are collected in the collecting tank.

The tank required to store and treat 400 litres of wastewater is calculated as follows:

Let the height (H) and length (L) of the tank be 1 m and two times the breadth (B) respectively.

$$\text{Volume of the tank} = (L \times B \times H) \text{m}^3 \quad (1)$$

Therefore,

$$\begin{aligned} B &= \sqrt{\frac{\text{Volume of tank}}{2H}} \\ \Rightarrow B &= \sqrt{\frac{400 \text{ l}}{2 \times 1 \text{ m}}} \\ \Rightarrow B &= \sqrt{\frac{0.4 \text{ m}^3}{2 \times 1 \text{ m}}} \\ \Rightarrow B &= 0.45 \text{ m} \end{aligned}$$

and

$$\Rightarrow L = 2 \times 0.45 \text{ m} = 0.9 \text{ m}$$

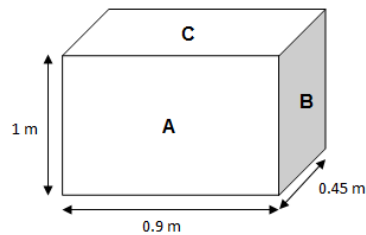


Figure 3. Proposed tank dimensions.

The tank size is therefore 0.9 m × 0.45 m × 1 m as in figure 3 and 336 bricks are required for its construction as calculated by (2).

$$\text{Number of Bricks} = \frac{\text{Volume of brick work}}{\text{Volume of 1 brick with mortar}} \quad (2)$$

The size of a standard brick is 0.19 m × 0.09 m × 0.09 m and standard mortar thickness is 0.01 m. Hence,

Volume of a standard brick with mortar = $0.2 \text{ m} \times 0.1 \text{ m} \times 0.1 \text{ m} = 0.002 \text{ m}^3$

and

Volume of brick work = Area of the wall $\times$ thickness due to the brick (3)

Therefore,

$$\text{Number of bricks for wall A} = \frac{0.9 \text{ m}^2 \times 0.19 \text{ m}}{0.002 \text{ m}} = 85.5 \cong 86 \text{ bricks}$$

$$\text{Number of bricks for wall B} = \frac{0.45 \text{ m}^2 \times 0.19 \text{ m}}{0.002 \text{ m}} = 42.75 \cong 43 \text{ bricks}$$

$$\text{Number of bricks for wall C} = \frac{0.9 \text{ m} \times 0.45 \text{ m} \times 0.19 \text{ m}}{0.002 \text{ m}} = 38.48 \cong 39 \text{ bricks}$$

Total number of bricks required for construction of one tank
 $= 2 \times 86 + 2 \times 43 + 2 \times 39$
 $= 336 \text{ bricks}$

4 Feasibility and difficulties of domestic wastewater treatment setup

The wastewater treatment plant requires extra space to install the tanks. This can create difficulty when the location is small. However if the residents wish, they can utilize the underground space of their garage or gym for installing the wastewater treatment plant. Figure 4 shows the schematic of the proposed wastewater treatment plant. The aeration in the aerobic reactor is given manually to exclude any cost of energy required for aeration.

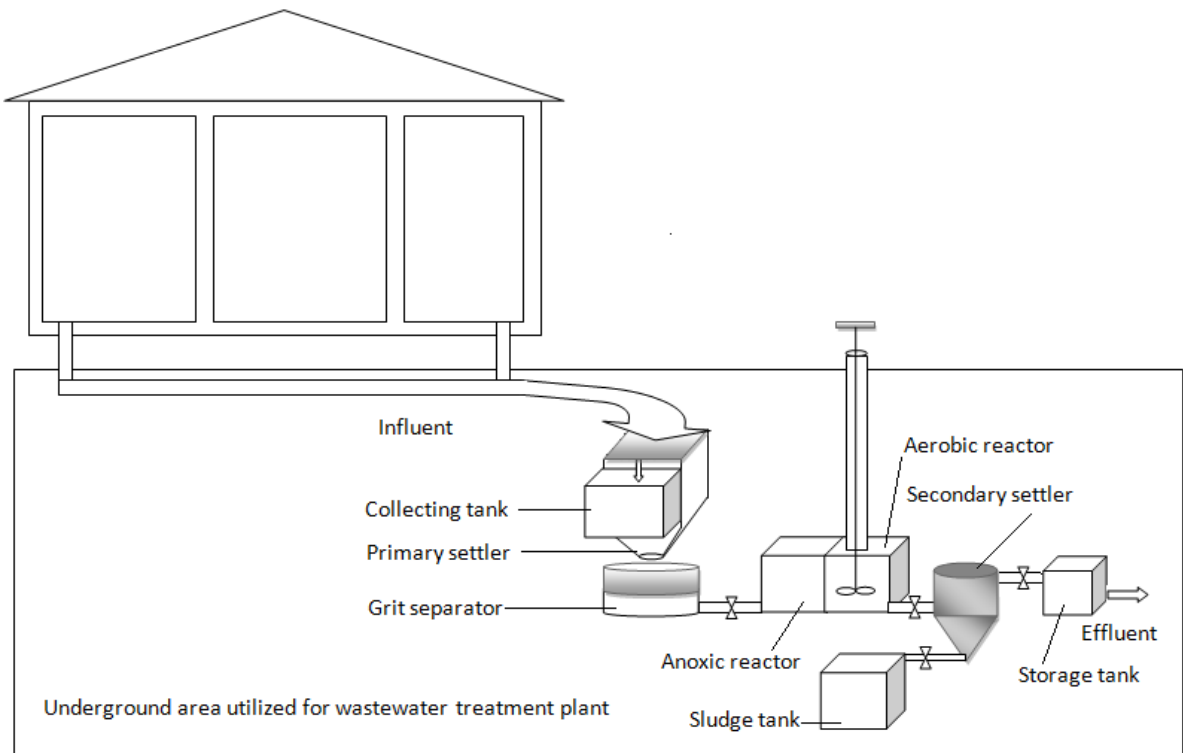


Figure 4. Proposed Structure for wastewater treatment plant.

5 Cost Analysis

The materials required for construction of the proposed wastewater treatment plant are:

- i. Bricks
- ii. Cement
- iii. Iron rod
- iv. Sand
- v. Pebbles
- vi. Steel wire

The authors conducted a market survey in the Kamrup district of Assam. After consultation with the local experience people, the approximate amount required for construction for a $0.5 \times 0.5 \times 0.5 \text{ m}^3$ underground tank are listed in table 2 along with the and price of the above mentioned materials. Size of the tank was selected based on the minimum possible size that can be constructed and the total cost is exclusive of the manpower required for construction.

Therefore the capital cost of setting up a wastewater treatment plant can be calculated using the proposed expense equation in (4).

$$\text{Cost} = C_b + C_c + C_i + C_s + C_p + C_{sw} + C_m \quad (4)$$

where C_b , C_c , C_i , C_s , C_p , C_{sw} and C_m are the cost of bricks, cement, iron rod, sand, pebbles, steel wire and manpower respectively.

Table 2. Materials and approximate cost required for construction of a $0.5 \times 0.5 \times 0.5 \text{ m}^3$ tank.

Material	Amount	Price (Rs)	Total cost (Rs)
Bricks	200 pieces	8 per piece	1600
Cement	75 kg	6 per kg	450
Iron rod (10mm)	15 kg	50 per kg	750
Sand	1 cm^3	700 per cm^3	700
Pebbles (3:4 and 1:4)	0.5 cm^3	1400 per cm^3	700
Steel wire	0.5 kg	60 per kg	30
Total Cost			4,230

Total cost of constructing a minimum sized single tank is Rs 4230 and if the proposed tank size of $0.9 \text{ m} \times 0.45 \text{ m} \times 1 \text{ m}$ is to be constructed, total 336 bricks are required. Keeping the other parameters same, the cost of the tank is shown in table 3

Table 3. Materials and approximate cost required for construction of a $0.9 \times 0.45 \times 0.1 \text{ m}^3$ tank.

Material	Amount	Price (Rs)	Total cost (Rs)
Bricks	336 pieces	8 per piece	2688
Cement	75 kg	6 per kg	450
Iron rod (10mm)	15 kg	50 per kg	750
Sand	1 cm^3	700 per cm^3	700
Pebbles (3:4 and 1:4)	0.5 cm^3	1400 per cm^3	700
Steel wire	0.5 kg	60 per kg	30
Total Cost			5,318

Total 8 tanks are required for the proposed structure. Since the capacity of all tanks are almost similar, the total cost capital of setting up an underground wastewater treatment plant can be approximated as Rs 5,318×8= Rs 42,544.

6 Discussion

The proposed design can therefore store and treat the 400 l wastewater generated for one day and retain it for the same period so that the treatment is done efficiently. Considering the treatment plant of same sized tanks and made with easily available materials, the treatment plant setup can be easily augmented with the residential building architecture. The capital cost of setting up a wastewater treatment plant with the minimum sized tank is Rs 42,544 which is feasible if the benefits of the treatment plant are compared. The underground area of the plot can be utilized in setting the treatment plant to optimize the space. The operation cost is very minimum as manual aeration is added to the system.

However, if some individual families could not afford such treatment plant for each household because of the cost and space, people in a locality including more than one family can come up together to reduce the cost and space for setup of the proposed wastewater treatment plant. In such cases the aeration must be provided frequently to maintain the quality of treated wastewater. Solar energy will be a good option in such a case to reduce the running and maintenance cost.

This treatment plant will be a great addition in the reduction of environmental pollution. The water which is treated can be used in gardens and lawns for plantation and also for flushing toilets. This will also reduce the average per capita water use per day.

7 Conclusion

A schematic of treatment plant to treat household wastewater at the generation source is proposed. The cost involved in setting up such a plant using underground tanks of similar size is also calculated which the people may hesitate to invest. This can be reduced if a community come together to set up a single plant for themselves. This will not only save the environment but also maintain health and hygiene among the residents of the particular locality.

The usability of treated water quality and disposal of physical waste and sludge from the treatment plant can be considered for future works. Also the construction materials can be replaced with other alternatives to decrease the capital cost and make it feasible to be integrated to any household design.

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Energy Initiatives for Empowering Smart Villages

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Abstract: Rural-urban migration is a socioeconomic phenomenon, inherent in the development process of a region. About 45 percent of world population lived in rural areas in 2018, and the same is projected to reduce to approximately 32 percent by the year 2050. Similarly, Indian rural population is estimated to decrease from 66 percent to about 47 percent during the same period due to lack of job opportunities, and absence of power supply and higher education infrastructure etc. Access to Information and communication Technology (ICT) and electronic media during the last decade has fuelled the aspirations of rural populace, and urban migration is the next preferred step. Energy is the common, key enabling factor which supports public and private initiatives for improvement of infrastructure in rural areas. Globally, 11.1 percent and in India, 17.4 percent (50 million households) of population does not have access to reliable electric energy. The objective of this paper is to review the potential of Renewable Energy (RE) sources and technologies available for harvesting the same, to meet the electrical energy needs of smart villages in rural areas, in the Indian context. The study is carried out by using the explorative method of research from open sources available on IoT. Results of our research indicate that adequate opportunity exists for tapping of RE from nature in India. Additionally, some environmental and socio-economic impacts of RE have been discussed, and Key components of successful energy solutions for smart villages have been identified. The study concludes that provision of quality electrical energy will boost avenues for growth, development and employment generation in smart villages in rural areas.

Keywords: Smart Villages, Renewable Energy, Rural Areas, Infrastructure

1. Introduction

1.1. Profile of a smart village hub

A smart village hub can be conceived to be a cluster of villages that would preserve the essence of traditional rural community life with matching facilities that are available in a classical urban setting (NRuM, 2016). A smart village must also move the villagers up the value chain to improve socio-economic status of its inhabitants, enable greater participation in governance processes and build communities that are more resilient to face the world (Holmes, 2017). In this study, the term smart village will be used as a synonym to smart village hub or a smart village cluster.

1.2. Objectives of creating smart village hub

The key objectives of creating a smart village hub could be: to undertake economic, technological and infrastructural development aimed at reduction of poverty and unemployment, and to create an environment for attracting corporate investment (NRuM, 2016). These objectives can materialise only if a robust power supply infrastructure is put in place.

1.3. Aim.

The aim of this research is to examine the state of electrification and to suggest mitigation measures to meet the electric energy needs of a smart village hub in the Indian rural hinterland.

1.4. Research Objective

Keeping the research problem in view, the objective of this research is to explore the potential and scope of employment of Renewable Energy (RE) Sources to meet the electrical energy requirements of a smart village hub, in the Indian context.

1.5. Layout

The layout of the paper is as follows: Section 2 covers the research methodology used for the review, including details of material selection. Section 3 enumerates the results of material evaluation. Salient aspects of the findings are also discussed along with the results in this section, and Section 4 presents the conclusions of the current study.

2. Research method

We followed the explorative method of research to conduct the review. The data for the study was shortlisted using snowballing method as an alternative to the usual scientific database searches. The selected material includes, relevant research articles, and grey material such as reports and compendiums published by government and other independent agencies, available as open source on the IoT. The Scope of research is restricted to use of RE only for generation of electricity and all other applications such as solar thermal, and stand-alone systems for individual household lighting and operation of irrigation pumps etc., have been excluded from this study.

3. Results and Discussion

3.1 Concept of smart village clusters

The elements of cluster development can be based on analysis of demographic, social, cultural, economic, and administrative profile of the cluster. The smart village could aspire to equip itself with infrastructural facilities and basic amenities for economic growth and public utility as shown in Figure 1 (NRuM, 2016).

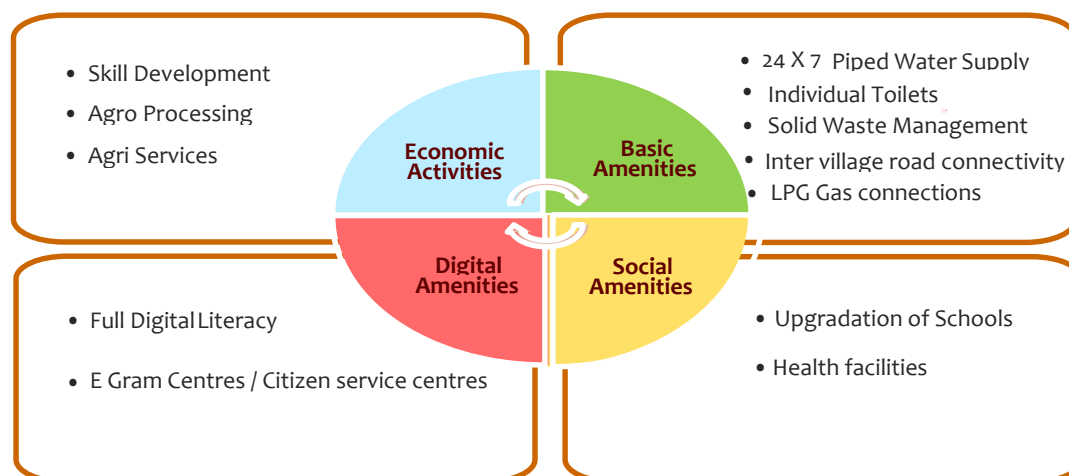


Figure 1: Infrastructure and facilities for smart village cluster (Adapted from NRuM (2016))

3.2 State of power sector

World power scenario

World electricity demand is projected to grow at an average annual rate of 2% (from 20550 TWh to about 34000 TWh) between 2014 to 2040 in the New Policies Scenario, but grows slower at 1.5% (from 20550 TWh to about 30000 TWh) in the 450 scenario, compared with global economic growth of 3.4% (Figure 2) (WEO, 2016).. In the World Energy Outlook 2016, the 'Current Policies Scenario' depicts a picture when no new policies or measures are taken beyond mid-2016. The 'New Policies Scenario', reflects the expected post implementation effect of new policies of governments across the globe in the coming decades, and the '450 Scenario', is the energy pathway aiming to limit the concentration of greenhouse gases in the atmosphere to around 450 parts per million (ppm) of CO₂ equivalent by the year 2100. The share of coal-fired power generation is projected to fall from above 40% in 2014 to 28% in 2040 in the New Policies Scenario. Whereas, the combined market share of wind, solar and bioenergy-based renewables would increase from 6% to 20% during the same period (WEO, 2016).

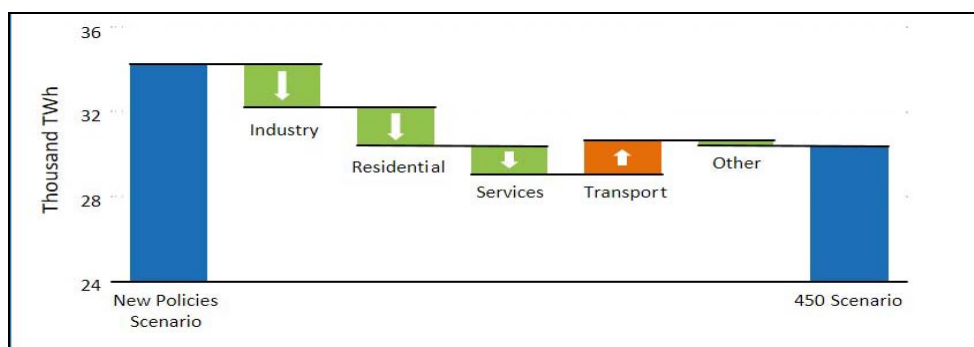


Figure 2. Change in global electricity demand in 2040 in the 450 Scenario relative to the New Policies Scenario (WEO, 2016).

On the emissions front during the outlook period of 2014 to 2040 in the Current Policies Scenario, emissions intensity of power sector is projected to improve from 516 g CO₂/kWh to 415 g CO₂/kWh and total CO₂ emissions rise steadily from 13.5 Gt to over 19 Gt. Whereas, in the New Policies Scenario, the emissions intensity falls to 335 g CO₂/kWh, and total emissions rise modestly from 13.5 Gt to 14.4 Gt over the same period. In the 450 Scenario, emissions intensity falls steeply to nearly 80 g CO₂/kWh and total emissions from the power sector fall to 3.6 Gt by 2040 (WEO, 2016) (Figure 3).

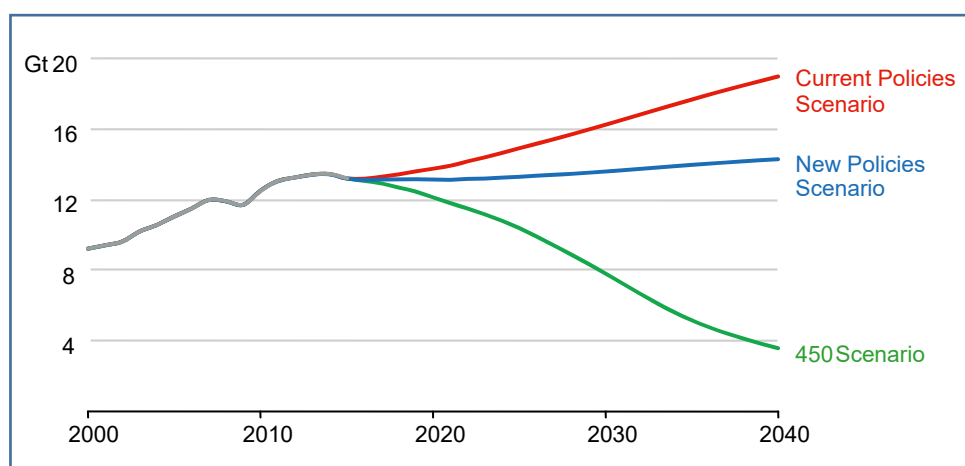


Figure 3: Global CO₂ emissions from fossil-fuel combustion in the power sector by scenario (WEO, 2016)

India power scenario

India with a power output of nearly 1300 TWh is the world's third-largest national power producer. India has made impressive strides in expanding power supply since 2000, with output growing at an average of 6% per year. As of 30 Sep 2019, despite having an installed capacity of nearly 370 GW of power against the peak load demand of approximately 175 GW, the country still faces power deficit of around 1 %. The reasons for such a dichotomy can be attributed to serious structural issues in the power market such as, the distribution sector, where (Distribution Companies) DISCOMs have been accumulating large financial debts due to high technical losses. In addition, the non-technical losses e.g., theft, non-billing and non-collection of payments aggregating to

about 20% are the highest in the world. Notwithstanding such high installed capacity, an estimated 240 million people still lack access to electricity and many more suffer from access to quality and reliable power supply (WEO, 2016). In such a scenario, RE based grid connected and off-grid electrification may play an important role in fulfilling the electricity requirements of these 'last mile' consumers.

3.3 Need for use of RE

Consequent to the Paris Agreement on climate change in December 2015 (Seo, 2017), India has declared its Nationally Determined Contribution (NDC) to reduce emissions intensity of GDP by 33-35% below 2005 levels by 2030. In addition, India is slated to achieve about 40% cumulative electric power installed capacity from non-fossil sources by 2030 with the help of technology transfer and low cost international finance (Rogelj et al., 2017). RE resources accrue social benefits of providing energy access and energy security to remote areas. Thus, the following drivers emerge from study of literature, for development of renewable energy in India: –

- (a) National energy security;
- (b) Limited stocks of Fossil fuels;
- (b) High potential of wind and solar energy;
- (c) Emissions reduction by shifting from polluting sources like oil and coal;
- (d) Free availability of RE sources in nature with only a technological cost for tapping them;
- (e) High and fluctuating cost of imported coal and oil for thermal power plants.

3.4 Potential for use of RE

A number of RE sources are available in India, out of which, solar, wind, hydro, biomass and biogas have been commercially exploited. Other RE sources such as hydrogen energy, chemical energy, ocean energy, bio fuels, and geo-thermal are currently at R & D stage. The selection of RE alternatives is dependent on the geographic location, the prevailing climatic parameters of a region and the techno-economic feasibility of energy production. It is observed that only about 7 percent of total RE potential has been harnessed till 31 May 2019 (Table 1), which shows that India still has a very large RE potential (83 percent) awaiting to be tapped. In the interim, the Indian Government has declared a target of 175 GW of RE installed capacity by 2022 ((CEA, 2019); (MNRE, 2019b)).

Table 1: RE potential, installed capacity and targets for 175 GW production in India by 2022 ((CEA, 2019) ; (MNRE, 2019b)).

RE Source	Total potential (GW)	Installed capacity (up to 31 May 2019) (MW)	Percentage of total potential installed (%)	Target 2022 (MW)
Solar	750	29409.25	4	100, 000
Wind	300@	36089.12	12	60,000
Bio-power	25	9269.80	37	10,000
Small hydro	20	4603.75	23	5,000
total	1095	79371.92	7	175,000

Note. @ - At a hub height of 100 metre.

3.5 RE sources for on-grid and off-grid applications

RE sources can be used effectively in both the cases i.e., for smart villages which are grid connected but under-electrified and for smart villages where grid connectivity is not available due to difficult terrain, and where RE sources are economically more viable than conventional grids. Accordingly, the Ministry of New and Renewable Energy (MNRE) has issued a draft National Policy on renewable energy based on mini- and micro-grids in 2016 for development of 10,000 off-grid projects totalling 500 MW by 2022 (MNRE, 2016). A brief discussion on the viable RE sources is presented below.

3.5.1 Solar Power

India is endowed with vast solar energy potential. About 5,000 trillion kWh per year energy is incident over India's land area with most parts receiving 4-7 kWh per sq. m per day. Hence both technology routes for conversion of solar radiation into heat and electricity, namely, solar thermal and solar photovoltaics, can effectively be harnessed providing huge scalability for solar in India. The estimated potential for solar power in India is shown at Table 1 and the Solar Map of India is shown in Figure 4 placed at Appendix A. Off-grid decentralized applications will be advantageous from rural electrification perspective and meeting other energy needs for power, and heating and cooling in rural areas. For economic viability, the annual average Global Horizontal Insolation (GHI) should be greater than or equal to 4.5 kWh/m²/day. Presently, the electric power conversion efficiency of different PV technologies is quite low and varies from 9-18% (Table 2) (MNRE, 2015).

Table 2: Efficiencies of different PV technologies

PV Technologies	Efficiency
Poly Crystalline Silicon (c-Si)	14%
Mono Crystalline Silicon	18%
Copper Indium Gallium Diselenide (CIGS)	11%
Cadmium Telluride (CdTe)	9%

3.5.2 Wind Power

Some states in India have abundant wind energy potential as shown in the Wind map in Figure 5 placed at Appendix B. The estimated potential for wind power in India is shown at Table 1. In addition, a study was carried out considering a representative 2 MW turbine with a 100 m rotor diameter(D), with spacing between the turbines based on a 5D x 7D and 3D x 5D array configurations. Results indicate that, the 3D x 5D layout was found more optimal to provide a capacity density of 13.3 MW per sq. km. Considering an average plant load factor of 40%, the total wind power potential in India is estimated to be about 2000 GW in the seven states considered for the above analysis viz., Tamil Nadu, Andhra Pradesh, Telangana, Karnataka, Rajasthan, Gujarat, and Maharashtra (MNRE, 2015), but these estimates are yet to be formally accepted by the MNRE.

In order to realise the estimated wind energy potential at a given place, the turbine should be chosen such that its response curve complements the wind speed distribution of the site to yield maximum energy. As an example, the power curve for a 2 MW rated power Wind Turbine Generator (WTG) at 100 m hub height and 100 m rotor diameter is shown at Figure 6.

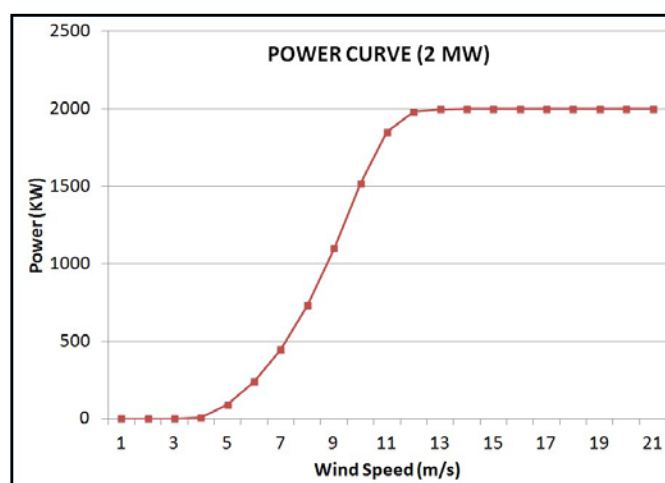


Figure 6: Power Curve for a typical 2 MW WTG

3.5.3 Small Hydro Power

Small Hydropower Projects (SHP) can play a critical role in improving the overall energy scenario of the country and in particular for smart villages in remote and inaccessible areas. The estimated potential for SHP in India is about 20,000 MW. Most of the potential for SHP is in Himalayan States as river-based projects and in other States on irrigation canals. Small hydro power projects are further classified in Table 3: -

Table 3: Classification of small hydro power projects

Class of SHP	Capacity in kW
Micro Hydro	Up to 100
Mini Hydro	101 to 2000
Small Hydro	2001 to 25000

3.5.4 Biomass Power/Cogeneration

Small biomass gasifier based power plants up to 2 MW capacities can operate in a stand-alone, off-grid mode or connected at the tail end of the grid to provide benefits such as reducing Transmission and Distribution (T&D) losses and access to electricity in villages etc. Currently, about 70 biomass gasifier systems are providing electricity to more than 230 villages in the country (MNRE, 2019b). The present estimated potential and installed capacity of biomass power in India is 25 GW and about 9.27 GW respectively (Table 1). The smart village cluster may attract industries such as sugar, paper and pulp, textiles, fertilizers, petrochemicals and food processing, etc., which

require both, electrical and thermal energy for their operations, and can be met through captive RE co-generation power plants.

3.5.5 Biogas

Biogas production is a clean low carbon technology for efficient management and conversion of organic wastes into clean renewable biogas, and organic fertilizer source. It has the potential for leveraging sustainable livelihood development as well as tackling local land, air and water, as well as global pollution. Biogas obtained by anaerobic digestion of cattle dung and other loose and leafy organic matters can be used for reliable decentralized power generation in the range of 3 to 250 kW for remote areas. The current installed capacity of biogas power generation in India is 138.30 MW of on-grid interactive projects and 111.43 MW Off-grid power projects (MNRE, 2019a). As no specific biogas power potential has been assessed by MNRE and most projects are developed on need basis, this RE source is not discussed any further in this study.

3.5.6 Hybrid power systems

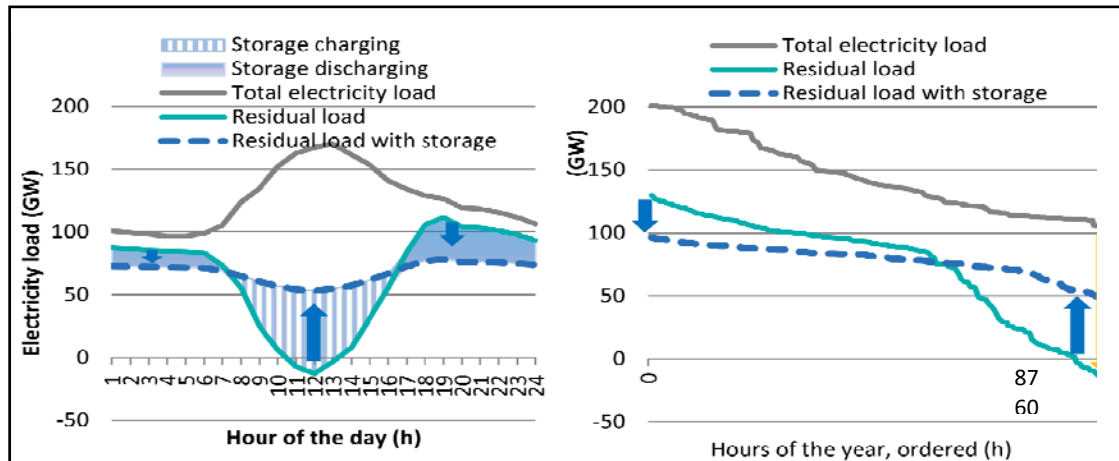
In order to minimize the variability of individual RE sources, two or more RE sources may be used to produce power in different hybrid configurations. For instance, wind and solar can act as complementary sources in a wind-solar hybrid system to provide better grid security and optimum utilisation of power generation and transmission infrastructure. Adequate fiscal and financial incentives have been declared by the Government of India under the latest Wind-solar hybrid policy, 2018 (MNRE, 2018). Any other combination such as solar-biomass, wind-solar-biomass and wind-solar-small hydro etc., may be used depending on site specific techno-economic feasibility.

3.6 RE Site Suitability Analysis

A preliminary screening is first conducted to exclude areas unsuitable for RE such as, water bodies and agricultural land (in the case of solar). Areas with resource quality below thresholds of 5.5 m/s wind speed (approximately 200 Watts per m² power density) for wind and 4.3 kilowatt-hours per m² per day for solar PV are to be excluded. Areas with slopes greater than 5% for solar and 20% for wind, and areas with elevation above 5,000 m are also not found technically viable (Palchak et al., 2017). Typical land use factors for wind and utility-scale solar are 9-MW per km² and 30 MW per km², respectively ((Denholm et al., 2009); (Ong et al., 2013)). However, restricting the practical land availability to 25%, land use factors of 2.25 MW per km² for wind and 7.5 MW per km² may be assumed for utility-scale solar plants

3.7 Storage of RE

The main drawback of any renewable energy is its intermittent nature due to daily and seasonal variations. Therefore, integrating proper energy storage mechanism with solar and wind power systems, can reduce stress on the grid by making the solar power dispatchable. An illustrative example of load balancing using storage from Solar power is shown in Figure 7. The upward blue arrow shows storage charging during mid-day and the downward blue arrow shows discharging of storage during night time to smoothen the residual load of the power plant (Keramidas et al., 2018).



Note. Residual load refers to the total load net of non-dispatchable production from renewable energy sources.

Figure 7: Load balancing using storage from Solar power (Keramidas et al., 2018)

The current global RE storage capacity is limited to about 153 comprise of mostly pumped hydro storage (150 GW), thermal storage (2 GW), and Stationary battery storage (1.3 GW) (WEO, 2016). Future trends in RE storage indicate sharp rise in development of other techniques such as, development of flexibility instruments for demand side management (DSM), vehicle to grid (V2G) options, large stationary battery storage, and compressed air energy storage(CAES) between 2030 to 2050 (Figure 8) (Després et al., 2018).

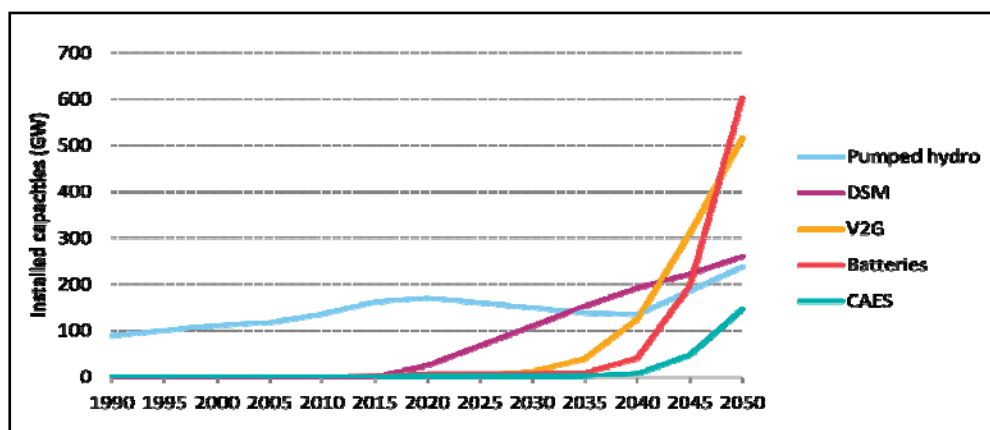


Figure 8: Future trends in RE storage technologies (Després et al., 2018)

3.8 Grid Parity

The present conventional electricity tariffs vary from INR 2 to 4 per kWh in the Indian states and has a national average tariff of INR 3.6 per kWh.(CERC, 2019). The renewable solar and wind tariffs have reduced sharply in the last few years on the strength of fall in prices of solar PV modules and wind turbines, economies of scale, and reverse bidding auction mechanism. Currently, wind and solar have turned from being expensive sources of power that needed subsidy support to becoming cheaper than conventional power in the range of INR 2 to 3 per kWh during the successful bids in 2018 (Chandra Bhushan, 2019), signalling the onset of solar and wind grid parity in India.

3.9 Environmental and Socio-economic impacts of RE projects

3.9.1 Environmental impacts of renewable energy projects

RE projects are not completely emission free as some GHG emissions are embodied in all renewable technologies during manufacturing of RE equipment, waste disposal, recycling, etc. Clearance of vegetation from RE project sites also increases GHG emissions otherwise sequestered in the vegetation (Turney and Fthenakis, 2011). However, these life-cycle emissions are significantly lower than those coming from conventional sources of power (Figure 9) (Sherwani and Usmani, 2011).

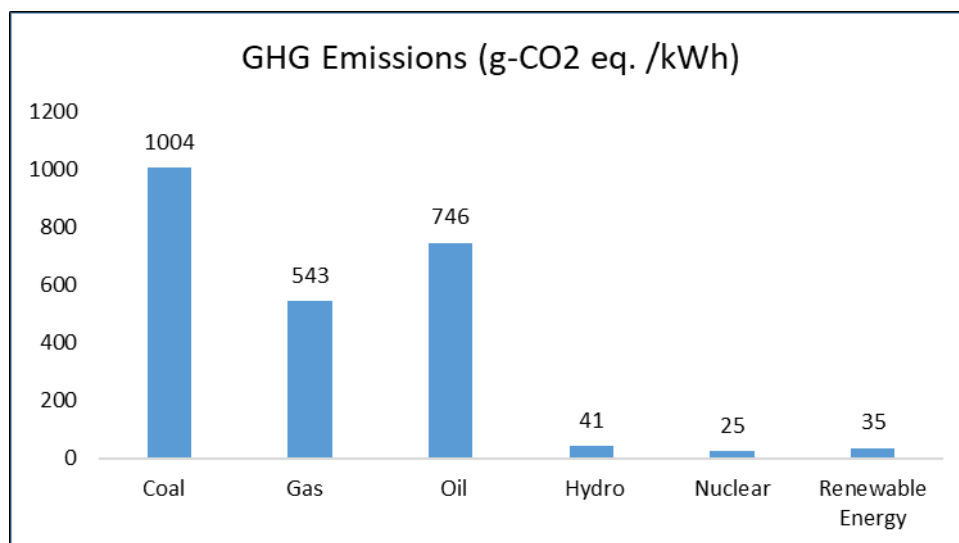


Figure 9: Electricity generation associated GHG emissions in India (Adapted from (Sherwani and Usmani, 2011))

Apart from GHG emissions, prolonged inhalation of mercury vapours associated with solar power plant can lead to respiratory disorders (Giang et al., 2015). Similarly, exposure to cadmium can result in kidney dysfunction and pulmonary diseases. However, past studies reveal that intensity of these pollutants are significantly lower as compared to coal fired plants (Table 4) (Turney and Fthenakis, 2011). Also, ecological impacts of RE projects like, exposure to emissions, soil erosion, loss of tree cover, noise pollution, and loss of natural habitat can be minimised by proper site selection and safe disposal of PV panels.

Table 4: Comparison of emissions of Mercury and Cadmium from coal Fired and solar power plant (Turney and Fthenakis, 2011)

Impact category	Solar power plant	Coal fired power plant	Comments
Emissions of mercury	~ 0.1 g Hg/ GWh	~15 g Hg/ GWh	Solar emits ~ 150 times less mercury than coal fired
Emissions of cadmium (from Cd-Te PV cell)	~ 0.02 g Cd/ GWh	~ 2-6 g/ GWh	Solar emits ~100-300 times less cadmium than coal plant

3.9.2 Socio-economic impacts of renewable energy projects

As the RE sector develops, the resource demand by such projects may rake up several socio-economic issues. Solar farms require about 5–8 acres of land per Mega Watt Power (MWp) (Denholm and Margolis, 2008), and about 2000 to 4000 Litres of water per MWp per year for cleaning of solar panels (US-BLM, 2013). Land and water being scarce resources, may raise concerns from local communities. However, use of innovative ideas such as, installing solar panels over school buildings, community centres, and irrigation canals will help reduce land centric conflicts. Similarly, use of sprinklers for cleaning of solar panels, water recollection, storage and reuse, can mitigate the water centric conflicts in future. On the positive side, the RE sector is able to generate a substantial number of skilled and unskilled jobs for design, installation, fabrication, operations and maintenance, project development and marketing functions.

3.10 Some case studies re-visited

Three representative case studies, showing one each, on use of solar, biomass and small hydro power are discussed enumerating the benefits accrued to the local communities.

Case Study 1- Solar micro grids in Uttar Pradesh

A Solar Micro Grid (SMG) is a flexible, modular, and reliable solar-powered system that can provide electricity access to communities ranging from 10 to 80 households, at costs lower than their current expenses on kerosene. The Energy and Resource institute (TERI) with support from the Norwegian Government, has installed SMGs in three village market places of Jagdishpur Block (CSM Nagar District) and Shivgark Block (District Rae Bareli) in Uttar Pradesh. The system uses LED lights and the micro-grid is modular, which can scale up connections starting from 10, up to 200 connections. The pre-installation survey indicated regular power cuts during evening hours from 5 pm to 9 pm, and unreliable supply during other time of the day. With the installation of the micro-grids the entrepreneurs were able to enhance their incomes (Figure 10). In addition, replacement of diesel gen-sets and kerosene at comparable cost helped in reducing

carbon emission along with providing clean and reliable power to the rural households (MNRE, 2012).

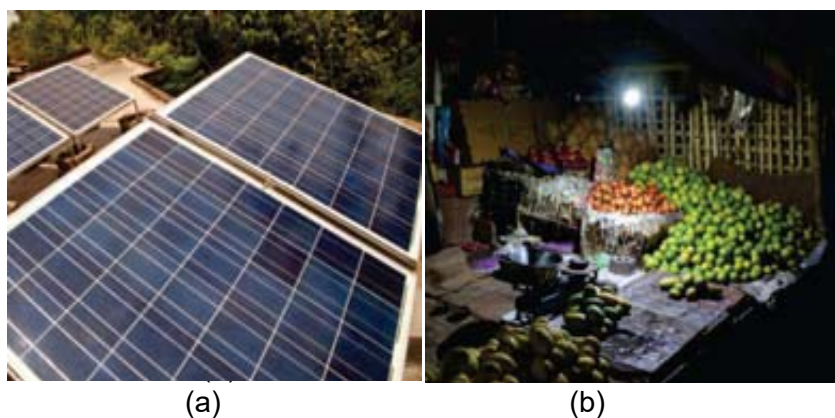


Figure 10: (a) Typical solar micro-grid display in rural India.
(b) A villager in India is able to carry on business after dark.

Case Study 2 - Installation of 10 kW Bio mass gasifier at Kakadpana Test Project in Nasik District of Maharashtra

Kakadpana is a tribal hamlet surrounded by thin forest and consists of 85 households. The hamlet is situated at a distance of about 110 Km from district headquarters. One gasifier of 10 kW capacity has been commissioned under this project in April, 2011. The project has been implemented by Gomukh Environmental Trust for Sustainable Development, Pune. The biomass gasifier meets the daily requirement of domestic lighting in 85 households, street lighting and other entertainment activities for 6- 7 hours a day from 7.00 PM to 2.00 AM at night. Each household has been provided with two light points and one power point for domestic lighting and entertainment. With the introduction of electricity, the lifestyle of the villagers has been transformed. They have now started working after sunset, which has resulted in increase in their income. The students are also started studying during night. The fear of wild animals has also been reduced, as 10 street lights in the village provide adequate illumination during night (MNRE, 2012).

Case Study 3 - Remote village electrification through a micro-hydro project in Arunachal Pradesh

The obtaining terrain in Arunachal Pradesh is mostly hilly and is covered with dense forests, with a long rainy season of almost six months. Villages located along perennial streams and tributaries are ideally suited for hydel projects ranging from pico to micro and mini. A Micro Hydro Project of 2 X 15 kW capacity has been installed at Bikhi in Papumpare district in Arunachal Pradesh in 2008 at a total cost of INR 42 lakhs including a subsidy grant of INR 24 lakhs from MNRE, Government of India. The project has been running successfully, under the Village Energy Management Committee (VEC) with technical assistance from Arunachal Pradesh Energy Development Agency. Three villages namely Seema, Gungtung, and Taw with a total population of about 450, have been electrified through this project. The plant also provides power to the government middle school near Seema Village, a health sub-centre and the Anganwadi centres of the three villages (MNRE, 2012).

3.11 Energy solutions for smart villages: Key components

Smart villages can be energised based on past experience on electrification of remote villages, to comprise of key components as discussed below.

Local Institutional frame work

The present mini and micro-grids in India are generally managed through the VEC, and lack an organised delivery approach as compared to conventional grid systems. The VEC is found to be ill trained in many cases. Therefore, instead of the VEC model, alternative service delivery models involving energy service provider (ESP) or BOOM (built, own, operate and maintain), and BOM (built, own, maintain) models could be adopted. The ESP could play the role of the stand-alone power producer, distributor and supplier of electricity. The VEC, with appropriate training, can act as a local-level regulator to enforce compliance of standards and benchmarks, negotiate the tariff, and resolve disputes between stake-holders (GNESD, 2014)..

Selection of technology

The selection of technology for renewable energy mini-grid projects for smart villages will be dependent on various factors, viz., the geographic and climatic conditions of the region, the policy framework promoting different technologies, state of supply chains, and the local micro-level socio-economic conditions. Selection of technology should be based on robustness and availability of skill-sets of local population for efficient operation and maintenance. Also use of modular equipment will afford scalability of capacities based on population density. Additionally, the mini-grids should be capable of seamless connection to the conventional grid on its arrival to the region, to dispel fears of obsolescence.

Smart grids

Smart distribution grid architecture can be employed to reduce network losses, improve systems efficiency and reliability by real time monitoring and control (Bayindir et al., 2016). Smart grids will also enable better demand side response, and cost-effective integration of distributed generation and distributed storage of RE to meet the power supply requirement of smart villages during peak load and lean periods of RE generation.

Cluster-based approach

Stand-alone renewable energy solutions such as solar lamps or solar home systems are unable to meet the full requirement of reliable power supply of a village. Mini and micro-grid projects will perform better in case of clustering of smart villages to attain economies of scale. A structured implementation network consisting of skilled manpower for operation and maintenance, readily available spare part set up, and adequate supply of feed material/ availability of RE source, will enable sustained supply of power (GNESD, 2014)..

Policy and regulatory Support

A robust enabling policy and government support would form the back-bone for successful and sustained performance of the energy projects. The policy framework could include laying down of standards, benchmarks, financial support mechanism and measures for capacity-building. Some examples of policy actions are: (a) Bundling of

renewable electricity with (cheaper) thermal power, and (b) Easing liquidity, de-risking and availability of low-cost finance (NITI Aayog, 2015) .

Direct and indirect financial incentives

Apart from policy support, some financial incentives from the Government of India for instance, Accelerated Depreciation (AD) to offset overall tax liability, Viability Gap Funding (VGF) to reduce capital cost of the project, Generation Based Incentive (GBI) payment for every unit of electricity generated, Provision for low cost and longer tenure debt, and Dollar denominated tariffs to attract foreign investors, can result in reducing the incremental cost of RE procurement by the state DISCOMs (NITI Aayog, 2015)

Capacity-building

Training and enhancing awareness of stake holders for taking informed decision making in regular O&M would be required for capacity building and sustained operation of the plant and equipment for efficient project performance. Active community mobilisation and empowerment for improved integration through participatory governance system would also be beneficial in the long run. Another important step would be to design support systems to ensure that plans and policies dynamically match the changing needs of all stakeholders (GNESD, 2014).

Decentralized distributed generation system

Decentralised, distributed generation (DDG) refers to the installation and operation of small modular power generating technologies directly connected to medium voltage (MV) or low voltage (LV) distribution systems (Akorede et al., 2010). It is used to improve the operations of the electricity delivery systems at or near the end user (Zhou et al., 2013). DDG systems are ideally suited for smart villages as they can absorb seasonal and peak load variations, help in reduction of T&D losses, and minimise grid failure disruptions.

4. Conclusion

Renewable Energy can meet the energy needs of smart villages in both, grid interactive and off grid power modes to ensure energy security and access in remote areas, where off-grid applications are the preferred solution. Most new RE power generation systems are likely to adopt decentralised, distributed, hybrid configurations to ensure optimum resource utilisation and increased power reliability. RE technologies have considerably lower ecological footprints, hence such projects may be accorded fast track environmental clearance. Also, subsidy support from the government will encourage private investments in RE sector. Use of innovative ideas, proper site selection and effective management of scarce resources such as, water and land required for RE installations, and community engagement strategies will help reduce potential conflicts with local inhabitants in future.

Provision of reliable, quality electrical energy to smart villages would boost ICT accessibility and would promote better opportunities like, distance education, studies at night time, e-commerce for local produce and handicraft industries, improved health facilities and above all, increased avenues for employment, which will eventually act as a dampener to the need for urban migration.

Appendix A

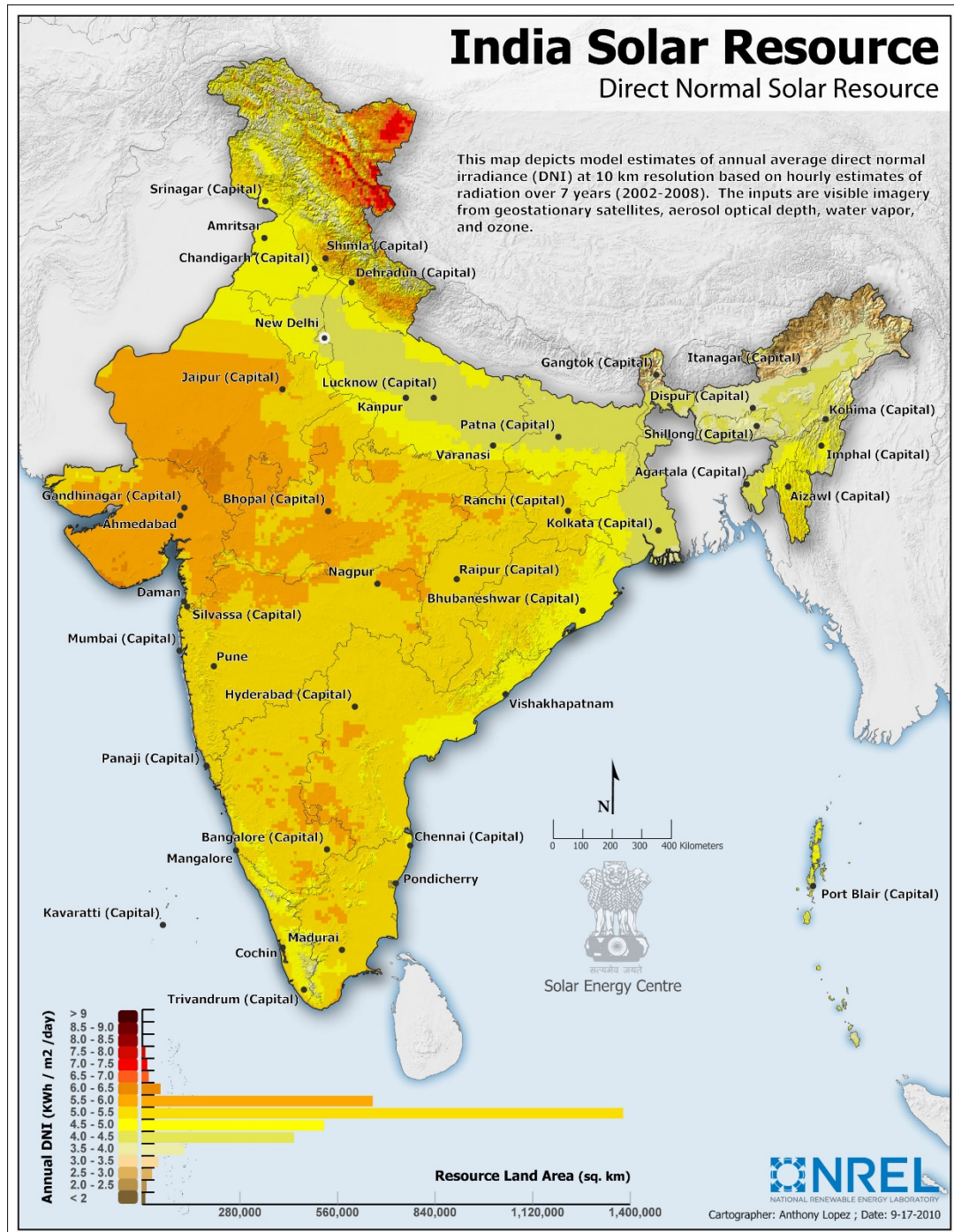


Figure 4: Solar Map of India (NREL, 2016)

Appendix B

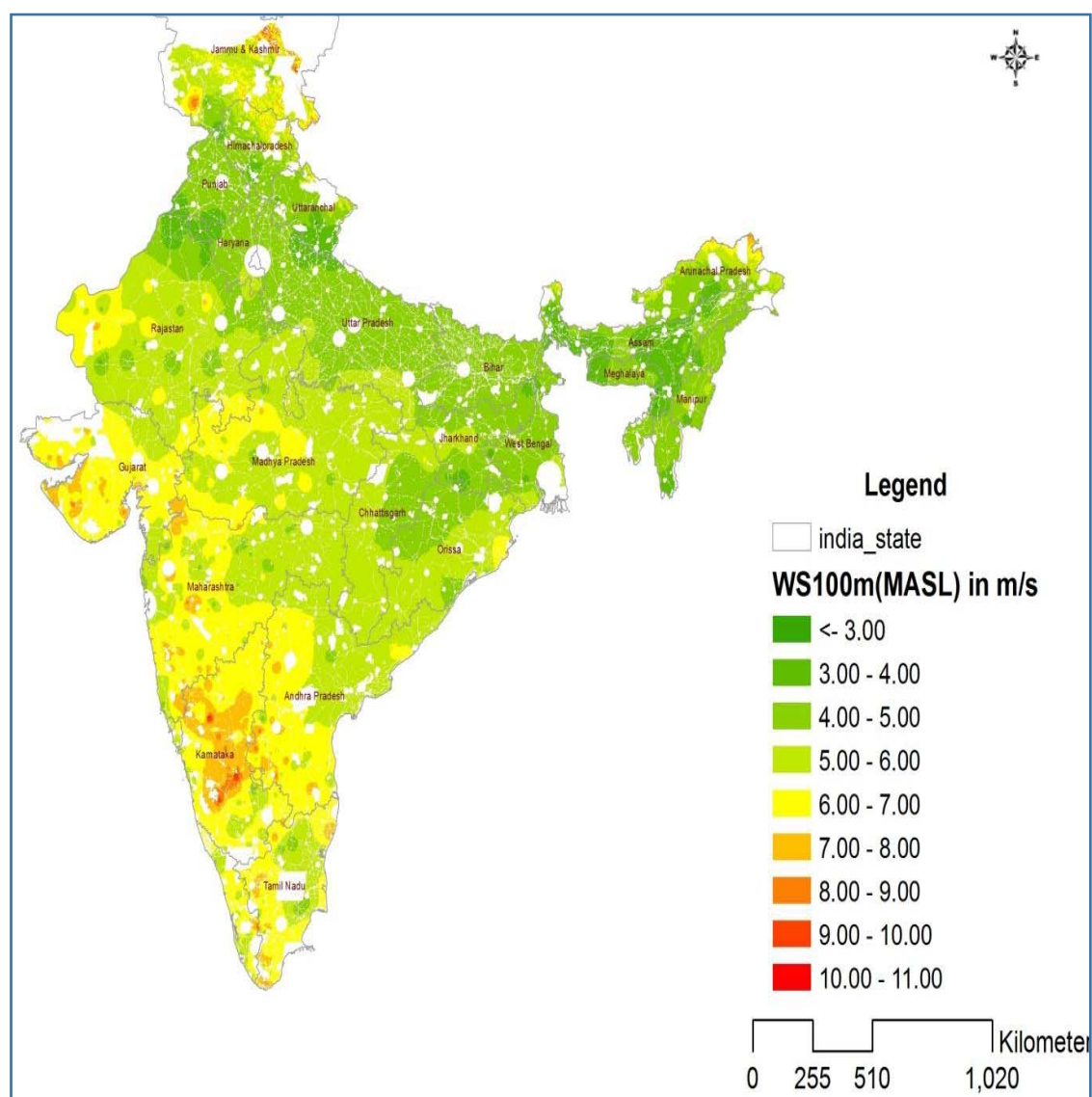


Figure 5: Wind Speed Map of India at 100 m Hub Height (MNRE, 2015).

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HOUSING SYSTEM FOR FLOOD MITIGATION IN RURAL ASSAM: A CASE STUDY

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Abstract: *Floods have been a recurring problem in the floodplains of Assam for a long time. The Assam State Disaster Management Authority (ASDMA) reports show that an approximate average of one lakh people is affected across the districts in the state every year. This not only causes loss of property and valuables but also risks the lives of people. The traditional housing design originally used by the Mishing Community has been an adaptation to this scenario by means of houses raised on stilts. The different traditional housing design and their capability of safeguarding of lives and the valuables of people will be studied and analysed in the Majuli district which is the most flood prone district of rural Assam. The study of materials and settlements used in these areas will be a beneficial attempt for a safe and stable condition even in the time of flood. The present study examines the traditional materials and settlements used in these areas for flood mitigation. It further proposes few modifications with respect to the conventional structure which must be maintained while planning the house architecture to minimise the destruction incurred by flood in these areas.*

Keywords: *Flood, Sustainable structure, Majuli, ASDMA*

1 Introduction

Majuli is a beautiful river island in the Brahmaputra River. The island holds an area of around 421.65 square kilometres (163 sq. mi). The place offers a great blend of culture and history which attracts people from all across the globe. It is located at a distance of around 20 km from Jorhat town. The island of Majuli is accessible via ferries which can be taken from Jorhat. It is well known as the cultural capital of Assam. Moreover, the place holds Assamese civilization for more than 500 years. The island preserves antique items from the ancient civilizations such as weapons, jewellery and utensils in the Satras. However, Majuli being a flood plain area, the region faces a regular issue of flood every year. This in turn causes innumerable loss to the people residing in the villages of the region. In addition to that animals are also not safe from the heavy destruction. It is crucial to study the aspects of the flood plain areas.

Climate change is real and its implications are quite visible in the form of adverse climatic activities like rising earth's surface temperature and rise in sea level (Greenwood 2014, Moorhead 2009, Samanta 1997, Houghton 1996). To fight these adverse climate changes many communities have adopted various strategies in the built environment and to adapt with the scenario. These strategies have been developed over the years and are sensitive to the local environment and the climate. These strategies mainly include the housing settlements adopted from the traditional "Missing Chang Ghar" which most of the people are inhabiting. These kinds of traditional houses help the residents of Majuli to overcome the natural disaster which occurs every year to an extent.

(Harikrishna, 2013) investigated on the cyclone disaster mitigation by the engineering of non-engineered and semi-engineered dwellings. The study found that by adopting the cyclone resistant features-which includes metal straps, plates and U-Bolts, the substantial reduction in damage to non-engineered and semi-engineered dwellings can be realised in the outer regions of land area traversed by cyclonic wind field. (Thomalla, 2006) scrutinises key communalities and differences between the climate change adaptation and disaster risk reduction communities. It further proposes three exercises that is helpful to structure a multi-community dialogue and learning process. (Morshed, 2010, Morshed, 2003) investigates for proper latrine solutions in flood prone areas in Bangladesh. The study proposed a pump which minimised the human health risks instead of manually cleaning of latrine.

The present study aims to identify the traditional local housing settlements by focusing on the pros and cons of silt housing in Majuli so that the heavy loss can be incurred.

2 Traditional houses in Assam

The traditional houses in Assam are made of mud-plastered bamboo walls and thatched roofs built on both flat and slopped terrain. The house structures are typically L or C shaped and an open verandah. Sal or Hallock wood were used to make the frames and pannels of these houses.

2.1 Unit Level types

At Majuli most of the dwellings are made on stilts. However, special care is taken to ensure that the granaries are at a level higher than the dwelling unit. Figure 1 shows the cluster comprising of two types of units in which one is used for living and consists of dwellings of the same family. The other unit is used for annual food grain storage.



Figure 1: Cluster of two units

2.2 Shape and Size

Simple, compact and symmetrical shapes like square and rectangular shapes works best in cyclone prone areas (Agarwal, 2007). Therefore, square and rectangular shapes are preferred. Such structures can also be efficiently used for various purposes and are used commonly in the housing architectures of Majuli. Figure 2 shows a rectangular true shape that enables easy distribution of spaces within the house.

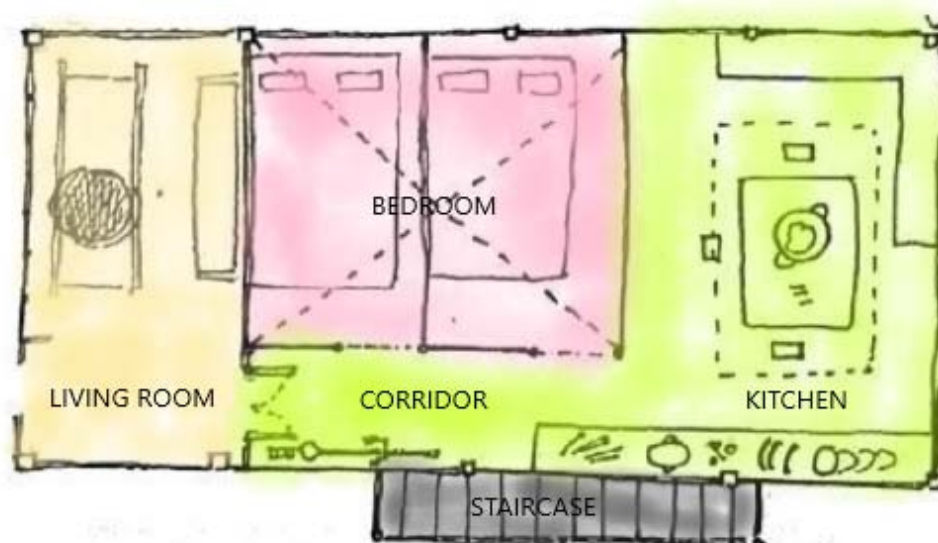


Figure 2: Rectangular shape work inside a house

2.3 Orientation

The shorter side faces the windward direction so as to minimise the contact with high velocity winds. Whereas, the units in the villages in Majuli avoid being directed towards the west, this leaves them with an orientation. Houses are arranged in all directions except West (Dey 2005, Dey 2012) as shown in figure 3. Also the houses are arranged along and perpendicular to the river.

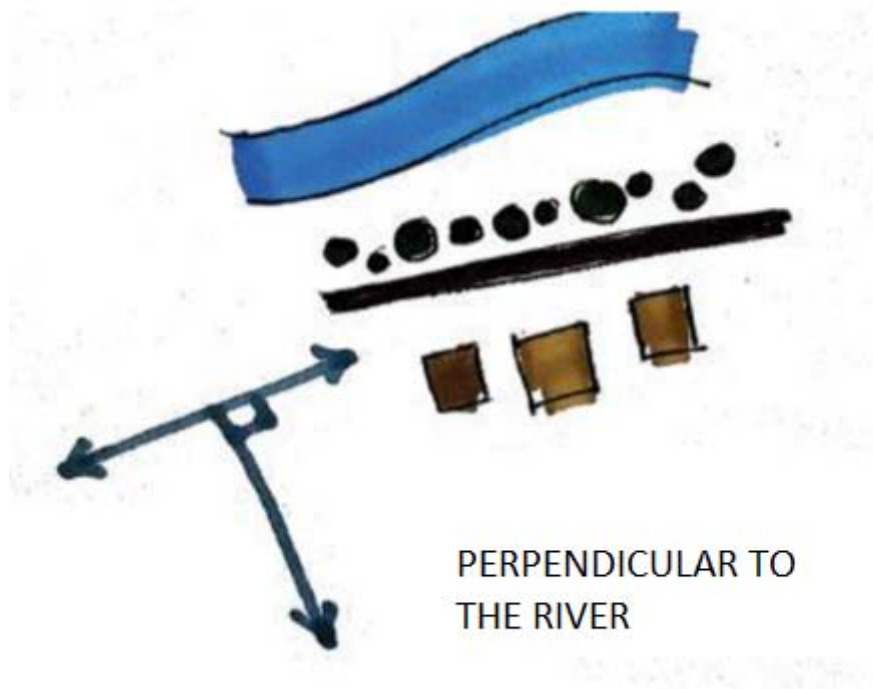


Figure 3: Direction of arrangement of the houses in Majuli

2.4 Fenestrations

In Majuli, there are no openings, but there are gaps done by weaving the mats in a particular manner. In the areas where velocity of winds is higher, there should not be a larger fenestration, instead, smaller openings should be used for cross ventilation.

3 Construction and materials details

Traditional knowledge systems dwell on the idea of indigenous resources and these are perhaps best suited to deal with the environment and climate in which it dwells. In both case studies the indigenous materials like bamboo and timber are excellent at dealing cyclones and floods (Singh, 2009). However, the techniques differ from place to place. Locally available materials like bamboo and timber as in figure 4 is used for load bearing members. Lap joint is used to increase the length of the bamboo. Two bamboos are joined with the help of wire.

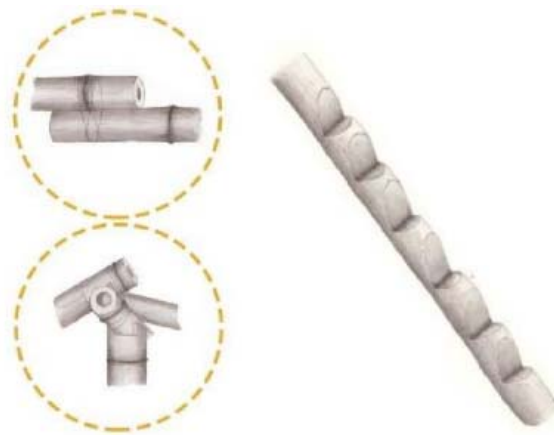


Figure 4: Bamboo and timber

3.1 Walls and partition

For walls and partitions woven bamboo mats locally treated with coal tar coating can be used for water proofing and resisting termites. As in Majuli, split bamboo members were used for making the woven mats with different patterns in order to create panels of the walls. One such pattern is shown in figure 5 which is commonly used for walls. These partitions are made of bamboo which is an abundant indigenous material.

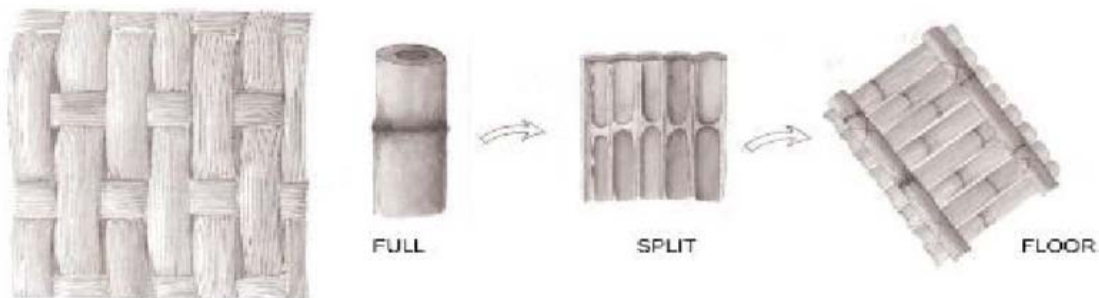


Figure 5: Wall and partition pattern in Majuli

3.2 Roofing

The ratio of hipped or pitched roof in these areas is kept high to ensure easy runoff of rain water. In addition to this patio, other separate structures are provided with the separate roof to ensure their respective structural integrity in events of high velocity winds (Agarwal, 2007).

In Majuli, hipped roof and separate roof for dwelling and patio is preferred to avoid the damage caused by high velocity winds. Such hip roof structure is shown in figure 6. Some houses use a method of tying fishing net over thatched roof to strengthen roof against high velocity winds.

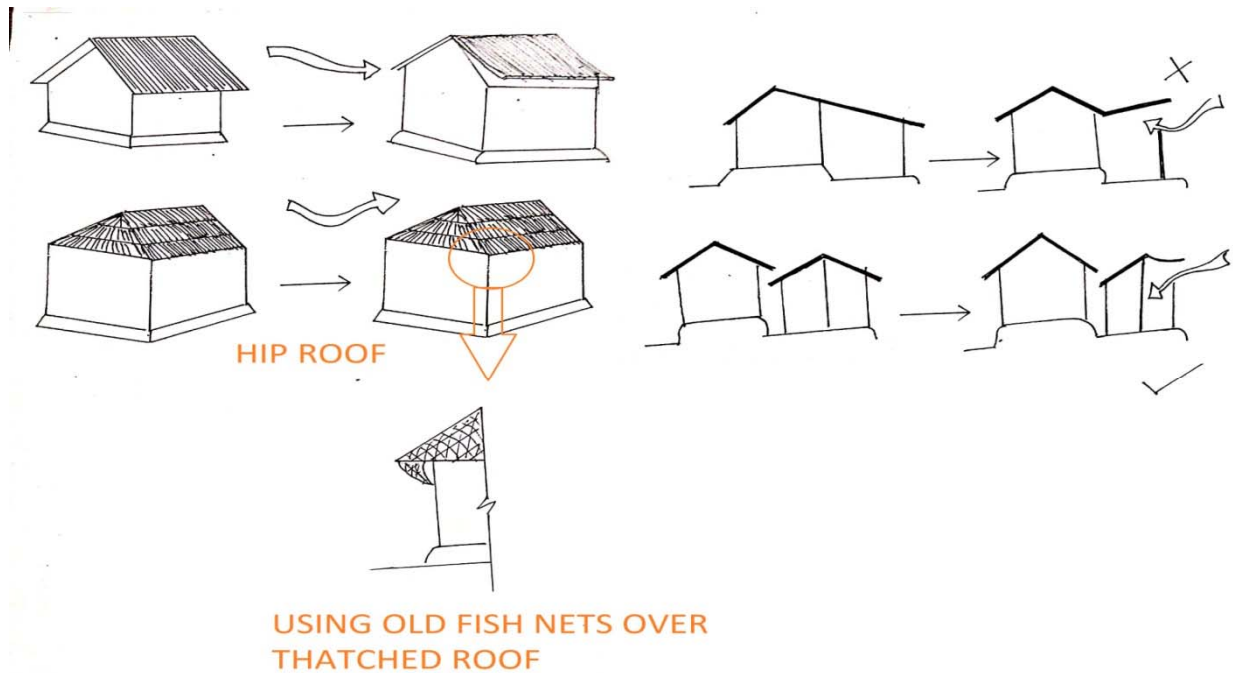


Figure 6: Roofing in Majuli

3.2.1 Orientation of roof

Roof of houses are arranged in direction opposite to wind flow. Such orientation of a roof in Majuli is illustrated in figure 7. It is necessary to arrange the houses in opposite direction to resist the wind flow and so that it donot harm the house in a bad condition.



Figure 7: Orientation of roof in Majuli

4 Structures:

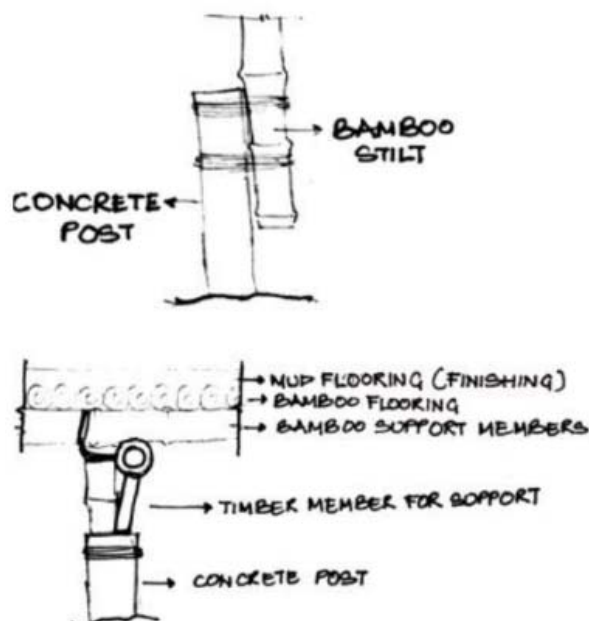


Figure 8: Slited Structure of the supports near river bank

All structures near the river bank are stilted to avoid flood water coming inside the structure during storm and high tides. Figure 8 shows how the slited structure is made using a combination of concrete and bamboo posts. Such supports are commonly found near river banks.

- (i) Horizontal bamboo members of floors are supported on concrete posts.
- (ii) Concrete post reduces in width above floor level to provide support for horizontal members.
- (iii) Polythene sheet is used for water proofing the structure.

5 Housing

Housing is a major issue in Majuli. As in most parts of the world there are housing shortages. Resilience of housing is also a big issue as Majuli is prone to both flood and earthquakes. Designing affordable housing that can withstand these phenomena presents a challenge for any housing scheme. In Assam, the cost of land is relatively cheap, while construction is very expensive. In a secluded region like Majuli, the cost and availability of building materials is limited by many factors- lack of transport infrastructure, making it difficult to transport building materials to the island. As a result, many houses are built in a piecemeal fashion, with people building as much as they can afford initially and then adding to their house over time.

6 Mishing Chaang Ghar

The best architectural adaptation to the flood scenario in Assam is the Mishing Chang ghar as in figure 9. They have been practicing effective flood mitigation for generations. They build their houses on stilts whose height is based on their knowledge of their highest flood level. Such houses are prevalent but widely accepted.

Figure 10 shows the plan of a conventional Missing chang ghar. The front and side sections are shown in figure 11 and figure 12. The illustrations also show how the different rooms are designed as per the usage of the residents.



Figure 9: Mishing chang ghar

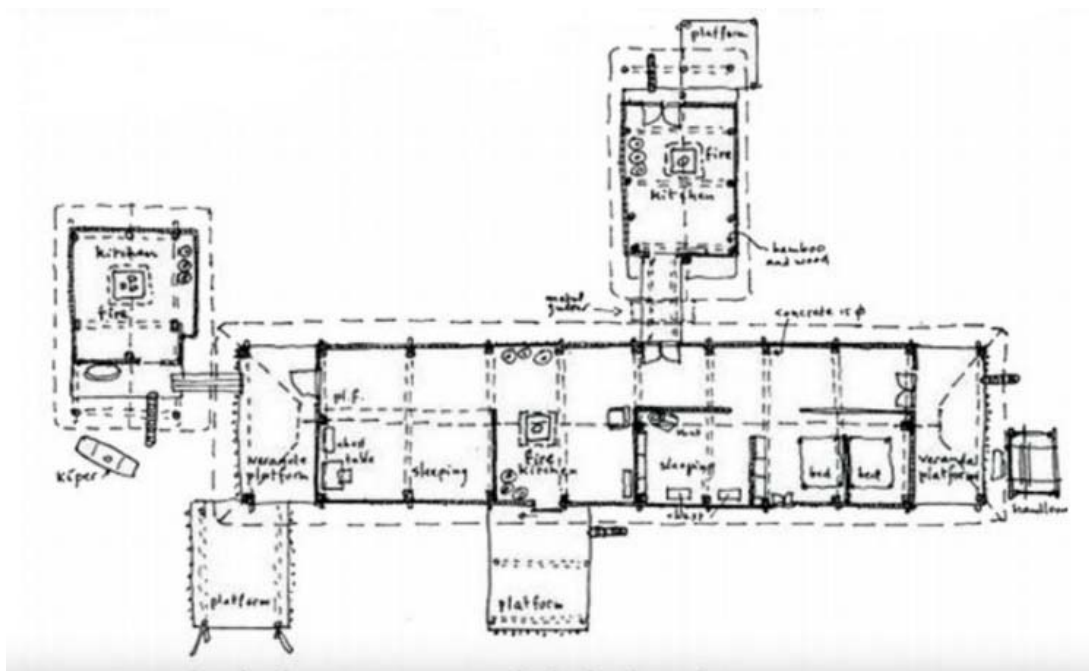


Figure 10: Plan of a typical Mishing house

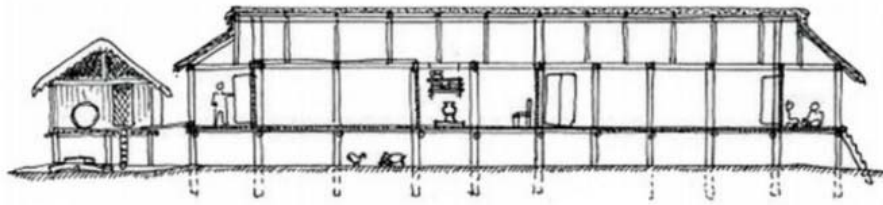


Figure 11: Front-section of a Mishing house



Figure 12: Side-sections of a Mishing house

7 Analysis and Recommendation

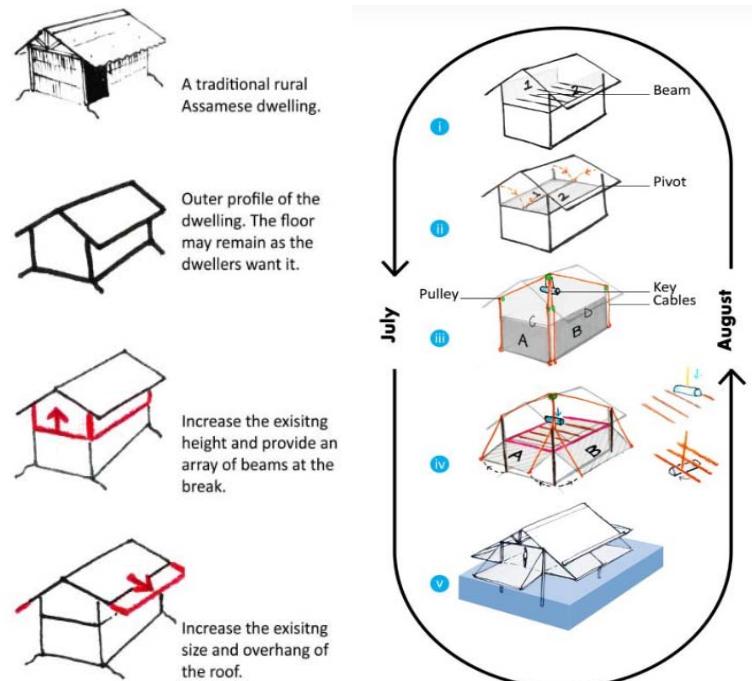


Figure 13: Tradition mud house and mishing house comparison

A ground-based mud house is the real Assamese traditional house. They do not like to live in stilt houses like the Mishing do, because they think it will not be comfortable and

convenient. According to them cleanliness, hygiene and good sanitation practices cannot be ensured in this style of living. For conservation people, it is virtually useful to follow the Mishing way of living as illustrated in figure 12.

The figure can be interpreted as follows:

- (i) Beams run along the break of the extended wall which works as storage for the year.
- (ii) Before the onset of monsoon, upper walls 1 and 2 swing along the pivot on the beams to make a floor on upper level.
- (iii) A system of pulleys connects to the sidewalls which are attached to 1 key counterweight.
- (iv) On pulling the key down, the existing walls rise up and transform into floors for the upper level.
- (v) Raising up the walls into floors allows.

Figure 14 shows how free passage of flood waters through the building during monsoon. Decreasing the surface area exposure to floods also reduces damage risk and allows the settlement to continue above with least disturbance.

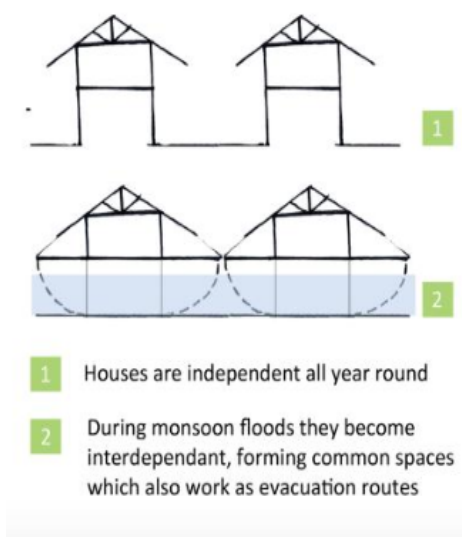


Figure 14: Mishing house all year around and during monsoon

8 Conclusion

The houses in Majuli are long, narrow and raised up on silts to reduce exposure to floods. A single house is inhabited by two families, which allows them mutual assistance during floods. The inhabitants make effective usage of the local materials as the houses are made entirely of bamboo and vegetable fibres. Jungle grass is used as roofing. They live close and in small clusters which indicates good social bonding. They keep materials to be shifted separately for quick evacuation during emergencies.

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INCOME GENERATION, FOOD SECURITY AND GROWTH IN LOCAL INDUSTRY – A NEW APPROACH FOR RURAL EMPOWERMENT

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Abstract: *Income generation is one of the fundamental requirements for developing rural community. However, identifying the means for income generation within the local context and getting the community participation in variety of activities is a challenging task. Without involvement of wider participation in income generation activities, no community can secure a sustained growth and become independent. While rural development policies especially among the socialist countries focus on subsidized intervention programs, the effectiveness of such programs for long term development of the community is limited. As part of the current research within the Smart Villages Lab (SVL) numerous ideas have been reviewed and tested for supporting sustained income generation in local context. Among many practices, in this research, one the key ideas around the concept "locally grown - locally consumed" is being put forward for empowering rural community focusing on Assam, one of the north eastern states in India. The land in Assam is generally fertile and most Assamese people have the habit of growing local produces in their backyards. However, often, home-grown fresh produces are not sufficient for meeting the daily needs of a family. At the same time, there is no any mechanism among the people for exchanging or liquidating the home grown produces against the other items they need within their households. An idea is postulated for supporting the small scale food growers to be able to sell their produces for cash and then buy the necessities for maintaining a balance of food flow among the local community*

Keywords: *Income, Rural Development, Industry, Smart Villages*

1 Introduction

One of the key practices in the developing economics is that government is almost the sole authority responsible for the well-being of the community. While majority of the available resources are consumed in the welfare activities, there is often limited funds being available for the development activities. As a results, the resources are spread thin across many pressing priorities (Abdurahman et al 2016)

As the rural communities in developing economies are mainly agrarian, the heart of the UN's sustainable development strategies is around the increased food security and hunger elimination in entirety (United Nations, 2015). With increase in global population and rapid reduction of agricultural land, the need for increasing productivity in agriculture with the limited land resources is the need of the hour. Agriculture being the sole activity around most rural community especially in the developing economies, income generation potential around the agriculture based activities is highly significant (Lyon et al 2017). Thus income generation coupling with the food security is one of the key enablers for ensuring growth in local economy and achieving sustainability in rural development (Allison et al 2015).

Anecdotally, free assistance given to people for meeting their daily needs makes people complacent and demotivate for working hard. Free entitlements make people lazy and often diminish the understanding of the value being created by any public interventions (Banerjee et al 2015a, 2015b). The government policies that attach with the public funds for providing direct support to rural community in terms of meeting the personal needs do not go very far and often, due to large number of people at the recipient ends results in spreading the limited resources too thin. For instance, the review conducted on the government housing program being implemented in rural Assam revealed that one of the most expensive and ambitious programs "Housing for All" by the Government of India is failing to realise the true benefits being delivered in developing rural housing across the country.

The premise of this research is to conceptualise a model that entices the rural empowerment through income generation, food security and growth in local industry. To meet this objective, a new trading model has been developed as a proof-of-concept in a local context. The remainder of the paper discusses about the model and the underlying processes involved in rolling out including operations and growth.

2 A Localised Model

In order to promote self-motivation and self-sufficiency among the rural community, a Non-Government Organisation "Society for Unified Rural Empowerment (SURE)" has been established to facilitate a hybrid barter model focusing on a few rural locations in Assam. In this research, the author intends to discuss the model and highlight the operational modalities including pros and cons, sustenance for scalability and growth. One of the premises of the model is that every person within the community will be motivated to utilise the basic skills and resources for production of fresh produces, sell for cash and then support the households by meeting with the necessities. This will eventually support food security, entrepreneurship and prosperity in a localised manner (Chirenje 2017).

If successful, the model has the ability to revolutionise the local food industry and contribute rural empowerment significantly. Figure 1 demonstrates the some of the key functionalities of a rural trade center.

The functions are cash and barter provisions, wide community participations, growth and scalability, motivations, self-sufficiencies, independence and empowerment, interdependence, respect and sense of pride and health and well-being. The functions are discussed below:

2.1 Cash and barter provisions

In rural areas, often people are poor in cash. This is due to lack of opportunity in employment in the rural area. Thus, any idea that can potentially get the cash earnings among the rural community will be a game changer in the effort of rural empowerment. In the proposed trading model, the fresh produces from the villagers' backyards will be accepted for cash. Such a practice will encourage every member of the household to be involved in backyard farming (Pretty et al 2011). An alternative arrangement can also be put in place for anyone wishes to exchange a produce following a barter system, but as far as possible, this process may be discouraged for transparency and accountability purposes.

2.2 Wide community participations

With the proven idea of transforming backyard produces into liquid cash, the community at all levels is expected to be participating in micro-farming. Along with the households, public institutions such as local primary schools, local secondary schools and religious organisations will get attracted to participate in the farming within their premises (Battilana and Dorado 2010). The practice will not only provide cash support towards running the institutions but also train the school kids and elderly people for engaging in innovative farming and develop the useful skills for promoting sustainability within their local community.

2.3 Growth and scalability

Once the produces from micro-farming start giving the cash incentives to the villages especially the senior people usually poor in cash, there will be a natural tendency to put more effort for receiving higher yields. Crop diversification with the focus on rare and valuable fresh produces (such as lower GI values) may be possible to achieve with scalability with the limited cultivable lands within the household premises. Some people with experience in farms may even expand the farming to a commercial levels for supplying fresh produces in bulk which will eventually support in sustenance of the trading center within and beyond the local community.

2.4 Motivations, self-sufficiencies

Due to the virtue of the trading model being organic and community-centric, the community will be highly motivated to get involved in the micro-farming with innovations and enthusiasms. Once the members in the community realise the potential of fresh backyard produces being the cash cow, the motivation will grow across all sections of the community.

2.5 Independence and empowerment

The fact that any cash at an individual levels will provide the sense of self-sufficiency, the practice will break the mutual dependencies and promote independencies that will eventually contribute to the empowerment of rural community significantly. For the community to grow and develop in entirety, independencies and empowerment across all segment of the community is a fundamental requirement. For instance, the female community especially the house-wives in the rural villages are usually engaged in more

indoor activities (such as cooking, cleaning etc.) rather than outdoor activities (such as gardening, weeding etc.). One of the key inspirations of the proposed trading model being cash-able without much of an effort or demand on new resources, the female community will be particularly benefitted by being independent and empowered.

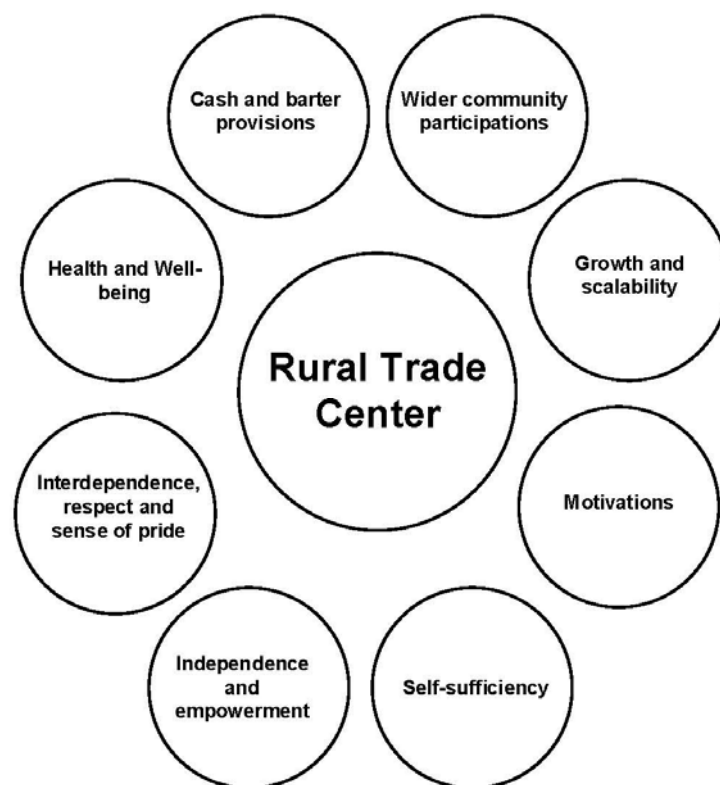


Figure 1: Functionalities of a rural trade center

2.6 Interdependence, respect and sense of pride

The model being a low cost and low maintenance, wider community engagement will promote local competition, sense of pride and mutual respect with high stimulus to growing bigger and better within a short period of time. The innovative micro-farming including sustainable harvesting and packaging practices could be portrayed for others to see, learn and general interests which will eventually attract tourists into the villages. Once the outsiders visit and start taking notice of community engagement in the local trading models, the ancillary services such as organic or home cooked restaurants, home stay etc. could develop as well. Overall, such a practice will have a significant potential for supporting community engagements and self-empowerment across the regions.

2.7 Health and well-being

The benefits of physical activities in community health and wellbeing is always a positive experience. The engagement of wider community in micro-farming at the household, villages and regional levels will result in good health in the community which will eventually bring positive social benefits by reducing community health-related costs.

3 Impacts and benefits

The impact of implementing the rural trading model with the ability for not only liquidating the local produces for cash but also positivity and involvement across a wider section of the community will be highly significant. Some of the key benefits of implementing this model are:

- Liquidation of home produces
- Promoting local economy
- Wider participations including women and children
- Physical exercise and wellbeing
- Appreciation of local effort, motivation and health-benefits
- Scientific farming and maximization of yields
- Organic farming
- Self-dependencies, reduction of wastes and maximize returns
- Scalability and expansion
- Multi-trading
- Promotion of circular economies
- One stop trading
- Micro-economy and tourism growth
- Local employments
- Rural empowerments and sustainability

4 Modalities and operations

In regard to implementing and running the model, there needs to be facilitating agency at the core of the operations. Figure 2 depicts the arrangement of the facilitating model with inward and outward transaction units. As seen, inward and outward transaction units need to be separated due to different functional requirements. Inward transaction unit is usually responsible for receiving the goods, ensuring the quality, packaging and daily quantity inflows in relation to the supply-demand balance. Outward transaction unit is responsible for stocking, selling and replenishments and catering the markets. Facilitating agency supports the back-end operations by ensuring smooth cash flow including disbursements for incoming and outgoing services.

The function of the facilitating agency includes a range of advisory issues such as logistical, finance, staffing, fieldworkers' management including trading and business operations. This facilitating agency will consists of local people with necessary skills and competencies to operate the center. Once the local trading center is reasonably successful in operation and management and reaches its service capacity, a new trading center may be opened by mentoring local people who should have interest, idea and passion to do so.

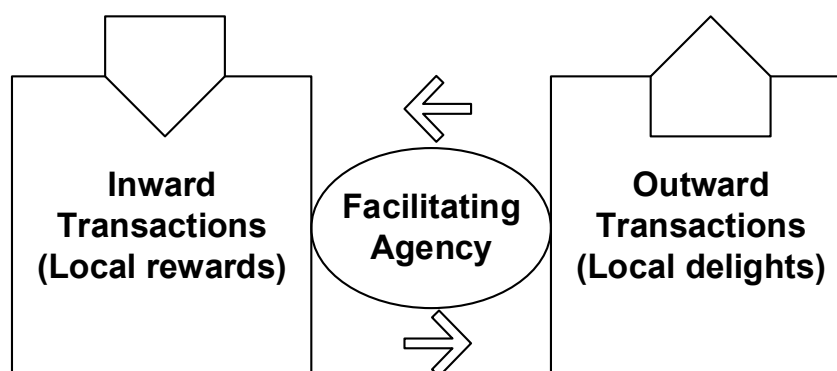


Figure 2: Facilitation of inward and outward transactions

5 Growth, Scalability and Sustenance

In order to operation a long term sustainable center, both growth and scalability is an important consideration in business operation. As seen in Figure 3, growth and sustenance in the current model is characterised by four key elements. The four elements are *operating capital*, *transactions and cash flow*, *capital growth* and *leverage and expansions*.

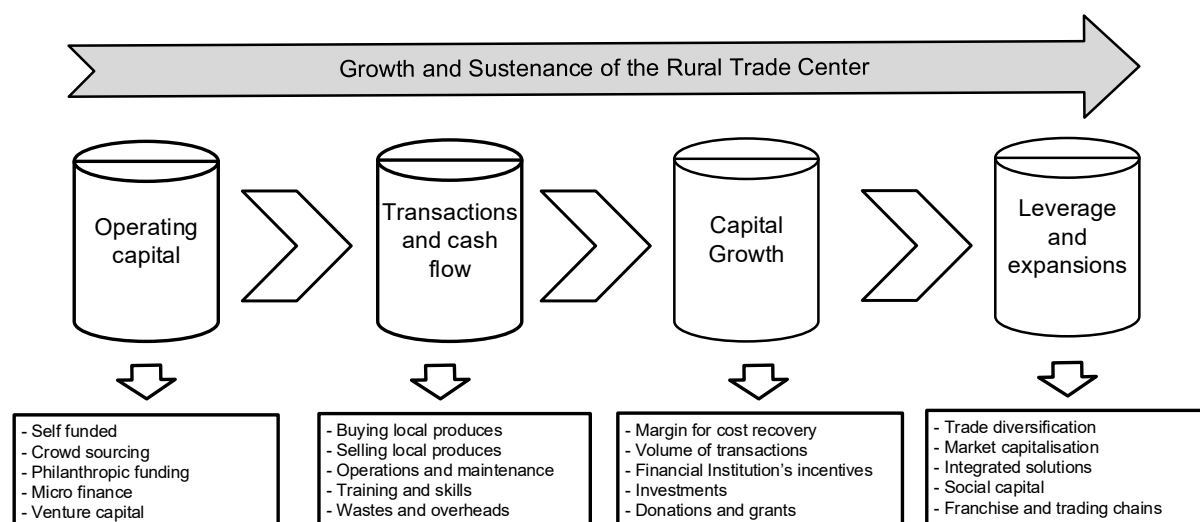


Figure 3: Growth model of the rural trade center

Operating capital is one of the key elements among the four. Operating capital comprises the capital raised through self-funded, crowd sourcing, philanthropic funding, micro-finance or even venture capital. For starting and operating a successful model, a decent sized operating capital will be required especially for transacting with the local suppliers and perhaps subsidizing the operation costs of the center at the early stage of business. The need for the physical space and facilities for a smooth running of the trading model, location of the site, accessibility including security will be some of the important considerations (Hermes et al 2011).

As far as possible, the land for setting up a trading center should be sourced from the community or government agencies. The land could be taken on a lease for a say minimum of 10 yrs. The built facility of the center should not be an expensive one but could be built using local materials and skills.

While the local materials in most places in rural Assam could be just bamboo, timber and mud, it is expected that brick, mortar, steel and concrete is used to build the structure till plinth level. Walls and cladding could be either made from bamboo, timber or light steel sheets (e.g. colorbond). The roof could be either steel or thatch. Internal shelving and boxes could be fit-out of bamboo or timber which should be locally sourced. The need for water, sanitation, energy should be locally sourced with basic facilities for operation.

Transaction and cash flows entail the processes of buying and selling local produces, ensuring cleanliness, sustainable packaging, hygiene requirements, storage and maintenance, training and skilling local volunteers, reduction of wastages and overheads.

Capital growth comprises the considerations of maintaining a reasonable margin between buy and sale. While the operational model of the rural trade center is not for profit, a small margin will be required to cover the overheads, wastage, supporting workers with minimum wages including running the facilities to a reasonable standard. It is expected that the lateral funding such as donations and grants will need to be accepted for a sustainable growth and operations. Any surplus money from operation of the center will need to be reinvested for sustained growth and expansions.

Leverage and expansion comprises the ideas around scalability, growth, diversification and capitalisation of trades, resources and skills from one location to the other locations. The leverage and expansion depends on how successful is the first operation and how the model is perceived by the community in long-run. The benefits need to be realised in wider community and time must be allowed to learn, rectify and stabilise the operations in the first trading center.

6 Empowering community and development

The idea of local trade center is all about empowering community and development and thus the effort needs to be closely monitored to ensure that the objectives are achieved in long run. Figure 4 depicts the processes in tracking and monitoring of the empowered community and ensuring steady operations and growth.

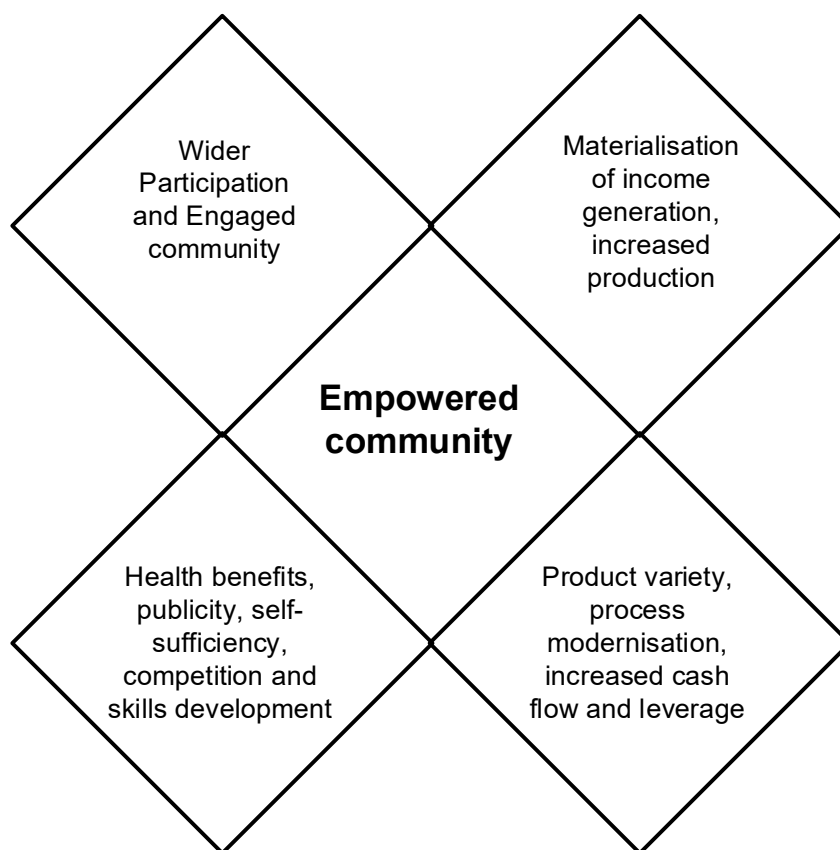


Figure 4: Tracking and monitoring of the empowered community and growth

As seen, the empowerment of the community is measured across four broad dimensions. These dimensions are a) *wider participation and engaged community*, b) *materialisation of income generation and increased production*, c) *product variety, process modernisation, increased cash flow and leverage* and d) *health benefits, publicity, self-sufficiency, competition and skills development*.

- a) Wider Participations and engaged community – Once the trading model is up and running, the wider community participation and pro-active engagement of the community at large will be one of the key indicators of the performance in the trading model. If the interests among all section of the population grow at a constant pace and the trading model becomes successful in both selling and buying measures, the model will result in positive experiences within an engagement community.
- b) Materialisation of income generation and increased production - Once the community sees the benefits of participating in localised trading culture and possibility of liquidation of the homegrown fresh produces through a cash transaction, the positive experience of engagement across all section of the population should be shared with wider community beyond the local jurisdiction (Orenstein and Shach-Pinsley 2017). As cash is considered as king, improved cash flow among the population especially the house wives and senior citizens commensurate their effort from home-based micro-farming will truly empower the community across all sections.
- c) Product variety, process modernisation, increased cash flow and leverage – While wider participation in the local trading is one of the key performance measures of community empowerment, innovations and continuous development is the next but

important level of performance in the process. Product diversification and process modernisation in the community-centric micro-farming is to be encouraged for adding value and leverage the success. Such effort will eventually result in increased cash flow and support rapid community empowerment.

- d) Health benefits, publicity, self-sufficiency, competition and skills development – The measure of success in the local trading model will not complete if the expected wellbeing including health benefits among the wider community is not realised in long run. Due the virtue of model being self-induced among the rural communities at the household level, skills and training required to maintain a healthy and sustained competition is developed organically. Due to the physical involvement of the community with practical farming activities at all levels, self-publicity and self-sufficiency will naturally be realised as the trading advances and process gets matured.

7 Conclusion

Income generation, food security and growth in local industry is considered to be one of the key requirements for rural empowerment. Focusing on the micro-farming concept, a new localised trading model has been conceptualised for facilitating wider participation of the rural community without any pre-requisite skills or capital. The local trading model is capable of generating concentration in farming activities across all section of the community and making aware of the self-sufficiency and independencies in their daily operations in lives (Nathan and Rosli 2014). The idea of receiving liquid cash for any fresh produces being produced organically at the backyard is considered to be one of the key acceptance criteria in the local trading model.

As Assam being the test-bed for current smart villages research, the concept "locally grown - locally consumed" is being put forward for empowering rural community focusing in one or two rural communities in Assam. Culturally, while Assamese people have the habit of growing local produces in their backyards, often, homegrown fresh produces are not sufficient for meeting the daily needs of a family. At the same time, selling or exchanging any surplus items for money or other goods are not considered appropriate in the societal setting. Though people are generally poor in rural community, the underlying cultural constraints not only prevents the community to explore new earning potentials but also reduces the opportunities for earning money using any non-traditional ways such as local trades. It is worthwhile to mention that traditional ways of earnings may include salaried or waged workers involved in any organised or unorganised sectors of employments.

With the introduction of the professional practice of selling and buying of local produces through the local trade center, the ideas for exploring new potential for earning money will be realised across all section of the community. Once the community sees the benefits of cash flow and self- sufficiency in their daily operations, the true empowerment will be realised. This will be one of the key steps in overall community development in the smart villages in rural Assam and other places.

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FLOOD AND EROSION INDUCED DISPLACEMENTS: DEPLOYMENT OF FLOOD RESILIENT HOUSING IN ASSAM

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Abstract: India has the highest level of internal displacements associated with disasters in South Asia in absolute terms and is consistently one of the countries with the highest level of disaster displacement, globally. A large percentage of the population in rural areas becomes homeless due to floods and erosion every year in Assam. By the end of the monsoon season in 2019 itself, as many as 2,000 houses have been destroyed and as many as 22,000 are damaged, hampering the return for many people. The 2018 Floods in the Tributaries of the Brahmaputra affected about 450,000 people in the state of Assam. According to the data available, over 3,000 houses belonging to individuals have been fully damaged and about 23,000 houses are partially damaged. The annually repeated occurrence of disaster by both flood and erosion has challenged the community's rebuilding effort, and their recovery process remains abysmally slow pushing the community back economically. The traditional houses built in timber and bamboo by the communities are found vulnerable to flood and erosion and require structural intervention to enhance their resilience against floods. Moreover, many traditional houses are being replaced with more vulnerable non-engineered and unconfined masonry houses. There has to be appropriate technology intervention to provide affordable, engineered and sustainable housing to reduce the vulnerability of the community. In this work, an attempt has been made to explore the possibility of adopting Light Gauge Steel (LGS) framed metal building structures with contextualization concerning the existing traditional housing and living practices. It has been found that, though various qualitative guidelines are available, no standard guidelines are presenting quantitative design data for the design and deployment of flood resilient houses in India. The various standard international guidelines are reviewed and referred and a prototype of a flood resilient house made of LGS, supported on reinforced concrete stilt foundation is presented.

Keywords: Flood, Erosion, Housing, Vulnerability, Light Gauge Steel

1.0 Introduction

Assam with its vast network of rivers is prone to natural disasters like floods and erosion which affect the overall development of the state. The Brahmaputra and Barak River with more than 50 numbers of tributaries feeding them, cause extreme flood devastation in the monsoon period each year. The flood-prone area of the state as assessed by the Rashtriya Barh Ayog (RBA) is about 3.1million Hectares against the total area of the state of 7.8 million Hectares i.e. about. 39.58 % of the total land area of Assam. This is about 9.40% of the total flood-prone area of the country. The flood-prone area of the country as a whole stands at about 10.2 % of the total area of the country, but the flood-prone area of Assam is 39.58 % of the area of the state. It signifies that the flood-prone area of Assam is four times the national mark of the flood-prone area of the country.

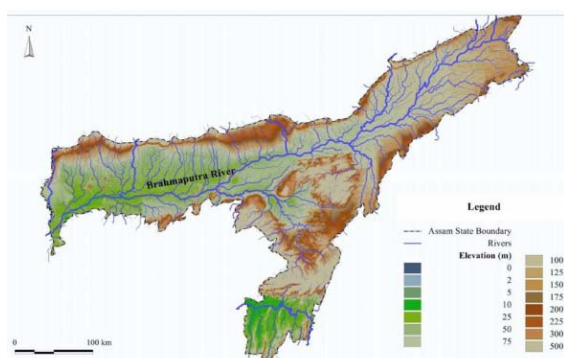


Fig 1.1(a): River Network in Assam - Assam State Disaster Management Plan, Govt. of Assam

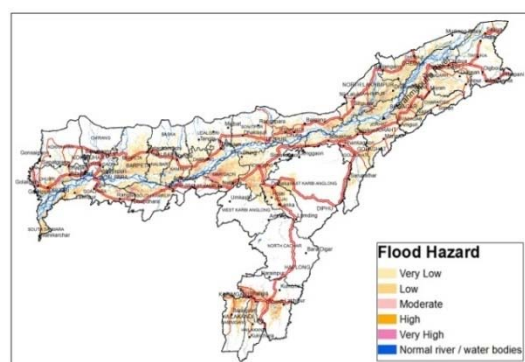


Fig. 1.1 (b): Flood hazard map of Assam 2016 - Assam State Disaster Management Authority, ISRO

The extensive river network in Assam covering the mighty Brahmaputra valley and Barak valley Basins (ADMA, 2013) is shown in Figure 1.1(a) and Figure 1.1(b) presents the updated flood hazard map released by the Assam State Disaster Management Authority with Indian Space Research Organisation. The major problem being faced by the state of Assam is bank erosion by the river Brahmaputra, Barak, and its tributaries. Bank erosion by the rivers has been a serious issue for the last six decades as more than 427000 Hectares of land was already eroded by the river Brahmaputra and its tributaries since 1950, which is 7.40 % of the area of the state. (WRD, 2019)

The annually repeated occurrence of disaster by both flood and erosion has challenged the community's rebuilding effort, and their recovery process remains abysmally slow pushing the community back economically. The situation requires structural intervention in terms of reducing the vulnerability of the community by providing safe and sustainable housing as internationally committed by the United Nations under the Sendai declaration framework - to which we are a signatory.

A attempt has been in this work to develop a prototype of a flood resilient house by replacing the traditionally constructed stilt house made of timber and bamboo in the flood plains of Assam by Light Steel Gauge (LGS) framed house, which would be sustainable against flood and would allow safe occupancy during flood or immediate occupancy after flood. The prototype should be affordable, culturally contextual and suitable for mass deployment and reduce internal displacements of people due to flood and erosion.

2.0 Damages and Economic Loss due to flood and Erosion

With the increase in population and developmental activities, there has been a tendency to occupy the floodplains, which has often resulted in serious flood damages to houses and loss of lives over the years. Because of the varying rainfall distribution, many a time, some areas, which are not traditionally prone to floods, also experience severe inundation. Flood disasters are among the most incapacitating problems faced by the country in general and Assam in particular (CWC, 2011).



Fig 2.1 (a) : Flood inundation in rural Assam
(source: Flood Report Assam)



Fig. 2.1 (b): Flood inundation and damage to houses in rural Assam
(source: Flood Report Assam)

According to data from the Central Water Commission (CWC, 2011), one-fifth of global flood-related deaths take place in India. In the 64 years from 1953 to 2017, damage to infrastructure and housing has been pegged at Rs 3, 65,860 Crores, which is 3 percent of the country's current Gross Domestic Product (GDP). The year 1977 saw the greatest loss of human lives due to floods with over 11,000 people dying. This is 10.5 percent of the total loss of lives in 64 years. The situation has not improved over the years and in this year itself the data from June 1 to July 16, 2019, show that in Assam, 34 people lost their lives and more than 5000 houses were either partly or fully damaged (ASDMA, 2019) as shown in Figure 2.1(a) and (b).

2.1 Internal Displacements due to Flood and Erosion

India has the highest level of displacement associated with disasters in South Asia in absolute terms and is consistently one of the countries with the highest level of disaster displacement, globally. In the first half of 2019, about 2,178,000 new displacements were recorded of which, 2,171,000 nos. of people were displaced by disasters and 6,800 were by conflict (IDMC, 2019). By the end of the monsoon season in 2019 itself, as many as 2,000 houses have been destroyed and as many as 22,000 houses have been damaged, hampering return causing displacements for many people (IDMC, 2019; ASDMA, 2019).

The 2018 Floods in the Tributaries of the Brahmaputra affected about 450000 people across the districts of Dhemaji, Barpeta, Lakhimpur, Biswanath, Majuli, and Dibrugarh in the state of Assam. According to the Assam State Disaster Management Authority (ASDMA), more than 3 million populations in 3186 villages in 25 districts of Assam were affected and over 3,000 houses belonging to individuals reportedly fully damaged apart from partially damaging about 23,000 houses in 29 districts (ASDMA, 2018). It is observed that, over the years, while, in other parts of the world, the internal displacements are caused by conflict, more people were displaced in this region by natural disasters like floods.

3.0 Flood Resilient and Flood resistant Housing- Design Methodology

The houses and other infrastructures in floodplain areas can be subjected to hydrostatic (standing water) and hydrodynamic (flowing water) pressures as well as impact loads during floods. These pressures can result in the displacement of foundation walls, collapsed structures, scouring around foundations and other damages. The flood resilient or resistant housing thus implies that structural and non-structural components of the houses be durable, resistant to flood forces (including buoyancy), and resistant to deterioration caused by inundation with floodwater.

Already numbers of flood resilient houses are developed and built in different parts of the world where damage to flood is severe and where flood occurs very frequently. Under the collaborative project of Assam Engineering College (AEC), India and the University of Melbourne (UoM), Australia, an attempt has been made to develop the prototype of an affordable flood resilient house that can be constructed in Assam. As the state of Assam is also prone to earthquake and wind, the flood resilient house is also designed for safety against earthquake and wind forces as per the Indian Standard Code of Practice. Figure 3.1 shows a traditional but non-engineered house on stilts made of bamboo in Majuli Island, Assam.



Fig 3.1: A Typical Flood Resilient House built in Majuli, Assam (Source: Google image; Alamy Stock Photo.)



Fig 3.2: Granaries on Raised Platform, Concept and Structural Design, Rural Volunteers Centre, Akajan, Dhemaji

Figure 3.2 shows a traditional house built on a raised reinforced concrete platform in Dhemaji in Upper Assam. Traditionally, people of the 'Mishing' community of Assam live in houses on stilts, these houses and the flight of 5-7 stairs leading to these houses have religious and social beliefs and practices attached to it. The house on stilts is a big hall with a central kitchen for a large joint family. The above two typical houses also represent the aspiration of affected people to have flood-resilient housing, of course without the much needed appropriate engineering interventions.

Although no one can completely stop or reduce a natural disaster like floods, the impact or damage caused by it can be reduced by reducing the vulnerability of the dwelling units in the flood-affected areas through appropriate engineering interventions. It should be noted that — flood resistance and — flood resilience are not mutually exclusive. Many flood resilience specifications will include flood resistance measures.

While in many countries around the world, where the dwelling units are largely on load-bearing masonry or timber structures, the primary measures adopted are to prevent

floodwater from entering the property. This is known as —flood resistance and is a practical flood protection measure for many properties. All parts of a building that are susceptible to flooding are made of materials that are capable of withstanding direct and prolonged contact with floodwaters without sustaining significant damage. The prolonged contact means at least 72 hours, and significant damage is any damage requiring more than cleaning or low-cost cosmetic repair such as painting. The need to replace flood-damaged drywall or other material is considered as significant damage and is thus not acceptable. Moreover, the components that are not inundated should be resistant to excessive humidity.

However, in Assam and other North Eastern States of India, the traditional structural measures primarily involve building houses on stilts or raised platform to avoid the direct onslaught of floodwater on the building components. The concern here is that, in some cases, the sub-structure supporting the stilt platform may not be able to cope with the pressures exerted by high levels of flooding.

3.1 Review of Existing Guidelines and Codes

Although India is a flood-prone country, no definite standard codes have been developed to date for designing a flood resilient house in India. The Govt. of India published guidelines for Below Poverty Line (BPL) houses in flood-prone alluvial areas (UNDP). The guidelines largely dealt with flood-resistant houses with the load-bearing masonry wall construction and drafted advisory about raised plinth height and general guidelines about making the masonry walls more durable and resistant to floodwater pressure and other related forces.

Building Materials & Technology Promotion Council (BMTPC), an apex body for the promotion of construction materials and processes, published guidelines for improving flood resistance of housing in 2010-11 (BMTPC, 2011). These guidelines provide design and construction details of small houses including recommendations for specifying appropriate clauses in the Building Bylaws. The design of a simple, economical and safe house for construction in flood-cum-earthquake prone areas is also presented with sufficient details for easy adoption by governments and people themselves. These measures aim at the prevention of flood from entering and impacting the habitations. The recommendations included flood forecasting, adoption, and enforcement of flood plain zoning. However, there is no program towards such flood zoning measures in the country as yet.

India's neighbour Bangladesh has developed a handbook with guidelines for improving the traditional housing and has also included traditional houses on stilt (ADPC, 2005).

However, all the above guidelines are qualitative and advisory and do not include any quantitative design parameters which are required in any design attempt. Hence, the current work relied on international codes and standards for developing the prototype of a flood resilient house in Assam. Few of the parameters as suggested in the FEMA guidelines (FEMA, 1993; FEMA, 2008) and ASCE guidelines (ASCE, 2014) are discussed briefly in the subsequent sections.

3.1.2 Review of Basic Design Parameters for Flood Resilient Houses

Although wind or earthquake loads can directly dictate the actual super and substructure design, the substructure is more affected by flood loads. The effects of flood load on buildings can be aggravated by storm-induced erosion and localized scour, and by long-term erosion. Erosion and scour lower the ground surface around foundation members

and can cause the loss of load-bearing capacity and resistance to lateral and uplift loads. Erosion and scour also increase flood depths and, therefore, increase depth-dependent flood loads (ASCE, 2005 & 2016).

3.1.2.1 Design Flood and Design Flood Elevation (DFE)

The design flood is defined by the American Society of Civil Engineers (ASCE, 2016) as the greater of the following two flood events:

- Base flood, affecting those areas identified as Special Flood Hazard Areas (SFHAs)
- The flood corresponding to the area designated as a flood hazard area on a community's
- Flood hazard map or otherwise legally designated.

The DFE is defined as the elevation of the design flood, including wave height and freeboard, relative to the datum specified on a community's flood hazard map.

3.1.2.2 Design Stillwater Flood Depth

Design still water flood depth is the vertical distance between the eroded ground elevation and the still water flood elevation associated with the design flood. Determining the maximum design still water flood depth over the life of a building is the single most important flood load calculation that is to be made; nearly all other coastal flood load parameters or calculations (e.g., hydrostatic load, design flood velocity, hydrodynamic load, design wave height, DFE, debris impact load, local scour depth) depend directly or indirectly on the design still water flood depth.

3.1.2.3 Design Flood Velocity

The direction and velocity of floodwaters can vary significantly throughout a flood event, approaching a site from one direction during the beginning of the flood event before shifting to another (or several directions). For design purposes, the Commentary of ASCE (ASCE, 2016) suggested a range of flood velocities factors that should be considered before selecting the upper- or lower-bound flood velocity for design include:

- Flood zone
- Topography and slope
- Distance from the source of flooding
- Proximity to other buildings or obstructions

3.1.2.4 Hydrostatic loads

Hydrostatic loads occur when standing or slowly moving water meets a building or building component. These loads can act laterally (pressure) or vertically (buoyancy). Lateral hydrostatic forces are generally not sufficient to cause deflection or displacement of a building or building component unless there is a substantial difference in water elevation on opposite sides of the building or component. Vertical hydrostatic forces viz. buoyant or flotation forces on a building can be of concern if the actual still water flood depth exceeds the Design Still Water flood depth. The buoyant force acting on an object must be resisted by the weight of the object and any other opposing force (e.g., anchorage forces) resisting flotation. In the case of a building, the live load on floors should not be counted on to resist buoyant forces.

3.1.2.5 Hydrodynamic Loads

The water flowing around a building (or a structural element or another object) imposes additional loads on the building. The loads (which are a function of flow velocity and structural geometry) include the frontal impact on the upstream face, drag along the sides and suction on the downstream side. One of the most difficult steps in quantifying loads imposed by moving water is determining the expected flood velocity.

3.1.2.6 Duration of Flood Impact

Uncertainty about the duration of impact (*the time from initial impact through the maximum deflection caused by the impact to the time the object leaves*) is the most likely cause of error in the calculation of debris impact loads. It is observed from laboratory tests that measured impact duration (*from initial impact to time of maximum force*) varied from 0.01 to 0.05 second. The recommended value is 0.03 seconds (ASCE, 2016).

3.1.2.7 Erosion and Localized Scour by Flowing Floodwater

Erosion may be defined as wearing away of the land surface by detachment and movement of soil and rock fragments, during a flood or storm or for years, through the action of wind, water, or other geological processes. The waves and currents during strong flood conditions are capable of creating turbulence around foundation elements and causing localized scour, and the moving floodwaters can cause generalized erosion (ASCE, 2005 & 2016).

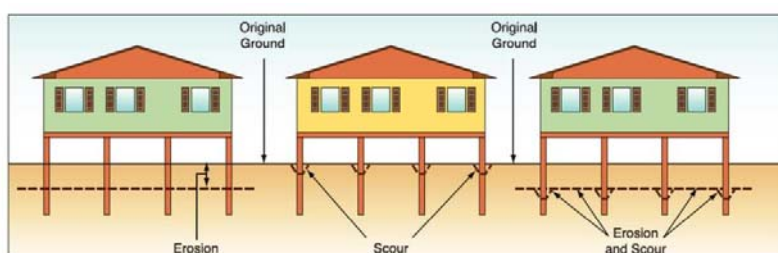


Fig 3.3: Distinguishing between erosion and scour. A building may be subject to either or both, depending on the building location, soil characteristics, and flood Conditions.

Determining the potential for localized scour and generalized erosion is critical in designing coastal or near river bank foundations to ensure that failure during and after flooding does not occur because of the loss in either bearing capacity or anchoring resistance around posts, piles, piers, columns, footings, or walls. Localized scour and generalized erosion determinations will require knowledge of the flood depth, flow conditions, soil characteristics, and foundation type.

3.1.2.8 Localized scour around vertical piles

Based on much of the evidence gathered suggests that the localized scour depths around piles and other thin vertical members are approximately equal to 1.0 to 1.5 times the pile diameter. The Federal Emergency Management Agency (FEMA, 2011) suggests that localized scour around a foundation element be calculated by the following equation: $S_{max} = 2.0a$; where S_{max} = Maximum localized scour depth (m); a = Diameter of a round foundation element or the maximum diagonal cross-section dimension for a rectangular element (m). Foundation systems should be analyzed for their ability to resist scour depths of 3 to 4 times pile diameters in addition to anticipated erosion levels. It is seen that a foot of erosion is more damaging than a foot of scour. While scour reduces pile/pier embedment and increases stresses within the pile, erosion reduces embedment, increases stresses, and, since it increases still water depths, it also increases the flood loads that the foundation must resist

4.0 Development of a Flood resilient Prototype for Assam

As part of the current collaborative research project between the University of Melbourne and Assam Engineering College, the development of solutions for a model flood resilient house was contemplated. The premise of the design was to incorporate all the ground realities for making the design not only affordable but also resilient against the natural

calamities such as floods, earthquakes, and wind in the context of Assam. Taking into consideration the ground realities in the flood-prone areas of Assam, a thorough investigation of the current developments in affordable housing was conducted internationally. Among many available ideas and solutions, the Light Gauge Steel (LGS) frame is considered to be one of the most feasible solutions in the context of Assam (Doloi, H. et al. 2017).

The LGS frame system for housing solutions provides a fully automated construction process which is easy to erect by unskilled workers. Due to lightweight rolled sheets of steel members being used in assembling the building frame, the workability in remote locations without any provisions of good infrastructure, transport and heavy lifting machinery, is quite easy. In the flood-prone areas, the frame can easily be installed on stilt foundations (Doloi, H. et. al. 2017).

While designing a house with an underlying consideration of fitness-for-purpose, the acceptability of the functionality and aesthetic appearance among the specific community is another important design consideration. Thus, any new design must be contextualized by incorporating community viewpoints. The use of local materials and workmanship in the building process are essential considerations for not only to bring the price down but also to maximize the opportunities for wider acceptance and adaptability of the final house form. Majuli, the flood-affected river island in Assam is a potential area for demonstrating the new design for experimental purpose, a field study was conducted by a five-member expert team in June 2017. Based on visual inspection of over four villages located in the South-East part of Majuli, sufficient information was gathered for understanding the traditional housing including functionality and size, use of materials, local skills and workmanships and numerous underlying issues associated with poor maintenance, health, hygiene, sanitation during and after flood events.

As regards to the design data for flood resilience, there are no Indian codes available with defined methodology and parameters for design. Therefore, the reference of international code is taken and the design parameters are adopted from internationally available guidelines, viz. Design Flood Elevation, Design Stillwater Depth, Design flood velocity. In this work floodwater approaching velocities of 0.9 m/s, 1m/s and 1.1 m/s are considered. The hydrostatic loads, erosion and localized scour, localized scour around vertical piles, etc. are considered for four different High Flood Levels (HFLs) viz. 2.5 m, 2.0 m, 1.5 m, and 1.0 m.

4.1 Light Gauge Steel (LGS) framed metal Building

Light Gauge Steel (LGS) Framed Structures is based on factory-made galvanized light gauge steel components and designed as per codal requirements, produced by cold forming method and assembled as panels at site forming structural steel framework of a building of varying sizes of wall and floor. Building Materials & Technology Promotion Council, India, identified and evaluated a few systems which can help in providing safe, strong and quality housing in a quick time. Light Gauge Steel (LGS) Framed Structures is one of the approved alternate construction technology for affordable mass housing in India (BMTPC, 2014).

The basic building elements of light gauge steel framing are cold-formed sections which can be prefabricated on-site using various methods of connection. LGS is already well established in residential construction in North America, Australia, and Japan and is gaining ground in India. LGS is typically ideal for one to three-story high buildings, especially in residential homes, apartments and commercial buildings. Due to its

flexibility, fast construction, and durability, this technology has great potential for countries like India. Apart from having the potential for mass housing, modular buildings can be used for long terms temporary or permanent structures such as schools and classroom, military and civil housing needs, post-disaster relief structures and industrial buildings. The advisable span for LGSF buildings should be 7.5 m. The sectional is manufactured using a Computer Numerical Control (CNC) machine has a production speed of 450-900 m/h with very high precision (BMTPC, 2014).

Steel framing is very innovative and permits infinite freedom in architectural and floor plan design. Moreover, it is possible to produce designs that are difficult to produce with other materials and at a lesser expenditure. Steel frames can perform well in a range of climate. They provide aesthetic appearances that do not change over time. Roofs do not sag over time even under heavy roofing such as concrete tiles and unlike timber frames; they do not settle and create openings. This helps to maintain proper thermal, dust and noise insulation.

The most important advantage of using a steel frame in an earthquake-prone region like Assam is that it is economically a very viable solution to seismically active areas. Light Gauge Steel Frames have significantly higher strength to weight ratio in comparison to timber and has stable material and geometric properties.

4.2 Development of Prototype LGS framed Building for Assam

Based on the understanding of traditional housing and living in rural areas of Assam, a representative housing design has been developed. The size of the experimental house and room layouts are as per the initial community consultation and visual understanding during the field study. The process makes uses of intelligent Computer-Aided Design (CAD) software which streamlines engineering, designing and detailing processes. This ensures a quick construction process while maintaining the desired strength and durability requirements. Following the design process, a high-speed roll former may be used for precision manufacturing of LGS sections. These sections will be then assembled into frames as per good for construction drawings with the help of common tools and local labour. This will make the entire process very cost-effective.

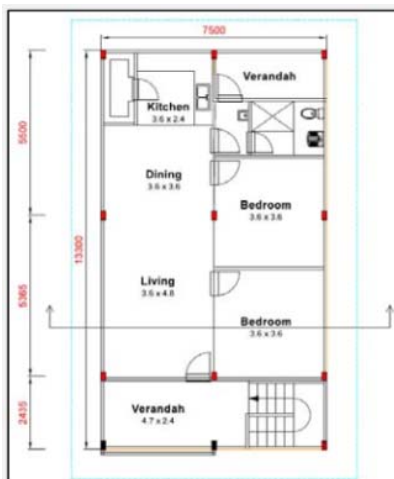


Figure 4.1: Floor Plan View of the prototype, Approximate floor area 100 square metre.

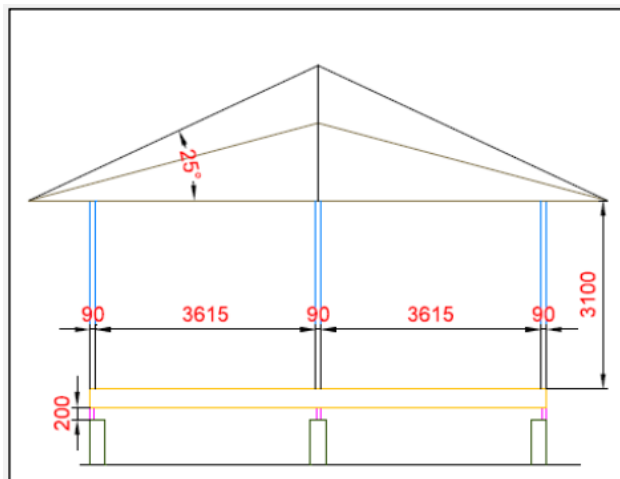


Figure 4.2: Cross-section view of the prototype, span within LGS span limit

4.2.1 The Form contextualization and Traditional Assam Type architecture

The various traditional construction practice and housing types prevailing today in different regions of the world have evolved based on technology transferred from one generation to the next by word of mouth or by some kind of documentation done by practicing masons and end-users. What is important is that these various construction schemes often have characteristics that address the prevalent local conditions of weather and other environmental and natural hazards viz. earthquakes, floods, and cyclones. The Assam Type Construction is one such construction practice that has the potential to emerge again as one of the most sustainable and safe housing forms. The Assam Type House is a Timber Building type and is most common throughout the Northeast India which lies in the most severe seismic zone of the country that is Zone V and corresponding to MSK IX (BIS, 2002, 2016). The British made this type of construction popular by preparing specifications and improving the construction technology during their occupation of India. The advantage of this lightweight, eco-friendly construction was well understood by the successive governments before and after independence and the practice was largely adopted for the construction of government offices and residences across these states. The Assam Public Works Department has specifications of this type of housing included in their schedule. In the rural areas, typically these houses are built with lightweight locally available material like bamboo, wooden planks, thatch, etc and generally termed as 'Thatch House'. The bamboo or seasoned wood has a natural resistance to decay, which makes these houses sustainable and low on maintenance. It was noted that the majority of houses survived the last two big earthquakes in 1897 and 1950.

An attempt has been made in this work to replace the timber panel framing with cold-formed section panel framing and the typical form the traditional rural housing has been maintained in design as shown in Figure 4.3 (a) - (c)



Figure 4.3 (a): CAD Model of LGS framing in Traditional Assam Type form



Figure 4.3 (b): CAD Model of LGS framing with the hipped roof as Traditional form



Figure 4.3 (c): CAD Model showing Diagonal brace for seismic resistance

4.2.2 Multi-Hazard Analysis and Design Simulation at AEC and UOM

As mentioned earlier, the proposed LGS Building has been designed for multi-hazard including Earthquakes and wind forces. The LGSS is designed based on the provision of the various Indian and British standards (BIS, 1975; BS, 1998; BS, 2000; BIS, 1987; BIS, 2002 & 2016).

The design Input parameters for Earthquake (Seismic) and Wind (Cyclonic) are considered as per the Indian Earthquake Code (BIS, 2002, 2016) and Indian Wind Code (BIS, 1987). The design input parameters for Flood were considered as per the FEMA and ASCE guidelines as discussed above.

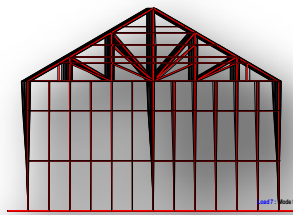


Figure 4.4 (a): Modal Dynamic Analysis for Earthquake in Global X-axis

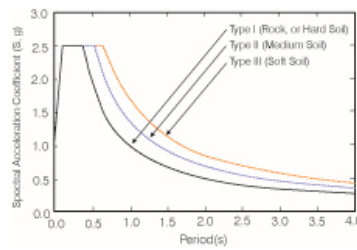


Figure 4.4 (b): Design Earthquake Spectra as per Indian Earthquake Code - soft soil condition considered

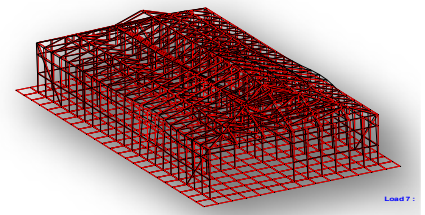


Figure 4.4 (c): Modal Dynamic Analysis for Earthquake in Global Z-axis

Building safety against maximum simulated earthquake and wind are analyzed as per Indian Standard. The maximum ground acceleration considered is 0.36g for MCE (Maximum Considered Earthquake) and 0.18g for DBE (Design Basis Earthquake). The spectral acceleration corresponding to the design earthquake and natural frequency of the building are adopted from the design spectra of the Indian earthquake code considering soft soil conditions to create a worst possible scenario in simulation (BIS, 2002).

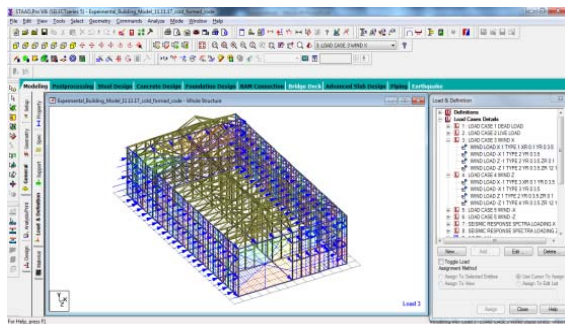


Figure 4.5 (a): CAD Model of LGS building analyzed for Wind in Global X-axis

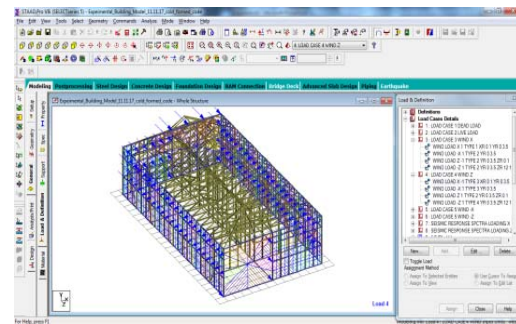


Figure 4.5 (b): CAD Model of LGS building analyzed for Wind Global Z-axis

The prototype is also checked for the prescribed wind forces and ideally, the wind force is calculated on the claddings/walls and the roof (both suction and normal pressure) based on the basic wind speed and finally derived design wind speed for the site under consideration. The Basic Wind speed considered in design is 50 m per sec or 180 km per hour and the building is considered to be in open terrain form maximum onslaught of design wind speed (BIS, 1987).

The model is analysed for a floodwater load as per the upper bound values of the parameters as discussed above. The floodwater entering the residential area will induce a lateral impact on the columns/piers/piles supporting the raised concrete platform of the structure. The highest flood level in any area is not a constant parameter and hence in this work, four different High Flood Levels (HFL) - 2.5m, 2m, 1.5m, and 1m have been adopted. As already mentioned, flood water generally induces two actions namely hydrostatic and hydrodynamic action. The hydrostatic forces are imparting a lateral force on to the columns/piers/piles while the effect of hydrodynamic loads will also govern the erosion and scouring depth. It has been generally observed that the flood water entering in any residential area has a velocity somewhat lower than river water. The water inundating the areas generally has a velocity of range 0.75 m/s to 1.2m/s. In this work, four values of floodwater velocity have been considered and they are 0.9m/s; 1.0 m/s

and 1.1 m/s. The hydrodynamic load like the hydrostatic load is also considered to act in two directions that are along Global X and Global Z direction.

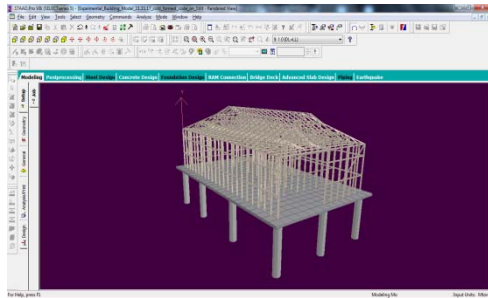


Figure 4.6 (a): CAD Model of LGS building on stilt for Flood load analysis

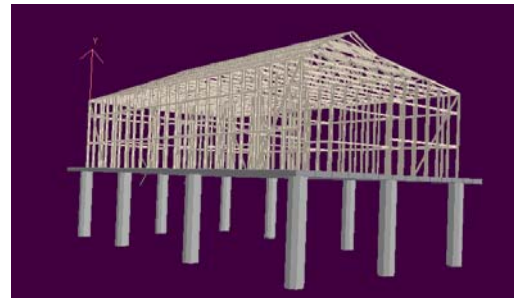


Figure 4.6 (b): CAD Model of LGS building on stilt for Flood load analysis

4.2.3 Foundation System Options Study

Amongst all the component of the building, the foundation system should be primarily resilient to floodwater load in terms of both hydrostatic and hydrodynamic loads to make the building resilient to flood as the building is proposed to be above the Design Flood Level (DFL), which is Basic Flood level added with the Freeboard. The Triodetic foundation system is a **Multi-Point Foundation (MPF)** support system shown in Figure 4.7 (a) & (b), which may be considered for buildings in areas with low DFL (<http://multipoint-foundations.com>).

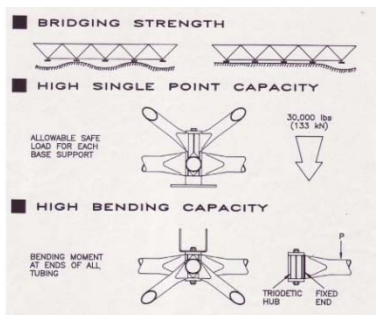


Figure 4.7 (a): MPF consists of a galvanized steel frame which is torsionally stable

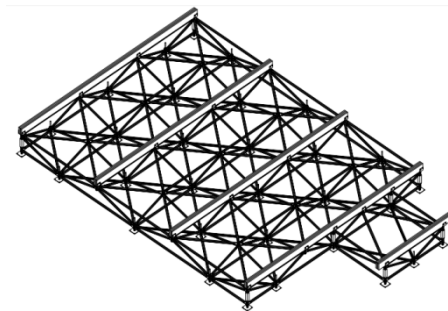


Figure 4.7 (b): MPF consists of a galvanized steel frame which is torsionally stable

Another ready to install foundation considered during the study was the Surefoot Footings, which is a concrete free alternative to screw piles (<http://www.surefootfooting.co.au>). This high strength, hybrid 'all-in-one' steel footings are specifically designed to resist gravity, uplift, shear and moment loads. The "Surefoot" is a concrete less footing solution that provides a speedy and cost-effective method for construction of foundation to support lighter structures like the LGS buildings. It consists of circular pipes of 2m lengths which can be driven up to the required depth without the need for excavation. The feasibility of this concrete free alternative for houses in a low DFL zone was examined in the field at the Burnley Campus of the University of Melbourne during the study. A Light Gauge Steel (LGS) frame along with an innovative footing system prototype had been built and tested at the Burnley Campus of the University of Melbourne. The whole process was coordinated with the industry partners Dynamic Steel Frame Melbourne (<http://dynamicsteelframe.com.au>), and Surefoot, Melbourne (<http://www.surefootfooting.co.au>). Figure 4.8 (a) shows the footing plate with 4 guide tubes on the corners of the plate at angles away from the centre and the Fig.

4.8(b) shows the installation without any mechanical assistance. Fig 4.9 (a) & (b) show the installation of Dynamic Frame on Sure foot footing.



Figure 4.8 (a): Footing plate with 4 guide tubes on the corners of the plate at angles away from the centre (SF150)



Figure 4.8 (b): "SureFoot" footing installation during the study project at Burnley Campus of the University of Melbourne



Figure 4.9 (a): Installation of "Dynamic Frame" during the study project at Burnley Campus of the University of Melbourne



Figure 4.9 (b): Installation of Prototype during the study project at Burnley Campus of the University of Melbourne

4.2.4 Contextualization and Costing

It is proposed to use locally available compressed bamboo panels as wall cladding and compressed wood panel or compressed bamboo panel over metal decking system of galvanized cold-formed section as shown in Figures below in figure 4.9 (a) to (d). These products are considered after due contextualization study to retain the traditional form and interior of the buildings. These products will add value and comfort and are highly moisture-resistant and durable.



Figure 4.10 (a): Galvanised cold-formed metal decking system for durability



Figure 4.10 (b): Locally available compressed wood panels for flooring

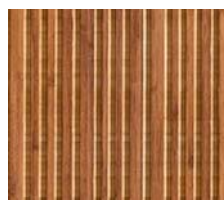


Figure 4.10 (c): Locally available compressed bamboo panels for wall claddings

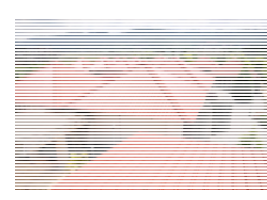


Figure 4.10 (d): Locally available coloured weather resistant Galvalume steel sheet roofing

After due diligence and considering the suitability of the LGS buildings on the raised reinforced concrete platform, the abstract cost of the prototype was evaluated and presented in Table 4.1.

Table 4.1: Abstract Cost of Multi-hazard safe 100 Squaremetre LGS building on RC Stilt in Assam

Description of Components	Cost in INR	Cost in AUS Dollar
LGFS Steel (3-3.25 M ton)	2,90,000.00	5800.00
Roofing	85,000.00	1700.00
Flooring	1,50,000.00	3000.00
Wall Cladding	2,25,000.00	4500.00
RCC work on foundation and Base (Stilt) for flood protection	2,45,000.00	4900.00
Services (@15% of Civil /structural Cost) (Electrical & Plumbing)	1,49,250.00	2985.00
Total Approximate Cost of the building	11,44,250.00	22885.00
Approximate Cost per sqm of built up area	11,442.50	228.85

5.0 Conclusions

- A large percentage of the population in rural areas becomes homeless due to floods and erosion every year in rural Assam.
- The annually repeated occurrence of disaster by both flood and erosion has challenged the community's rebuilding effort, and their recovery process remains abysmally slow pushing the community back economically.
- The traditional houses built in timber and bamboo by the communities are found vulnerable to flood and erosion and require structural intervention to enhance their resilience against floods. Moreover, many traditional houses are being replaced with more vulnerable non-engineered and unconfined masonry houses.
- An attempt has been made to explore the possibility of adopting Light Gauge Steel (LGS) framed metal building structures with contextualization concerning the existing traditional housing and living practices among the communities.
- The Light Gauge Steel (LGS) framed building on a stilt foundation is designed for multi-hazard viz. earthquake wind in addition to floods. The abstract cost estimate of the proposed building is presented to review the affordability of deployment.

Acknowledgments

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