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The potential and current status of earthen material for low-cost housing in rural India

Yask Kulshreshtha [a,*], Nelson.J.A. Mota [b], Kaup S. Jagadish [c], Jan Bredenoord [d], Philip J. Vardon [e], Mark C.M. van Loosdrecht [f], Henk M. Jonkers [g]

[a] Materials & Environment Section, Faculty of Civil Engineering and Geosciences, Delft University of Technology, the Netherlands
[b] Architecture Department, Faculty of Architecture and the Built Environment, Delft University of Technology, the Netherlands
[c] Department of Civil Engineering, Indian Institute of Science, Bangalore, India
[d] International Urban Planner/Housing Researcher, Amersfoort, the Netherlands
[e] Geo-Engineering Section, Faculty of Civil Engineering and Geosciences, Delft University of Technology, the Netherlands
[f] Environmental Biotechnology Section, Faculty of Applied Sciences, Delft University of Technology, the Netherlands
[g] Materials & Environment Section, Faculty of Civil Engineering and Geosciences, Delft University of Technology, the Netherlands

HIGHLIGHTS

- Survey conducted to understand factors favouring/limiting earthen construction in India.
- Low societal image of earth as building material is a key barrier towards its acceptance.
- Image of earth is strongly linked to poverty and intensive maintenance requirement.
- Compressed earthen technique (CSEB) has potential to improve image and acceptance for housing.
- Successful demonstration in diverse location needed to promote earthen construction.

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ABSTRACT

There is an enormous demand for rural housing in India that needs to be catered for within a short span of time. Building with earth (mud) is proposed as an economical and environmental friendly alternative due to the rising costs of conventional building materials. However, the construction of earthen houses has significantly declined in India and thus it is necessary to evaluate if they can make a valuable contribution to contemporary housing shortage. Therefore, an informal survey was conducted in India to understand factors favouring or limiting the construction and daily use of earthen houses. The outcome of the survey suggests that 'Image' is the key barrier against a wide acceptance of traditional earthen houses which are linked to poverty. While modern earthen construction is desired, it is expensive for low-income households. The role of earth in addressing the contemporary housing shortage is analysed and suggestions are given for the implementation of modern earthen technologies for low-cost affordable rural housing. Initiatives by middle-high income households, entrepreneurs and government can trigger a widespread interest in earthen construction. Successful demonstration of durable earthen structures at diverse locations and contexts can act as catalysts for change of the image of earth and make it a desirable material for low-cost housing in rural India.

1. Introduction

The World Bank has estimated a need for 300 million new housing units by 2030 to accommodate three billion people of the world [1]. There is high pressure on governments to cater for this enormous demand of housing. Housing is known to have a significant impact on economic development [2–5] thus, 80% of GDP (Gross Domestic Product)depends on 54% of world population that lives in the urban areas [6]). Therefore, urban housing projects, especially for slum upgrades, have been given significant attention by international organisations and media, while rural housing projects are comparatively neglected and given low importance. However, currently 46% of the world population lives in rural areas. This population is significantly higher in developing countries such as India, where about 67% of the population lives in rural areas [7].

* Corresponding author.
E-mail address: Y.Kulshreshtha@tudelft.nl (Y. Kulshreshtha).

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The rural economy in India constitutes 46% of the national income [8], which is significantly higher than in many other countries in the world. In the outcome of a survey carried out by the World Bank, providing better opportunities to low-income families in rural areas was considered important to achieving shared prosperity in India, and it has been prioritised over providing opportunity to low-income families in urban areas [9]. The government of India is actively working towards the provision of houses in rural areas under the scheme of 'Pradhan Mantri Awaas Yojana – Gramin (PMAY-G)'. To achieve PMAY-G's aims of housing for all by 2022, the government has identified (in 2016) a need for 29.5 million houses for low-income rural households by 2022 [10]. With 10 million claimed to be built so far (2018) [11], the implementation is far from the announced goal.

There is a need for an affordable solution to cater for this shortage of housing. Construction with conventional materials such as concrete or fired bricks is often considered plausible due to their wide availability and standardisation in use. However, the prices of these materials have risen significantly over the years and higher than the proportional rise in income [12]. To meet the demands of low income households, traditional and indigenous materials could be re-considered as interesting alternatives. Local construction materials and building practices that are tailored to rural lifestyles, topography, climate and resistance to natural calamities have the potential to offer solutions to the shortage of housing in rural India [13]. Traditional building materials are inexpensive, readily available and require minimal processing before use. Furthermore, the labour involved in the construction process is also sourced locally, often limited to the household, the extended family or members of the local community [14,15], thus saving on labour costs.

Earth or mud is one of such abundant resource that has been used as a construction material for over 9000 years [16]. Even today, one-third of world population is estimated to live in houses that are at least in part made of earth [17]. In developing countries, this number is estimated to be much higher. Earthen houses are considered environmental friendly and affordable as compared to houses built with concrete or fired clay bricks, for a multitude of reasons, for example earthen houses are known to improve the indoor air quality and thermal comfort [20], they consume minimal energy for material production [18] and the transportation costs are reduced due to local resource utilisation [19]. In recent years, the increasing price of building materials has resulted in revival of interest in earthen construction globally [21], which puts forwards an important question "Can earth be a solution to housing shortage in India?".

The aim of this study is to investigate the potential of earthen materials as a low-cost alternative for contemporary housing shortage in rural India. This proposition is evaluated based on a survey that was conducted to understand technical, socio-economical and other factors influencing construction with earth in India. The dominating factor(s) have been identified and discussed to point out the requirements for low-cost housing with earth in India. The research concludes with recommendations that can lead to better acceptance of earth for housing construction.

2. Earthen housing in India: past, present and future

The desire and access to modern building materials such as concrete and fired bricks have resulted in a decline in interest towards earthen construction in India. The changing trend of housing based on predominant materials of wall in rural and urban India is shown in Fig. 1. A significant decline in earthen houses in favour of burnt brick houses can be observed in past 40 years in rural India.

Until 1971, earth was the most widely used building material in rural India. However, the number of earthen houses in rural areas declined from 57% in 1971 to 28.2% in 2011. Mud or unburnt brick was the predominant material of wall construction in rural areas until 2001 when it was replaced by fired/burnt brick. In urban India, burnt brick is currently the most commonly used walling material whereas concrete is gaining popularity due to increase in construction of high-rise buildings.

Contrary to the popular perception that claims that Portland cement use is rising in India, the COI data does not directly reflect this trend (at least not as a predominant material for walling). The survey, however, does not show the data for secondary materials. For example, in brick construction, cement is the most used secondary material as a binder between bricks and as a material for plastering. Therefore, the popularity and availability of cement is one of the main causes for decline in earthen houses in India.

A decline in earthen houses indicates that the local and traditional materials and techniques have been unable to compete with industrial materials. In spite of low interest in earth as a building material, the potential of using earth as a construction material to build contemporary housing has been recognised by several studies and scholars. Organisations, such as Infrastructure Development Finance Company (IDFC) - Rural Development Network, have recommended the government of India to promote earth construction [13], and some authors argue that earthen houses are expected to make a comeback [26–29]. In addition, earthen houses are claimed to be up to 35% cheaper than concrete construction [26,28]. Moreover, the consumer price of cement is likely to

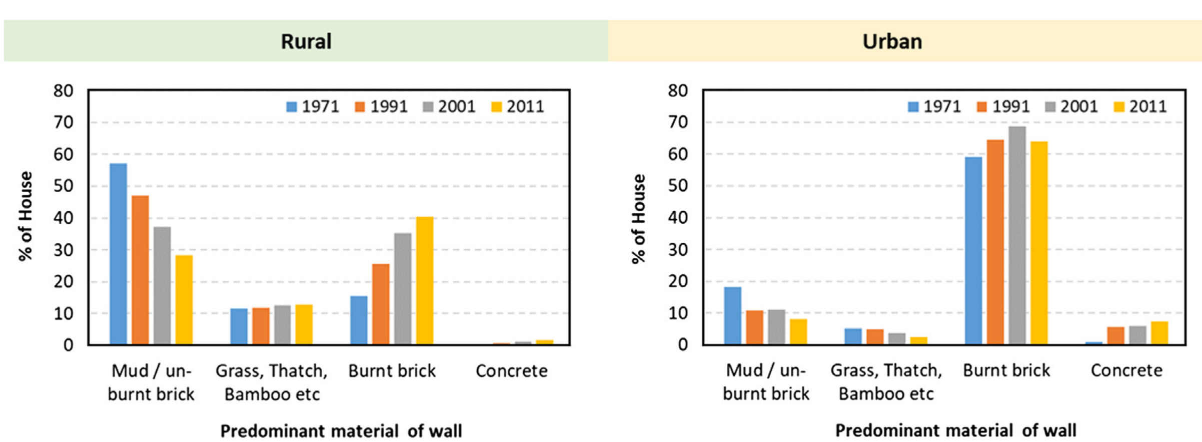

Fig. 1. The trend of housing based on predominant material of wall in rural and urban India. The data have been acquired from Census of India (COI) 1971 [22], COI 2001 [23] and COI 2011 [24]. Data for the year 1991 is obtained from the research of Ramancharla & Murty [25]. The data for year 1981 were not available.

increase due to the rise in price of petrol and therefore transport costs [30]. This can lead to financial difficulties in using cement for housing projects, especially in rural areas

3. Survey: methodology and scope

A survey was carried out in five different bioclimatic regions of India in order to understand factors favouring or limiting the construction and everyday use of earth houses. Forty informal and semi-structured interviews [31] were conducted by the first author in different locations of India as shown in Fig. 2, with further information presented in Appendix A. The scope of information provided by the interviewee was kept as broad as possible in an attempt to understand the emotions of each interviewee connected with the everyday use of an earth house. The adopted explorative research approach is close to the method suggested by O'Reilly [32] and in particular, similar to research work of Singh et al. [33] which was conducted in an rural Indian context.

Fig. 2. Map of India marked with interview locations. Information on bioclimatic, geographical and meteorological classification of the interview location can be found in Appendix A.

Informal talks and conversation can facilitate insight into sensitive topics [34] and are important to gain insight into people's needs and beliefs [35]. According to Narayanasamy [34] the informal talks should be complemented with observations. Visual remarks on state of housing and neighbourhood together with talks unrelated to housing were included in the discussion as tools for observation. Together with traditional earthen houses, earthen houses constructed in recent times were also considered in this research. The interviewee group consisted of people involved directly in earth construction. This included earth house dwellers with different socio-economic background, earth construction experts, architects, engineers, masons, contractors, consultants, educators and volunteers. More information on the survey group can be found in Appendix B.

The field survey was complemented by data analysis of notes, audio and video records. The data were compiled to form factors as shown in Fig. 3. These factors include motivation to construct an earthen house, performance of already existing structures, maintenance requirements, economy, image, influence of government and policies, and education and training.

4. Results: Factors affecting choice for and against construction and everyday use of earthen houses

An overview of major techniques and type of earthen construction in India is important for understanding the factors affecting choice. Earthen construction in India has a strong link to the climate, available local resources, soil type, traditions and heritage of a location. A short review of earthen construction techniques (with example of typical house construction) is presented in Table 1. Some earthen houses visited during the survey are shown in Fig. 4. The detailed information regarding earthen construction in India can be found in [36].

Two type of earthen houses were identified in the survey: 'traditional earthen houses' and 'modern earthen houses'. Traditional earthen houses are commonly found in most rural areas and adopted based on local conditions and cultural motives. These houses are often constructed with use of raw earth, with or without addition of natural fibre. Cob, adobe and, wattle and daub are examples of traditional earthen construction techniques (Fig. 4).

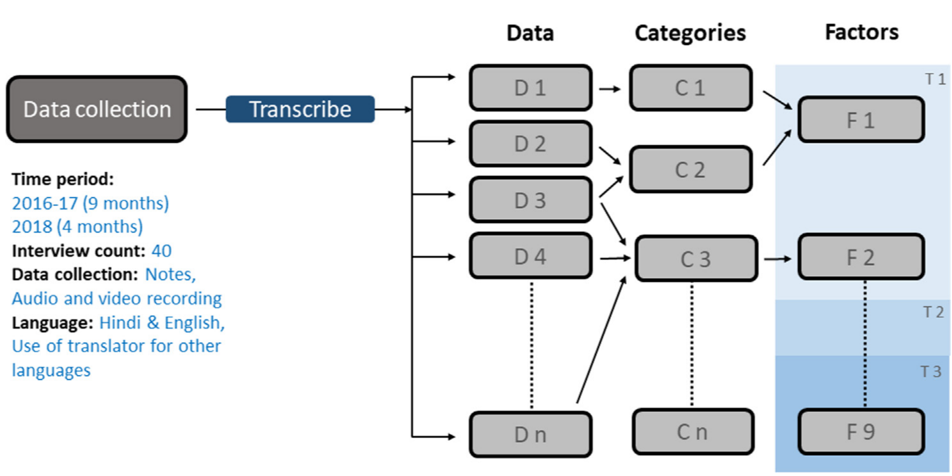

Fig. 3. Flowchart of data analysis of the survey. The data were transcribed and complied into categories that were combined to form factors. These factors were clustered together in specific themes.

Table 1
Information on few aspects of construction of a typical house visited during survey.

Construction technique	Bioclimatic region	Locations	Preparation of earth	Typical earthen house construction and materials	Note
Adobe(*rectangular blocks of mud/earth are cast in moulds and joined together with mud mortar)*	Cold and Cloudy	Bir and Dharmshala, Himachal Pradesh	Pine needles and rice husk was added to soil and mixed. Soil was kept undisturbed up to 3 days.Block cast in mould and dried in sun for 2 + days.	Foundation: Often with stones packed with mud mortar and first 75–90 cm raised (Fig. 4.a) Wall: Adobe blocks with mud mortar.Roof: Stone tile roof/ metal sheets supported by wooden beams / truss.	Special provision : Reinforcement rods used on the edges of wall for the protection against wind and earthquakes (new constructions). Use of fired bricks in toilet and bathroom (areas with use of water)
	Hot and Dry	Gandi na gam in Khavda, Gujarat and Kriparampur in Jaipur, Rajasthan	Soil was mixed with rice husk and cow dung. Blocks formed in a mould or were handmade.	Foundation: Often missingWall: Adobe blocks with mud mortar (often mixed with cow-dung). Roof: Thatch, asbestos sheet, metal sheet roofsupported by bamboo truss.	Stone bricks placed over metal roof to protect from wind. (Fig. 4. c)
Cob*(a thick monolithic wall raised from foundation)*	Composite/ Warm and Humid	Khunti, Jharkhandand Sundargarh, Odisha	Soil was mixed with water and left undisturbed overnight. Mixing of soil by stamping to form a uniform slurry. Soil moulded into balls that are easy to carry and pass.	Foundation: stones packed with mud mortarWall: raised layer by layer as a monolithic structure. Roof: *'Khapra'* Curved country fired tiles, asbestos sheet or thatch roof supported on bamboo, wood or metal tube.	Fired bricks placed over the asbestos sheet to protect the roof from wind. (Fig. 4.d)The walls are extended to make sitting platforms which serves as community spaces for cooking and get-together. (Fig. 4.e)
	Warm and humid	Tiruvannamalai and Sittlingi, Tamil Nadu			
Wattle and daub / 'Ikara'*(timber or bamboo frames with split bamboo weaves act as the structural wall members that are daubed with mud)*	Cold and Cloudy	Namchi, Sikkim	Soil was mixed with water and a slurry is formed. The slurry was left undisturbed for some time and later daubed on the bamboo or timber frame.	Foundation: Stone packed with mud/cement mortar and raised. Sometimes, concrete foundation is used in newly constructed traditional houses.Wall: Bamboo/wooden frames with split bamboo weaves and daubed with mud (Fig. 4.f, 4.g) Roof: Metal or Bamboo roof usually supported by metal tubes/bamboo.	The living unit and bathrooms have a plinth and floors made of concrete. Kitchen and bathroom separate from living area.
	Composite	Delhi			The foundation was missing in the houses in Delhi and roof were covered with plastic to protect against rain.
CSEB – Compressed stabilised earthen block*(blocks made by compressing the earth in a manual or hydraulic press)*	Cold and Cloudy	Namchi, Sikkim	Soil mixed with 8–10% cement or hydraulic lime and compacted in a manual press to make CSEB.	Foundation: RCC foundation, stone packed with cement mortarWall: CSEB bind together with cement mortar.Roof: CSEB or RCC roof, Metal roof supported on Wooden truss.	In some cases, columns and beams were made with Reinforced Cement Concrete RCC. (Fig. 4.i)
	Warm and humid	Auroville, Tiruvannamalai and Sittlingi, Tamil Nadu			

A modern earthen house uses contemporary construction techniques in combination with earth as a building material. CSEB (compressed stabilised earthen blocks), rammed earth construction' (soil is filled in formwork in layers and each layer is compacted with mechanical force to construct a monolithic structure) and poured earth (cement is mixed with soil and sufficient water or plasticiser so that earth is fluid enough to be poured into the formwork) are some examples of modern earthen techniques (Fig. 4). Modern earthen construction is usually labour intensive and use of inorganic binder such as cement and hydraulic lime is common. A comparison between these construction methods is shown in Table 2. Several of the comparisons are qualitative due to the nature of the research methods and are further explained in the sections below ().

The factors identified from the survey have been merged in the following 3 themes namely: Technical (based on facts related to earthen construction), Socio-economical (based on emotions that relates to economic status) and, Political and educational (based on policies and initiatives that are independent of households).

4.1. Technical

The technical aspects related to the performance of earthen construction such as environmental friendliness, better indoor climate and positive effects to health were widely acknowledged. However, the limitations such as poor resistance to external environmental forces (that result in frequent maintenance) and insect infestation were motivating factors behind the choice of conventional (industrialised) building materials.

4.1.1. Environmental and health benefits

Earthen houses were widely considered environmentally friendly due to local availability, minimum processing of raw material and, recycling and reuse. Limited transportation and simple processing techniques also make earth an economical and user-friendly material. Earth houses, especially those which are unstabilised, disintegrate in nature and can be re-used numerous times. Examples of traditional earthen houses built with materials of ancestral house were found in Bir and Khunti.

Earthen houses were reported to be good for health. The reason behind the positive effect on health were unclear but most dwellers attributed it to comfortable indoor climate and ability of soil to absorb pollutants. Conversely, issues such as cleanliness and problems with rodents were also acknowledged. For example, an interviewee mentioned that the mud flooring results in unhygienic conditions during the rainy season, i.e. when a person enters the house with wet feet, the whole house gets dirty and the floor becomes an active site for parasites which can be harmful for inhabitants.

4.1.2. Thermal performance

Earthen houses are known to regulate indoor temperature and humidity, thus providing comfortable indoor climate in all seasons. This was considered by far the most beneficial aspect of earthen houses. Although, widely acknowledged to be cool in summers,

Fig. 4. (a) Adobe structure in Bir built with attention to design and engineering [owned by an organisation], (b) Traditional earthen house 'Bhunga' in Khavda, (c) Adobe house with metal roof in Kriparampura, (d) Cob house with asbestos roof in Serjitkhel, Khunti, (e) Cob house with country fired curved tile in Tangerpalli, Sundargarh, (f) 'Ikara' house with metal roof in Namchi, (g) Under construction house in Delhi [split bamboo and grass visible on walls], (h) Earth bag house with thatch roof in Tiruvannamalai, (i) CSEB house in Namchi, (j) CSEB arch structure near Pondicherry [9.5 m span and 42 m length is 10 cm thick] , (k) Poured earth houses near Pondicherry and (l) rammed earth wall with country fired brick tiles and thatch roof in Tiruvannamalai.

Table 2
Comparison between Traditional and Modern earthen construction. The distinction is made based on the information collected in the survey.

Characteristics of earthen construction	Traditional earthen construction	Modern earthen construction
Life span	5–30 years (reported)	50 + years (estimated)
Construction	Non-engineered, foundation sometimes missing	Engineered, attention to details
Common construction technique	Cob, wattle & daub, adobe	CSEB, rammed earth, pored earth
Construction cost	Low	Medium to expensive
Type of labour	Self-help construction	Expensive and trained labour
Stabilisation	Some degree of physical stabilisation, biological stabilisation	Physical, mechanical and chemical/inorganic (cement and lime)
Weather resistance	Poor	Good
Termite resistance	Poor	Good
Compressive strength	Low (<3.5 MPa)	Medium (greater than3.5 MPa)
Maintenance requirement	Frequent	None to occasionally
'Re-use of soil' potential	High	Medium- low
Standardization	No	Some degree of standardisation

some earthen houses were reported to be colder in winters. A farmer in Khunti mentioned that the family prefers to stay in rooms constructed with earth during summer and in concrete rooms during winter. Although, the precise reason was not given, even after further questioning. In many cases, traditional earth houses were modified over time without full consideration and they lost the essential characteristics such as thermal behaviour and aesthetics of an earthen construction. Building elements such as roof was often replaced with modern materials such as metal or asbestos sheets. These materials have a high thermal conductivity and low thermal inertia resulting into excessive heat in summers and cold in winters.

4.1.3. Durability

The durability of traditional earthen houses was a major concern of all the interviewees. Most of the traditional earthen houses faced significant deterioration due to rain in past and required frequent re-plastering. Sometimes, construction without a foundation and inadequate protection against rainfall resulted in structural weakening of the earthen walls leading to their collapse (Fig. 5a). Several houses that were deteriorated by rainfall and flooding were abandoned (Fig. 5b). The performance of traditional earthen houses in case of flooding was considered poor. However, in some instances such as in Namchi (thin and light weight walls) and Bhuj (cylindrical wall geometry), the houses were found to be earthquake resistant.

One of the most commonly identified limitations of traditional earth houses was termite infestation. This problem was more prevalent in the houses which were not continuously functional for many years. This was attributed to change in method of cooking over the years, i.e. the traditional method of cooking in 'Chulas' (wood/coal fired stoves) resulted in smoke that worked as termite repellent whereas the modern gas or electric cooking does not emit smoke. The building and material techniques have not been upgraded to accommodate changes in lifestyle.

In modern earthen structures, good design, addition of inorganic stabiliser and adequate engineering measures results in a durable structure. These structures do not require frequent maintenance (re-plastering). However, the problem of weathering of CSEB (due to lack of proper curing and poor understanding of soil stabilisation), and flaking on the wall (due to rise in water from foundation in absence of impervious lining) and cracking on the exterior surface in cold climate (due to improper curing of CSEB) were also acknowledged.

4.1.4. Maintenance requirement

Traditional earthen house requires frequent re-plastering whereas modern earthen houses were reported to be low maintenance. Weekly plastering of floor and biannual plastering of walls in a traditional earthen house was a common practice which was reported to have declined possibly due to the influence of modern materials that do not require frequent plastering. A dweller in Khavda reported to use plastic sheets during rain to prevent re-plastering of walls. The roofs of traditional houses need to be replaced in 5–15 years, depending on the material used for roofing. Although the maintenance (repair and plastering) of traditional earthen houses is simple and economic, several dwellers reported the need for frequent maintenance took a significant amount of time which made earth construction undesirable.

4.1.5. Construction cost

The cost of construction of a typical earthen house depends on the price of stabilisers, transportation requirements, labour availability (if required) and involvement of engineers and designers. Traditional earthen houses are often self-help structures (structures built by the dweller with the assistance of neighbours and family members), using local soil and stabilisers, thereby reducing the cost of construction. In some households, such as in Khunti, the dwellers re-used the wooden frames and roof of an abandoned earthen house, resulting in no monetary investment in the house construction. A cob house construction in their neighbourhood in 2016 was built with an investment of □630/m^2 (~ €8/m^2). The wattle and daub houses in Delhi were reported to be built for □1000-2000/m^2 (~ €12.5-€25/m^2) with major expenditure being the cost of timber and labour for timber construction. The quality of construction of these inexpensive houses was observed to be poor with an estimated lifespan of 10–20 years. The low-cost of traditional earthen houses is a determining factor for many dwellers for choosing earth as a building material. However, they are in general perceived to be inferior in quality as compared to conventional or 'Pucca' houses.

Contrary to the traditional houses, modern earthen houses were reported to be expensive and comparable to the cost of concrete and fired brick houses. The cost of a modern earthen construction such as CSEB (the most prevalent modern construction technique in India) depends on the cost of earthen blocks, which are affected by the labour costs, quantity and price of stabiliser used. In most places, the difference in cost of fired brick and CSEB is marginal whereas the volume(size) of CSEB is up to 2.5 times (of fired brick). In addition, there is no need to plaster well finished CSEB walls which results in 10–15% cost saving in comparison with conventional construction (which typically use lower quality burnt bricks which must be plastered). It was mentioned by an architect that the running (life cycle) cost of an earthen house is lower than concrete and fired brick houses (over the lifespan) due to decrease in energy required for cooling/heating the building. In some instances, it was observed that the sale price of modern earthen houses was significantly higher due to high commission charged by engineers and architects involved in its (bespoke) construction, use of lavish finishing and interest from high-income communities.

Some architects and dwellers reported carrying out a cost analysis before deciding on material for construction. A lime stabilised earthen house was constructed with the investment of □9000/m^2 (~€112/m^2) which was calculated to be cheaper than construction with concrete and fired brick. Conversely, the cost of a rammed earth house in Sikkim was calculated to be twice that of a reinforced cement concrete (RCC) house and therefore, the owner decided to build with RCC.

The cost of earthen construction varies significantly based on location, availability of material and labour, and a proper investigation is required to decide if earthen construction is an economical

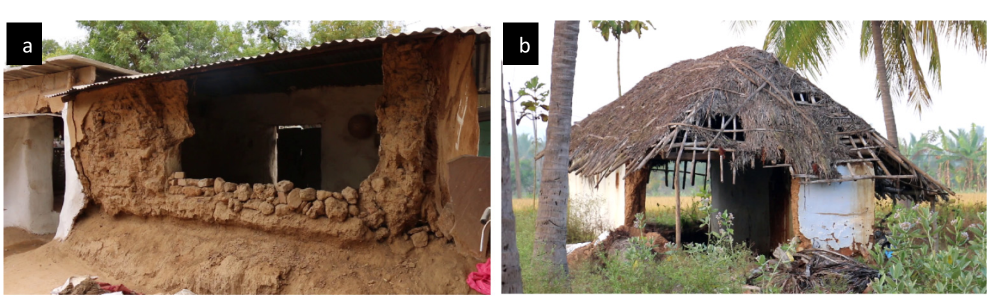

Fig. 5. Failure of structure due to the action of rain. (a) A collapsed adobe wal in Kriparampura, Jaipur that failed due to rainfall irrespective of being located in hot and dry climate and (b) an abandoned cob house in Sittlingi, Tamil Nadu.

option. The cost information reported by the dwellers, especially the ones living in traditional earthen houses, is anecdotal and in most cases, a crude estimation that the dweller could recall during the interview. Thus, there are concerns over the reliability of these figures. Collection of reliable cost information is a practical challenge and should always be considered while evaluating the impact of construction cost on decline of earthen houses. In the houses built in recent times (modern earthen houses) which are often built with the involvement of architects and engineers, the cost figures are much more reliable.

4.2. Socio-economic

The socio-economic factors such as motivation for building and image of an earthen house play an important role towards acceptability and use of earthen construction. Socio-economic factors are considered as the guiding factors that affects the potential of earthen construction in future.

4.2.1. Motivation for building earthen houses

The motivation to build earth structures has been observed to correlate with the economic situation of households. A low-income household may choose to make an earthen house due to economic reasons, whereas middle and high-income households may prefer to build earthen house due to their consciousness towards the environment.

A significant number of low-income interviewees responded that they are forced by their economic situation to live in earthen houses. A family dwelling in a poorly-built earthen house mentioned that the need for frequent maintenance and termite issues were demotivating factor in their interest in earthen houses. Contrary to the common view point against building with earth, a few low-income households reported to prefer earthen houses due to the indoor comfort and belief in its medicinal properties. A mason from Bir mentioned that earthen construction was preferred in the mountainous area due to higher costs of cement and fired brick. Fired bricks and Portland cement can cost up to 5 and 2 times (than in plain areas), respectively, because of higher transportation costs.

Contrary to low-income families, people with good income, good education and high societal status who were aware of the benefits of earthen construction were interested in earthen houses due to its low ecological footprint and good aesthetics. The availability of skilled labour, professionals and infrastructure for earthen block production were recognised as important parameters for choosing modern earthen construction over conventional fired brick construction. In fact, in Bangalore, the availability of infrastructure for earthen construction has resulted in construction of over 20,000 CSEB houses in past 3 decades. Although desirable, the economic aspects may also sometimes restrict people (that are aware of earthen construction) from constructing modern earthen houses.

Irrespective of economic and social status of households, several people reported that their decision to build with earth was influenced by successful examples of earthen houses in their neighbourhood. A rural family in Khunti mentioned that they noticed a similar roof construction in a nearby house and thus opted to replicate it in their new cob house. Whereas, a modern CSEB house dweller in Namchi was influenced by a CSEB house built by their relatives in the same region.

4.2.2. Image

Earthen construction in India and perhaps, in most of the developing countries suffers from a low societal image. A Pondicherry based architect elucidated the issue, "*Village people don't want a house which looks like a village house. They want something which urban people aspire for. It may be eco-friendly, or good for the climate or may be good for your health, but status and associations that people have with a concrete house is something which you can't change easily*" (transcribed from video recording). An architect from Gangtok mentioned that the powerful families which migrated to Sikkim started building their houses with RCC (reinforced cement concrete) which was perceived maintenance free and much more durable. RCC gave an opportunity to build taller in cities which was a definitive choice due to increase in land prices. Over time, "*RCC became a status symbol in Sikkim and people aspire for it*". The architect added that the banks don't consider a 'Katcha' or temporary house such as earthen house as collateral or asset and hence one may face significant issues in getting a loan based on it.

People from the tribal community of Sundargarh shared their views: "*Nowadays it has become all about the money in the world. Today we are in an independent India. The mud house days are gone. Before we used to use lungi (traditional pants) and now we use jeans pants. Likewise, slowly people are learning and getting educated and therefore they decided to move to a brick house. When we started earning some more money, we wanted to go for a proper concrete roof. Whoever has a bicycle, they think that their life will be better with a motorbike. We see changing from a mud house to concrete building as a positive change. We do it mostly to show to others that we are also modernising. We do not want to be left behind. When people see this place changing then they will get a good impression of the people who live here. The mud houses stay strong for 30 years but the brick houses will stay strong for more than 90 years. Hence, we have accepted change and have moved on to brick and concrete houses*" (translated from Oriya and transcribed from recording).

Considering the observations gathered during the survey, image is the most important factor that influences the choice of building materials. However, as the statements reproduced above confirm, for low-income households in the rural area the image of earth construction is low and associated with something that is outdated. They aspire for a house similar to the one they imagine urban people have. Although, the traditional building materials and techniques are cheap, people prefer conventional building materials despite the higher cost. This results into improper and unfinished construction that leads to disinvestment. The majority of people living in urban areas also have a low image of traditional earthen construction. However, modern earthen construction is desirable and accepted by people with a self-conscious interest in living a sustainable lifestyle. The number of such people is still limited but expected to rise. These people tend to have an educational background above the average and consider cement and other industrialised material as a major cause of pollution and find it highly undesirable. Actually, for this particular social group, the contribution of earthen construction in local economy and its natural aesthetics were the key reasons for the acceptability of earthen construction. A detailed log of perception of earth by an educated and environmentally-conscious owner of stabilised cob house can be found in the article by Kulshreshtha et al. [36].

In summary, the acceptability of traditional earthen construction is predominantly low in India. This is recognised as the main barrier towards the rise in earthen construction and its application as a low-cost housing technique.

4.3. Political and educational

The political and educational factors depends on the agenda of the government and independent initiatives (sometimes in collaboration with government) that can promote or decline the use of earthen materials.

4.3.1. Influence of government and lack of code

The government has a direct and indirect influence on the image and acceptability of earthen construction. The Census of

India (COI) developed by the Ministry of Home Affairs classifies building material as temporary or 'Katcha', semi-permanent or 'Semi-pucca' and permanent or 'Pucca' [23]. A permanent or 'Pucca' structure has walls and roof made up with materials such as cement, concrete, fired bricks, stone, iron, metal sheets, timber etc. Whereas, a temporary or 'Katcha' structure has walls and roof made up of mud (earth), unburnt bricks, bamboo, grass, leaves, reeds, thatch etc. Classifying earth and other traditional materials (that are locally sourced and produced) as 'Katcha' or temporary results in a bias against these materials. Government policies aim to convert all the temporary and semi-permanent houses to permanent or 'Pucca' [10], making materials such as concrete and fired bricks attractive, while 'Katcha' remains an undesirable material that is associated with poverty.

India's Ministry of Rural Development (MoRD) and the United Nations Development Programme (UNDP) have proposed over 130 affordable housing prototypes/designs based on the climatic conditions, disaster risk factors, locally available materials and traditional skills of different regions of India [37]. A majority of the proposed houses are built with local materials such as earth and bamboo. This proposal is, in fact, contradicting to the ambition of converting all the houses to 'Pucca' or permanent. Therefore, instead of choosing the proposed low-cost designs incorporating local material, people often prefer conventional materials that might be more expensive. This leads to an inferior quality of construction or incomplete construction.

The negative perception of government officers and their lack of trust in earthen materials results in lower approval rates of earthen construction projects. The transfer (relocation) of concerned government officers was reported to result in discontinuation or revision of earthen projects by multiple architects. However, in areas with successful examples of modern earthen construction, the acceptance and approval by government was higher.

The lack of official guidelines was also recognised as a barrier to construction with earth. Although, a building code on earthen construction, IS 1725, exists in India, not all architects and builders were aware of it. The building code is limited to CSEB construction with cement and lime stabilisation and does not cover other earthen construction techniques. On a contradicting note, lack of code was also reported to provide flexibility to innovate with earthen materials.

4.3.2. Education and training

The education and awareness of earthen construction is rising in India. Several institutes, organisations, and NGOs are advocating ecological construction with earth. Organisations such as Thannal (in Tiruvannamalai), Auroville Earth Institute (Auroville), Hunnershala (Bhuj), Dharmalaya (Bir) and Mrinmayee (Bangalore) were visited during the survey.

The common objective of all these organisations is to promote construction using local materials and provide consultancy and knowledge for safe construction with earth. These organisations are also responsible for providing training courses on earthen construction for people and professionals who are interested to and use the knowledge to build with earth. Mrinmayee and Auroville Earth institute are also involved in production of equipment (such as block making press) for construction of earthen houses.

Academic institutes such as the Indian institute of Science (IISc) in Bangalore have been active in research and development of earthen construction (since 1975 in the case of IISc) and have produced several scientific outputs related to it. The engineers trained in the Application of Science and Technology for Rural Areas centre (ASTRA) at IISc have contributed significantly to the dissemination of the CSEB technique. An independent educator from Jharkhand reported on their effort to teach the benefits of earthen construction to school children which resulted in shift towards positive perception of earthen buildings in the region. The educator emphasised that the importance of building with local materials should be inculcated at a smaller age.

5. Discussion

This survey into factors affecting construction and daily use of earthen houses demonstrates that the 'image' of an earthen house is a key factor that needs to be addressed in order to consider earth as a practical solution to the contemporary housing shortage. The following section addresses this factor and discusses necessary requirements for mass housing with earth in India. Firstly, the qualitative data collected from the survey is linked to the quantitative data in order to validate the findings. Thereafter, strategies for mass housing with earth in rural India discussed after drawing on the experiences in low-cost housing from Africa and other countries. Finally, steps towards the acceptability of earthen construction is proposed.

5.1. Linking image to economic development

Earthen materials are associated with poverty and widely considered as a material for the poor. Poverty is often linked to housing condition and therefore, housing materials may have direct or indirect impact on factors used for determining the poverty line. The poverty line in India is selected by individual states using the data of 'Socio Economic and Caste Census' survey which is conducted by the government of India. The data collected are then used to rank/score the households based on various deprivation indicators. The households with high deprivation score have a high probability to be included in the households below poverty line [38]. The indicator of deprivation related to housing type/condition is "Households with one or less rooms, Katcha walls and Katcha roof". Therefore, the houses made of 'Katcha' or temporary materials are an indicator of poverty. Earth/mud is one of the most widely used 'Katcha' material in India and thus, can be an indirect measure of poverty.

The correlation between the number of earthen households in surveyed states (based on 'Socio Economic and Caste Census' 2011 [38]) and the respective population below poverty line is presented in Fig. 6. The data of population below poverty line were collected from the Reserve Bank of India [39] for the year 2011–2012. The graph presented in Fig. 6 shows that a higher number of earthen houses correlates to a higher population below poverty line.

Fig. 6 seemingly confirms the traditional assumption that earthen houses are symbol of poverty. This assumption is not just

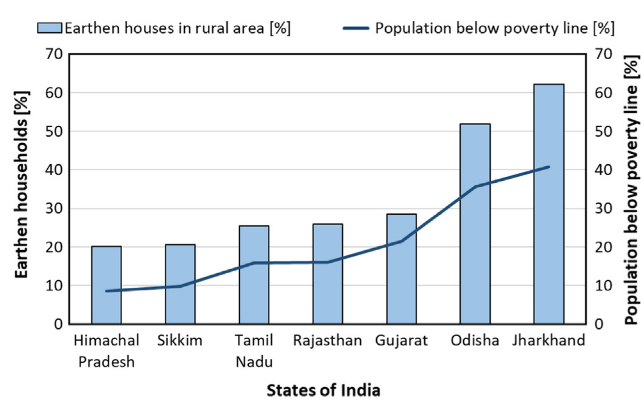

Fig. 6. Correlation between earthen households (based on predominant materials for wall) and population below poverty line for the surveyed states of India. The information related to surveyed locations and corresponding states can be found in Table 1.

a perception or anecdote but has statistical and quantitative root. Interestingly, rural people interviewed in Himalayan states (Himachal Pradesh and Sikkim) had an overall perception of earthen construction more positive than people interviewed in Odisha and Jharkand, the states with higher percentage of people living below poverty line.

5.2. Lesson from earthen construction in Africa and other countries

The use of earth as a building material is widespread, especially in developing countries. Surveys and case study analyses, similar to the one reported in this article, have been carried out in Zambia [40], Ghana [41], Algeria [21], Uganda [42] and other countries. All these studies have concluded that the traditional earthen construction lacks several aspects that hinder its promotion in contemporary construction practice.

Issues related to low social image of earth and link to poverty have been reported by several authors [40,43–45]. Issues such as erosion due to rain and other environmental forces [21,40,41,44,46,47], susceptibility to termite attack [44], low structural strength [21,40,41,47], short life span [40], frequent maintenance [41,46], and lack of standardization [44], have been reported to limit the construction of earthen houses. The experience of earthen construction elsewhere in the world resonates with the Indian scenario. Therefore, it can provide learning lessons that can be implemented locally in the Indian context. Moreover, the successful examples of low-cost earthen construction elsewhere can suggest the necessary strategies for construction of low-cost houses with earth in India.

Improvement in the material properties and access to infrastructure and knowledge is important for the promotion of earthen construction. In their study on structural aspects of earthen houses in Algeria, Baiche et al. [21] pointed out that the selection of appropriate soil and construction techniques, provision of training and implementation of suitable structural design and construction can lead to building safe and resilient earthen houses. Hashemi et al. [48] also recommended improving the quality and structural stability of earthen material in order to reduce the extent and frequency of maintenance required in houses proposed for low-income tropical housing in Uganda. Adegun & Adedeji [45] recommended the need of standardisation, availability of building codes, need for skill-training and opportunities to setup small-scale industries as the necessary steps towards acceptance of earthen construction. Additionally, Sameh [44] recommended educating and increasing awareness in youth, investment by government on earthen structures, incentives (such as tax reduction) for earthen construction and including earthen construction in curriculum of technical institutes. Zami [49]investigated the drivers that help adopting contemporary earthen construction and observed that the exposure of earthen construction through public media is important for wider acceptance of earth in low-cost urban housing.

While the technical recommendations for enhanced performance are important, the impact of government, entrepreneurs and education can be significantly higher. Although the government in some countries have shown interest in earthen construction (particularly in re-building after disaster), the initiatives by non-governmental organisations have played a key role in promoting earthen construction globally. For example, a social entrepreneur, named Hav Kongngy, in Cambodia has developed the 'My dream home' concept designed to provide quality housing with interlocking CSEB to those who cannot afford to buy conventional houses. These blocks are claimed to be up to 40% cheaper than conventional fired brick in this location [50] (note that due to transportation costs of conventional materials, this comparison is location dependent). In Nepal, the organization 'Build up Nepal' also uses interlocking CSEB for the construction of low-cost houses and schools that are able to withstand earthquakes. Their approach of community and entrepreneurship driven re-construction has promoted use of earth as a building material in Nepal [51]. In El Salvador, the NGO Fundasal has been working in the re-development of adobe blocks, improvement of its performance for application in contemporary construction and training building teams for construction of low-cost housing. In a social housing project in Bamako, Mali, LEVS architect (with partners) have constructed 280 homes from hydraulically compressed earth blocks (HCEB) that were manufactured with a mobile press and team of local workers [52]. A carefully prepared development plan, high level material performance and high quality of construction resulted in comfortable, attractive and desirable earthen houses. In Thailand, the use of interlocking CSEB or Interlocking Stabilized Soil Block (ISSB) was extensively promoted by Thailand Institute of Scientific and Technological Research (TISTR) for the past 35 years. Their efforts resulted in 665 ISSB manufacturing factories run by entrepreneurs spread across the country. These blocks were also offered online in 2017 with free delivery services and a house construction package, increasing the accessibility.

The construction of New Gourna village in Egypt is a classic example of rural mass housing with earth. Hassan Fathy, a renowned Egyptian architect, was commissioned in 1945 to construct housing for 7000 people who would relocate immediately from old Gourna and planned to be later expanded to 20 000 inhabitants. After the first three years, the project was stopped due to financial and political reasons, and people's resistance to be re-located, leaving the project only one third complete [53]. The design of the village was made incorporating ecological aspects, passive cooling techniques and community participation. A survey by World Monuments Fund [53] in 2010 found that the houses were incompatible with the current needs of the residents. In addition, they suffered from significant structural deterioration due to unpredicted rise in underground water flow which deteriorated the foundations and affected the structural integrity of the buildings. People mentioned that repairing earthen buildings is expensive and ineffective, therefore they have shifted to concrete buildings. Moreover, the housing project was designed for smaller families and the growth of families was not anticipated during the planning phase of the project.

The experience of New Gourna and other projects puts forward planning as an important aspect to consider while designing mass housing in rural areas. The change in ground water flow and modification of physical infrastructure can be harmful for earthen material thus, a proper foundation design with protective layers should always be incorporated. People should be included in the planning process and the structure should be designed considering the future growth of the family. Moreover, a community driven approach that involves local community and entrepreneurs is essential for the promotion of earthen construction. Understanding the socio-economical aspects, culture, values and aspiration of owners is necessary before introducing a new material in to a community [54].

5.3. Low-cost mass housing with earth in rural India

The shortage of rural housing in India in 2011 was estimated to be in order of 40 million houses [55]. With about 17.8 million houses claimed to have been built until 2018 [11], the need for housing remains a major concern in India. The housing shortage and the ambition of government prioritises the requirement of building millions of houses in a significantly short time span. Affordable or low-cost mass housing projects are one of the options that has the potential to overcome the housing shortage. Affordable mass housing focuses on construction of multiple units in a planned manner. While mass housing projects are common to cities where there is a constant inflow of migratory population, rural mass housing projects have been adopted only in special circumstances such as post-disaster housing (example multi-hazard resistant houses in Odisha and Bengal [56]), housing developments near overcrowded urban areas (Belapur housing in New Mumbai [57]) or forced relocation (example of New Gourna in Egypt). In order to develop a mass housing project, areas with inadequate housing need to be identified and a redevelopment plan of the entire village has to be made including re-designing, repair and retrofitting of existing infrastructure. The re-development should not only empower and generate income for locals through construction but also post construction. While construction of individual houses is possible in the selected area, low rise medium–high density mass housing can significantly reduce the total expense and reduce haphazard growth of a single or multiple villages located at a practical distance to each other.

As people have the tendency to modify their houses through time, many scholars suggest incremental housing strategies should be adopted by policymakers, planners and designers [58]. This provides residents an opportunity to extend their house based on their personal needs and growth. The availability of space in rural areas is an advantage for incremental housing. A sufficient distance is provided between the houses during the planning phase. Incremental housing was adopted in the Artists' Village, a mass housing project designed by one of India's most famous architects, Charles Correa and built in 1986. The Artists' Village was built in Belapur (New Mumbai) and includes 550 houses of different sizes (catering for different income groups) constructed in an area of 5.4 ha (54000 m2), and collective amenities such as recreational areas and educational facilities [57]. While the original houses were only one or two floors high, today many plots are occupied with houses with three floors, maximizing the potential of the plot to match the growth through time of the household, as well as the family's improved economic situation. In some cases, this transformation results from the expansion of the original houses (incremental growth), while in other cases is a complete new construction (redevelopment). To avoid the production of construction waste and reduce the embedded energy in the production of affordable housing, the design solutions and the construction materials and techniques should favour incremental growth rather than redevelopment.

The scalability of the adopted material and construction techniques is yet another key requirement of mass housing. Although, (traditional) earthen construction is often considered as non-standard, modern techniques such as CSEB is gaining popularity as a standard building material. The availability of CSEB making press at reduced rates and its increase usage in contemporary construction has made it cost-effective and desirable. In fact, it was reported that more than 600,000 blocks have been produced (with a hydraulic press) and sold in just 2 years by an entrepreneur in Tirthahally village, Karnataka. To ensure standard quality of blocks, a centralised production plant/unit for excavation and production of bricks is desirable. In the mass housing project of constructing 'Multi-hazard resistant houses' in Odisha (1450 housing units built in 2002) and West Bengal (200 housing units built in 2006) a central production unit was established in between two villages and pre-casting was adopted [56]. Prefabrication, as a tool for standardization, can be an important aspect of mass housing. The prefabricated elements should be light as to facilitate transportation from the production site to housing plot.

The construction of houses can be executed by house owners or artisans that are trained on site with the assistance of local building centres or local entrepreneurs. An assisted self-help can lead to better quality of construction [59]. Building centres can therefore play an important role in assisting the construction of houses by imparting knowledge and training to people. Nirmithi Kendra (Building Centre) in the state of Kerala, with over 15 centres spread across the state, has been successful in training artisans in low-cost construction techniques, producing and selling low-cost building materials, employment generation, housing guidance and counselling [60]. Inspired by their success, the Housing and Urban Development Corporation of India (HUDCO) reported the establishment of more than 500 building centres in the country and claimed to impart training to over 300,000 artisans on cost effective, environmental and energy efficient building techniques [61].

The finance required for the execution of rural mass housing project can be arranged through residents own funds or funds from government or external organisation. The government, under the scheme of Pradhan Mantri Awaas Yojana-Gramin (PMAY-G), gives a financial assistance for low-income households of ₹120,000 (~€1500) in plain areas and ₹130,000 (~€1625) in hill states to each eligible rural household for construction of a housing unit [10]. Additional funds and loans can be availed through complementary schemes leading to a total housing finance of up to ₹200,000 (~€2500) for construction of houses with a minimum required floor area of 25 m^2. It was reported that the people eligible under the scheme receive a total amount far less than promised due to corruption and malpractices. This amount was considered insufficient for construction of the desired housing unit by most interviewees. On a positive note, the manufacturing of CSEB bricks has been included by the national rural employment guarantee act (scheme), thus it can also provide employment opportunities for rural people [62].

The low-cost design for housing can be selected from over 130 affordable incremental housing prototypes/designs proposed by UNDP and Ministry of Rural development that are suggested can be built within an investment of ₹200,000 (₹2500-4000/m^2) [37]. Most of the proposed houses use locally available unstabilised and stabilised earth for the construction of walls. Use of modern earthen technique such as poured earth foundations and CSEB for walls can raise the cost. However, careful spatial planning of housing units and sharing facilities can lower the overall expenditure. Any mass housing project constructed with earth without full consideration to material properties, design, aesthetics and requirement of dwellers, will face rejection by the dwellers. In order to provide mass housing with earth, community participation, professionally trained labour and a superior quality of supervision is required. In addition, the material used in construction should match or exceed all the desirable requirements satisfied by conventional building materials otherwise the project won't be able to contribute towards acceptance of earth.

6. Recommendations: 'Catalysts of change'

In order to promote earthen construction especially for mass housing projects, these suggestions can play an important role in changing the image of earthen houses by acting as catalysts of change.

6.1. Improvement of material functional properties

The poor performance of earth during rainfall, weathering and erosion along with termite infestation are some of the material characteristics that need to be improved in order to increase its acceptability. Research is required into inexpensive stabilisers, perhaps stabilisers that can be sourced locally. Stabilisers derived from local biomass can provide exciting opportunities. In this regard, stabilisation with alkali activation, where the activator is derived from agricultural waste has potential for producing low-cost earthen blocks of good performance [65]. In locations where cement and hydraulic lime is inexpensive, they shall be used for the earthen construction or otherwise local, possibly bio-based, alternatives should be used, based on properties of locally available soil. Biological stabilisers such as cactus extract [66] and cow-dung [67] have been proven to improve water-resistance properties of earth and such stabilisers could be further explored.

Although the CSEB technique has a great potential to be applied for housing projects, scalability and adaptability of (more affordable) new construction techniques such as stabilised adobe (stabilised soil manually compacted in improved moulds) or poured earth for self-help construction could provide sound alternatives for CSEB. Research into design and architectural aspects on the different types of earthen houses can lead to bio-climatic designs that are affordable, optimal for specific locations and climate conditions and easy to build within the framework of assisted self-help construction.

6.2. Improvement of desirability

The presence of large number of earthen houses of good performance in multiple locations and contexts can lead to wider acceptance of earth. Two architects interviewed in the survey shared their viewpoints on the future of earthen construction. They believe its future is built upon the use of earthen materials by middle and upper income households. The desirability of concrete and brick is largely due to its widespread use by middle and high income classes. If middle and upper income families initiate building with earth, this can upgrade the perception of earthen construction from ‘Katcha’ to ‘Pucca’, contributing to make earthen construction an aspirational reference for low income families.

Also, the government can also play a pivotal role to turn the image of earthen construction. The classification of traditional material as ‘Katcha’ gives them a negative connotation. Revising the nomenclature can be the first step towards improving the image. A detailed code and guidelines for construction with stabilised and unstabilised earth that caters to local needs of different bio-climatic regions would enable requirements of local populations to be met. Moreover, if such a guide would include instruction for assisted self-help construction costs would be substantially reduced and trust would increase. Furthermore, entrepreneurs and researchers must also play a pivotal role. Researchers can provide insight into how earthen construction can be designed and optimized to local conditions such that the dwellers requirements are met equally to that using conventional construction (at lower costs without compromising the aesthetic value that modern earthen houses such as shown in Fig. 4 (i,j and k) can offer) and entrepreneurs must set up the commercial infrastructure required and promote earthen construction throughout the country. If the government can support these initiatives, it can lead to wider dissemination of modern earthen construction techniques. Only by doing all of these steps can the ‘building with mud’ revolution be implemented.

6.3. Education and need for demonstration

Educating the people on earthen construction technology is a vital step for its acceptance. In an investigation carried out in Uganda on the barriers to widespread adoption of ISSB technology (in relation to the rationale for building material selection) for low-cost urban housing, the author found that the earthen building, even though stabilised with cement, is perceived inferior, expensive and inappropriate use of cement [42]. The study suggested that educating the potential users on ISSB technology as sustainable and cost effective technology could improve its perception. Educating young architects and engineers about earthen construction by including it in the curriculum can also promote the dissemination of earthen construction. Inculcating the importance (and limitations to overcome) of traditional construction to children can change the perception from a young age. Education on earthen construction should be transparent and non-biased. An effective and comprehensive education can lead to successful demonstrations.

Demonstration of successful earthen house projects has the upmost impact on the perception of people and government. Rabie [63] demonstrated a wall of curved compressed stabilised earthen bricks to a group of rural families who had a negative perception of earth construction. This wall was readily accepted by them due to its aesthetic appeal and a demonstrated proof of its water resistance. On contrary, a failed demonstration in Bangalore lead to loss of trust and set back the growth of earthen construction in the region by several years [64]. The negative demonstration should be taken as an opportunity to identify the limiting aspects of earthen construction in order to re-invent earthen construction to suit contemporary requirements. Successful implementation of earthen techniques in large scale projects such as schools, museums and shopping centres can alter the image of earth as a building material and boost the confidence of people to use it in house construction. Design education is thus instrumental to empower a new generation of architects and planners and give them sound support to develop innovative design solutions for earthen construction.

7. Conclusions

Building with earth is widely considered ecological and economical. however, the low image of earth, in particular traditional earthen construction, is recognised as the key barrier towards its acceptance as a building material for low-income households. The image is strongly linked to poverty and it is significantly influenced by poor performance of traditional earth houses (in terms of poor water and weather resistance and termite infestation), frequent maintenance and, governmental policies and nomenclature that gives a negative reputation to earth.

The performance of modern earthen materials such as CSEB is comparable to conventional building materials, while its production is economical and sustainable. The CSEB technique is gaining popularity in India due to good quality of the finished product (which has an appearance similar to fired brick) and availability of low-cost CSEB making presses/machines. While modern earthen construction techniques are attracting environmentally conscious middle and high income families, earth is still a material less preferred than concrete and fired brick for the construction of houses in rural and urban areas. Earth as a building material triggers the image of a poor performing traditional house in people’s mind which results in a resistance to the rise of modern earth construction in India. Earthen construction might be a practical choice for many rural areas that are disconnected from building material supply-chain network. However unless it meets the desired specifications met by conventional materials in terms of durability, aesthetics and economy, it will not be adopted as a standard construction material.

While lifespan, resistance to external environmental forces, durability and structural related properties, of modern earthen construction are desirable, the economic, self-help construction potential and recyclability aspects of traditional earthen construction are valuable. A combination of the two construction types can result in structures that are economically, socially and ecologically sustainable. The high cost of modern (stabilised) earthen material can be reduced by minimising the use of cement and hydraulic lime in favour of bio-based alternatives. Assisted self-help construction can also reduce the cost of a building project significantly.

Modern earthen construction practices have a great potential to be used in low-cost housing in India. The availability of low-cost design options and access to building centres can provide necessary infrastructure for successful realisation of mass housing. However, earth may not be immediately applied to contemporary construction of mass housing due to lack of successful demonstration and trust of government and people. Demonstrations in diverse location and contexts can lead to wider dissemination of modern earthen techniques. The way forward is to build small-scale high quality structures where a significant attention to detail is given and the project should be implemented considering all the technical requirements and desires of the dweller. The PMAY-G programme offers a good opportunity to explore new applications for earthen construction.

The future of earthen construction rests on entrepreneurs, designers and researchers who can provide materials which have appropriate material properties, designs with minimal costs, the supply chain and manufacturing infrastructure, and training to result in a superior quality of construction. The research work on earthen construction should be based on the pillars of affordability, durability and most importantly, the desirability for a wider acceptance.

We declare that we have no affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

CRediT authorship contribution statement

Yask Kulshreshtha: Conceptualization, Methodology, Investigation, Writing - original draft, Visualization. **Nelson.J.A. Mota:** Conceptualization, Writing - review & editing, Supervision. **Kaup S. Jagadish:** Resources, Writing - review & editing. **Jan Bredenoord:** Resources, Writing - review & editing. **Philip J. Vardon:** Conceptualization, Writing - review & editing, Supervision. **Mark C.M. van Loosdrecht:** Writing - review & editing, Supervision. **Henk M. Jonkers:** Conceptualization, Writing - review & editing, Supervision.

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Appendix

Information on bioclimatic, geographical and meteorological classification of the interview location is presented in Table A1

Table A1
Bioclimatic, geographical and meteorological classification of the surveyed location. The number of census houses made up with mud/unburnt bricks as the predominant material of wall (based on Census 2011 [24]) is also listed.

Location	Indianstate	Geographical-Location	Elevation (m)	Bioclimatic-zone:*BIS classification (Köppen-Geiger)*	Ambient temperature	Relative humidity	Rainfall	No. of rural houses with mud wall (% of total houses)
Bir, Kangra district	Himachal Pradesh	North	1410–1620	Cold and Cloudy (Humid subtropical climate)	Summer: 17–29 °C (Jun 24.2), winter: 3–19 °C (Jan 7.6) Average temp" 16.6 °C	70–80%	2135 mm	518,775 (22%)
Rakkar village-Dharmshala, Kangra district	Himachal Pradesh	North	1260–1280	Cold and cloudy (Humid subtropical climate)	Summer: 21–32 °C (Jun 27.1), winter: 3–19 °C (Jan 8.6) , Average temp" 19.1 °C	70–80%	2883 mm	518,775(22%)
Delhi	Delhi (union territory)	North	209	Composite(Semi-arid)	Summer: 25–41 °C (Jun 34.3), winter: 6–25 °C (Jan 14.2) , Average temp" 25.2 °C	20–25% (dry), 55–95% (wet)	693 mm	82,507(urban,2%)
Kriparampura, Jaipur district	Rajasthan	North-west	295	Hot and dry/ Composite , (Semi-arid)	Summer: 25–41 °C (Jun 33.1), winter: 8–26 °C (Jan 15.5) , Average temp" 25.1 °C	25–40%	601 mm	3,089,906(26%)
Namchi	Sikkim	North-east	1325–1340	Cold and cloudy, (Oceanic climate)	Summer: 16–22 °C (Aug 21.4), winter: 7–18 °C (Jan 11.1) , Average temp 17.5 °C	70–80%	2699 mm	13,159(13%)
Khunti	Jharkhand	East	610–620	Composite/ Warm and humid (Humid subtropical climate)	Summer: 21–39 °C (May 31.3), winter: 10–29 °C (Dec 16.8) , Average temp 23.9 °C	20–25% (dry), 55–95% (wet)	1350 mm	3,684,954(67%)
Sundargarh district	Odisha	East	210–220	Composite/ Warm and humid (Tropical wet and dry climate)	Summer: 23–42 °C (May 34.2), winter: 11–30 °C (Dec 19.3) , Average temp 26.5 °C	20–25% (dry), 55–95% (wet)	1448 mm	4,883,041(49%)
Bhuj	Gujarat	West	125–130	Hot and dry, (Desert climate)	Summer: 22–39 °C (May 32), winter: 10–29 °C (jan 17.9) , Average temp 26.3 °C	25–40%	358 mm	2,109,301(26%)
Khavda	Gujarat	West	15–20	Hot and dry, (Desert climate)	Summer: 25–42 °C (June 33.8), winter: 7–30 °C (jan 17) , Average temp 26.9 °C	25–40%	300 mm	2,109,301(26%)
Auroville	Tamil Nadu	South	30–60	Warm and Humid	Summer: 25–37 °C (June 31.8),	70–90%	1141 mm	3,020,940(28%)

Table A1 (*continued*)

Location	Indianstate	Geographical-Location	Elevation (m)	Bioclimatic-zone:*BIS classification (Köppen-Geiger)*	Ambient temperature	Relative humidity	Rainfall	No. of rural houses with mud wall (% of total houses)
				(Tropical wet and dry climate)	winter: 20–30 °C (jan 24.3) , Average temp 28.1 °C			
Sittling	Tamil Nadu	South	380–400	Warm and Humid (Tropical wet and dry climate)	Summer: 23–36 °C (May 30.1), winter: 17–33 °C (Dec 23.3) , Average temp 26.8 °C	70–90%	877 mm	3,020,940(28%)
Tiruvannamalai	Tamil Nadu	South	160–170	Warm and Humid (Tropical wet and dry climate)	Summer: 25–38 °C (May 32.1), winter: 19–31 °C (Dec 24.2) , Average temp 28.2 °C	70–90%	1033 mm	3,020,940(28%)
Bangalore	Karnataka	South	880–940	Moderate(Tropical wet and dry climate)	Summer: 19–34 °C (April 27.1), winter: 14–30 °C (Dec 20.7) , Average temp 23.6 °C	20–55% (dry), 55–90% (wet)	831 mm	649,849(Urban, 10%)
Pondicherry	Pondicherry	South	30–35	Warm and Humid (Tropical wet and dry climate)	Summer: 25–38 °C (June 32.1), winter: 22–30 °C (Jan 24.5) , Average temp 28.3 °C	70–90%	1171 mm	15,385(14%)

Appendix B: Information on survey group, Table B1

Table B1
Information on the region, profession and the relation of each interview with earthen construction.

Identification	Region	Profession	User/ Expert
P1	Eastern	Farmer	User
P2	Eastern	Homemaker	User
P3	Eastern	Farmer	User
P4	Eastern	Head of village	User
P5	South	Architect	Expert
P6	South	Architect	Expert and User
P7	South	Farmer	User
P8	South	Volunteer	None
P9	South	Mason	Expert
P10	South	Consultant/ Engineer	Expert and User
P11	Western	Head of village	User
P12	North	Homemaker	User
P13	North	Mason	Both
P14	North	Volunteer	None
P15	North	Architect	Expert and User
P16	North	Psychiatrist	User
P17	North	Government	None
P18	North	Volunteer (student)	Student
P19	North East	Architect	Expert
P20	North East	Architect	Expert
P21	North East	Farmer	User
P22	North East	Homemaker	User
P23	North east	Writer	User
P24	North east	Engineer (Government)	Expert and User
P25	South	Architect	Expert
P26	South	Consultant/ Engineer	Expert
P27	South	Architect	Expert and User
P28	South	Architect	Expert
P29	South	Architect	Expert
P30	South	Potter	Expert
P31	South	Architect	Expert and User
P32	South	Mason	Expert
P33	South	Architect	Expert and User
P34	North	Policy maker (Government)	None
P35	North	Head of village	User
P36	North	Shopkeeper	User
P37	West	Mason	Expert and user
P38	West	Farmer	User
P39	West	Homemaker	User
P40	West	Priest	User

References

[1] G. M. Grandolini, E. Ijjasz-vasquez, "3 reasons why 'Housing for All' can happen by 2030," World bank Blog, 2016. [Online]. Available: https://blogs.worldbank.org/voices/3-reasons-why-housing-all-can-happen-2030. (Accessed: 26-Mar-2018).

[2] S. Malpezzi, "Chapter 44: Economic analysis of housing markets in developing and transition economies," in: Handbook of Regional and Urban Economics - Volume 3 - Applied Urban Economics, Elsevier B.V., 1999, pp. 1791–1864.

[3] S. Jahan, R. McCleery, Making Infrastructure Work for the Poor, United Nation Development Programme, New York, 2005.

[4] G. Arku, The housing and economic development debate revisited: economic significance of housing in developing countries, J. Hous. Built Environ. 21 (4) (2006) 377–395.

[5] R. Harris, G. Arku, Housing and economic development: The evolution of an idea since 1945, Habitat Int. 30 (4) (2006) 1007–1017.

[6] World Bank, "Urban development", World bank [Online]. Available [Accessed http://www.worldbank.org/en/topic/urbandevelopment/overview#3. 26-Mar-2018].

[7] World Bank Rural population (% of total population) [Online]. Available [Accessed https://data.worldbank.org/indicator/SP.RUR.TOTL.ZS?end=2016&start=1960&view=chart&year=1996. 13-Apr-2018].
[8] R. Chand, S.K. Srivastava, J. Singh, Changing Structure of Rural Economy of India Implications for Employment and Growth, National Institution for Transforming India - NITI Aayog, 2017.
[9] Public Opinion Research Group - The World Bank Group, India - World Bank Group Country Survey 2015. The World Bank Group, 2015.
[10] Ministry of Rural Development, "Pradhan Mantri Awaas Yojana –Gramin (PMAY-G)" Online Available: http://pmayg.nic.in/netiay/Uploaded/English_Book_Final.pdf 2016 Accessed: 17-Apr-2018.
[11] Ministry of Rural Development, "Quality House Construction Under PMAY-G" Online Available: https://rural.nic.in/press-release/quality-house-construction-under-pmay-g 2018 Accessed: 08-Jul-2019.
[12] S. Bhide D.B. Gupta T. Buragohain D.V. Sethi S. Kumar S.K. Bathla Roof above the Head- A Qualitative Assessment of Rural Housing in India 2009 New Delhi, 101.
[13] IDFC-RDN, India Rural Development Report 2012|13. Delhi: IDFC Rural Development Network, 2013.
[14] H. Schroeder, Sustainable Building with Earth, Springer International Publishing, Cham, 2016.
[15] J. Bredenoord, Sustainable Building Materials for Low-cost Housing and the Challenges Facing their Technological Developments: Examples and Lessons Regarding Bamboo, Earth-Block Technologies, Building Blocks of Recycled Materials, and Improved Concrete Panels, J. Archit. Eng. Technol., 06, no. 01, 2017.
[16] G. Minke, Building with Earth, Birkhäuser Basel, Basel, 2006.
[17] UNESCO, "Earthen architecture: the environmentally friendly building blocks of tangible and intangible heritage" Online Available: http://www.unesco.org/new/en/unesco/resources/earthen-architecture-the-environmentally-friendly-building-blocks-of-tangible-and-intangible-heritage/ 2018 Accessed: 01-May-2018.
[18] H. Houben, H. Guillaud, Earth Construction: A Comprehensive Guide, Intermediate Technology Publications, 1994.
[19] J. Morel, A. Mesbah, M. Oggero, P. Walker, Building houses with local materials: means to drastically reduce the environmental impact of construction, Build. Environ. 36 (10) (Dec. 2001) 1119–1126.
[20] V. Cascione, D. Maskell, A. Shea, P. Walker, A review of moisture buffering capacity: From laboratory testing to full-scale measurement, Constr. Build. Mater. 200 (2019) 333–343.
[21] B. Baiche, M. Osmani, N. Walliman, R. Ogden, Earth construction in Algeria between tradition and modernity, Proc. Inst. Civ. Eng. - Constr. Mater. 170 (1) (Feb. 2017) 16–28.
[22] A. Chandra Sekhar, "Census of India 1971: Housing tables," New Delhi, 1972.
[23] J.K. Bhathia Census of India 2001: Tables on Houses, Household Amenities and Assets 2001 New Delhi.
[24] C. Chandramouli Census of India 2011: Tables on Houses, Household Amenities and Assets 2011 New Delhi.
[25] P.K. Ramancharla, C.V.R. Murty, Earthquake safety of houses in India: understanding the bottlenecks inimplementation, Indian Concr. J. 88 (9) (2014) 51–63.
[26] V. Varghese, "The trend of mud house construction is making a comeback," The Economic Times, 2012. [Online]. Available: https://economictimes.indiatimes.com/the-trend-of-mud-house-construction-is-making-a-comeback/articleshow/14178255.cms. (Accessed: 22-Jan-2019).
[27] N. Vijayan, "Homes that breathe," The Hindu, 2017. [Online]. Available: https://www.thehindu.com/society/the-new-age-of-earth-homes/article18246547.ece. (Accessed: 23-Jan-2019).
[28] The times of India, "Mud houses are the new fad in the capital", The times of India Online Available: https://timesofindia.indiatimes.com/city/thiruvananthapuram/mud-houses-are-the-new-fad-in-the-capital/articleshow/64116032.cms 2018 (accessed: 22-Jan-2019)
[29] A. Menon, "Two Young Women Left Their Cement Homes to Build a Mud House Entirely from Trash in Kodaikanal," The better India, 2016. [Online]. Available: https://www.thebetterindia.com/57509/priyashri-nishita-mud-house-kodaikanal-sustainable-living/. (accessed: 23-Jan-2019).
[30] The Economic Times "Cement prices may increase by up to 10% in next 6 months: CMA", Online Available: https://economictimes.indiatimes.com/industry/indl-goods/svs/cement/cement-prices-may-increase-by-up-to-10-in-next-6-months-cma/articleshow/66202603.cms 2018 Accessed: 28-Jan-2019.
[31] H.R. Bernard, *Research Methods In Anthropology: Qualitative and Quantitative Approaches*, Forth, AltaMira Press, Oxford, United Kingdom, 2006.
[32] K. O'Reilly, Ethnographic Methods, Routledge, 2004.
[33] A. Singh, A.T. Strating, N.A. Romero Herrera, H.W. van Dijk, D.V. Keyson, Towards an ethnography of electrification in rural India: Social relations and values in household energy exchanges, Energy Res. Soc. Sci., Aug. 30 (2017) 103–115.
[34] N. Narayanasamy, Participatory Rural Appraisal: Principles, Methods and Application, SAGE Publications India Pvt Ltd, New Delhi, India, 2009.
[35] A. Mink, Design for Well-Being: An Approach for Understanding Users' Lives in Design for Development, Delft University of Technology, 2016.
[36] Y. Kulshreshtha, P. Vardon, N. Mota, M. van Loosdrecht, and H. Jonkers, "A case study on technical and social aspects of earth houses in rural India," in Earthen Dwellings and Structures, Bangalore, 2019.
[37] UNDP, Pahal: A compendium of rural housing typologies. United Nations Development Programme, 2016.
[38] Department of Rural Development, Socio economic and caste census. Online Available: https://secc.gov.in/reportlistContent 2011 (accessed: 29-Mar-2019).
[39] Department of Statistics and Information Management (RBI), Handbook of Statistics on Indian Economy 2017-18. Reserve Bank of India, 2018.
[40] K. Hadjri, M. Osmani, B. Baiche, C. Chifunda, Attitudes towards earth building for Zambian housing provision, Proc. Inst. Civ. Eng. - Eng. Sustain. 160 (3) (2007) 141–149.
[41] H. Danso, Building houses with locally available materials in Ghana: benefits and problems, Int. J. Sci. Technol. 2 (2) (2013) 225–231.
[42] M. M. Nambatya, "Investigating the rationale for material selection in tropical housing projects in Uganda – A Case for Interlocking Stabilised Soil Blocks (ISSB) Technology," University of Cambridge, 2015.
[43] M. Zurakowska J.J. Hughes J. Jez "History materials and social aspects of building from unfired earth in Poland", in Proceedings of the 11th International Conference on Non-conventional Materials and Technologies (NOCMAT 2009), 2009.
[44] S.H. Sameh, Promoting earth architecture as a sustainable construction technique in Egypt, J. Clean. Prod. 65 (2014) 362–373.
[45] O.B. Adegun, Y.M.D. Adedeji, Review of economic and environmental benefits of earthen materials for housing in Africa, Front. Archit. Res. 6 (4) (2017) 519–528.
[46] A.A. Hammond, Prolonging the life of earth buildings in the tropics, Build. Res. Pract. 1 (3) (1973) 154–163.
[47] A.B. Ngowi, Improving the traditional earth construction: a case study of Botswana, Constr. Build. Mater. 11 (1) (1997) 1–7.
[48] A. Hashemi, H. Cruickshank, A. Cheshmehzangi, Environmental Impacts and Embodied Energy of Construction Methods and Materials in Low-Income Tropical Housing, Sustainability 7 (6) (2015) 7866–7883.
[49] M.S. Zami, Drivers that help adopting stabilised earth construction to address urban low-cost housing crisis: an understanding by construction professionals, Environ. Dev. Sustain. 13 (6) (2011) 993–1006.
[50] My Dream Home, "Build houses, Build hope," 2019. [Online]. Available: http://www.ourdreamhomes.biz. [Accessed: 14-Aug-2019].
[51] Build up Nepal, "Interlocking bricks - building with Impact," 2019. [Online]. Available: https://www.buildupnepal.com/.
[52] LEVS Architecten, "Social housing in Bamako." [Online]. Available: https://www.levs.nl/bureau/levs-internationaal/#!sociale-woningbouw. [Accessed: 13-Aug-2019].
[53] World Monuments Fund (WMF) New Gourna Village Conservation and Community 2011 New York
[54] A. Marsh, A. Heath, V. Reddy, M. Evernden, "A Holistic Materials Design Requirements Framework (HoMDReF) For Future Housing Materials", in *Integrated Design at 50: Building our*, Future (2016).
[55] Ministry of Rural Development, "Working Group on Rural Housing for XII Five Year Plan," New Delhi, 2011.
[56] S. Chaudhury, Reviewing the Issue of 'Acceptability' of Earthen Structures in Housing, in: B.V.V. Reddy, M. Mani, P. Walker (Eds.), Earthen Dwellings and Structures, Springer, 2019, pp. 141–152.
[57] C. Correa, Housing and Urbanization: Building Solutions for People and Cities, Thames & Hudson, New York, 2000.
[58] Mundus Urbano International cooperation and Urban Development- TU Darmstadt and SIGUS group-MIT, "The search for high-density multi-story incremental housing", MIT Online Available: http://web.mit.edu/incrementalhousing/WUF-Rio/pdfs/Goethert_Nohn_MultiStory_IncrementalHousing_online.pdf 2012 Accessed: 01-Aug-2019.
[59] J. Bredenoord, P. van Lindert, Pro-poor housing policies: Rethinking the potential of assisted self-help housing, Habitat Int. 34 (3) (2010) 278–287.
[60] R. Goel, *Strengthening the Role of Building Centres in India*. Housing and Urban Development, Corporation Ltd. (HUDCO), India, 2002.
[61] HUDCO, "Building Technology," 2019. [Online]. Available: https://hudco.org//Site/FormTemplete/frmTemp1PLargeTC1C.aspx?MnId=47&ParentID=23.
[62] Ministry of Rural Development, "Building, guidelines for field trials for production of Materials for MGNREGA works" Online Available: https://nrega.nic.in/Circular_Archive/archive/guidelines_field_trials_production_building_materials.pdf 2014 Accessed: 19-Aug-2019.
[63] O. Rabie, Revealing the Potential of Compressed Earth Blocks: A Visual Narration, Massachusetts Institute of Technology, 2008.
[64] K.S. Jagadish, Building with Stabilized Mud. I, K International Publishing House, 2009.
[65] A. Marsh, Developing Alkali Activated Earth-Based Construction Materials to Provide Sustainable, Practical and Affordable Mass Housing in Less Economically Developed Countries, University of Bath, 2018.
[66] E. A. Heredia Zavoni, J. J. Bariola Bernales, J. V. Neumann, and P. K. Mehta, "Improving the moisture resistance of adobe structures, Mater. Struct., vol. 21, no. 3, pp. 213–221, 1988.
[67] Y. Millogo, J.-E. Aubert, A.D. Séré, A. Fabbri, J.-C. Morel, Earth blocks stabilized by cow-dung, Mater. Struct. 49 (11) (Nov. 2016) 4583–4594.