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REVIEW ARTICLE

Examining earthen dwellings as opportunities for disaster resilience: furthering the potential for achieving UN-SDGs

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Abstract: Vernacular construction techniques like earthen practices have a greater role in post-disaster self-recovery and rehabilitation efforts that utilize indigenous knowledge, skills, and locally available resources. The present review aims to examine the positive and negative effects of various hazards on earthen structures in brief, and further investigate the opportunities and best practices of earthen construction techniques for disaster resilience. Through case studies, this study demonstrates that in some countries, various modifications and adaptations have led to a disaster-resistant earthen construction design. In contrast, in many other regions where such measures were not incorporated, the vulnerabilities of the earthen-built environments in rural settings increased. Further, this study investigates the relationship between earthen-building techniques and the aspiration to achieve relevant targets of various United Nations Sustainable Development Goals (UN-SDGs) by utilizing a scoring matrix. As a study outcome, this paper presents a conceptual framework for disaster-resilient recovery planning with the vernacular housing approach highlighting “engineered for disaster resilience” as the key component for adopting vernacular techniques. This study also found that earthen materials and methods have a visible positive contribution for achieving the relevant targets of SDGs 01, 07, 09, 11, 12, and 13. Such studies on the interconnectedness between adopting indigenous knowledge and locally sourced building (earthen) materials, and SDGs can help inform and inspire policymakers, practitioners, and developers to formulate strategies for disaster reconstruction and resilience that are community-centric.

Keywords: Earthen structures, disaster resilience, vernacular techniques, sustainable construction, SDG11, SDG13

1 Introduction

Natural disasters can cause significant threats to property, people's health and safety, vital infrastructure, and even national security. During disasters, the impacts on populations are exacerbated due to interactions between hazard exposure, and inherent social and physical vulnerabilities [1]. The most visible consequence of many disasters is the widespread devastation of houses, with housing losses often exceeding 50% of total losses worldwide [2]. Thus, adaptations towards these disturbances and shocks are necessary, and this capacity of communities and groups is termed as resilience [3]. Scholars posit that resilience strategies should also consider the cultural and socioeconomic conditions of the

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region [4]. The resilience framework for rural housing strategies needs to integrate environmental and ecological concerns, practices, and behaviors, to be able to promote a transition towards an environmentally conscious rural lifestyle and consumption patterns [5].

Therefore, for the success of a post-disaster housing recovery program, multiple interrelated vulnerabilities have to be addressed while rebuilding [6, 7]. Over time, recovery policies and initiatives have changed to highlight three aspects of sustainable reconstruction which are, (a) social, which involves enhancing community participation and capacity building; (b) technical, which involves building in-situ rather than relocating and incorporating disaster-resilient features and environmental considerations in material selection; and (c) spatio-temporal, which involves localising construction skills and integrating them into the local economy and culture, and receiving financial and knowledge support from government agencies for disaster recovery and risk management [8].

In a majority of post-disaster situations, top-down aid for temporary shelter and housing needs from external agencies are able to cover less than 10% of the total needs [9]. In remaining situations where homes are damaged, survivors are adopting a self-recovery approach in which either repairing or rebuilding homes is done with the resources available at hand by family members using their own knowledge of construction with little to no outside assistance, considered a bottom-up approach [10]. Oftentimes, the top-down reconstruction projects initiated by government and aid agencies have met with dissatisfaction as recipients, due to their inability to practice traditional livelihoods, lack of social cohesion and cultural sensitivities, or inefficient management and coordination, requiring tearing down and reconstructing, leading to budget shortfalls, delays, and added anxieties in survivors [11,12].

In the self-recovery approach, Disaster Risk Reduction (DRR) attributes are included in the shelters, like those in any other recovery program [13]. Knowledge exchange to increase local capacity and understanding of safe building practices is a crucial component of self-recovery [14]. Therefore, during this process, collaborative efforts can be brought among multiple service providers for capacity building to ensure DRR features are transferred to the communities adequately [6]. Also, these agencies have a greater role in immediate support by providing tools, equipment, and other utilities during disasters [13]. The vulnerabilities of rural housing can be attributed to various reasons, including the interconnectedness of various aspects of habitat development, such as skill-building, choice of appropriate materials, financial accessibility, and safe construction techniques [15].

Disaster self-recovery in many regions where traditional construction practices are the norm depends primarily on locally available natural materials [13]. Thus, the success and shift towards owner-driven approaches from a donor-driven top-down approach has brought more recognition toward vernacular construction techniques [16]. Studies indicate that traditional construction methods can be effectively strengthened as a mitigation prevention strategy against hazards such as earthquakes and also applied to reconstruction projects [16]. Also, many studies show that disaster-resilient features can be incorporated with locally available building materials [17]. At the same time, depending upon the local hazard conditions, many vernacular techniques can be adapted to be more disaster resilient.

According to estimates, 8–10% of households globally and 20–25% on average in developing nations live in earthen dwellings [18]. In many regions, traditionally, vernacular earthen construction techniques have incorporated many design features to adapt to local geographic and hazardous conditions such as floods, snowmelts, earthquakes, etc. Hence, there exist variations in the earthen construction techniques adopted in different regions of the world. For example, the safety against earthquake characteristics of earthen buildings involves symmetrical layouts, enhanced structural integrity, decreased mass of constructed walls, and providing masonry confinements with bamboo or wood reapers. These characteristics have evolved as a result of the long-term exposure of local communities to earthquakes and the lessons they learned over time [19]. Therefore, in order to examine the opportunities for disaster resilience, it is important to discuss these varied country-specific case studies of earthen structures from disaster-prone regions of the world.

Since 2015, the concept of sustainable housing for human settlements has been linked with the United Nations Sustainable Development Goal (SDG) 11: Make cities and human settlements inclusive, safe, resilient, and sustainable [20]. Scholars like Omer and Noguchi (2020) have made a noteworthy contribution in this direction by investigating the relationship between building materials and the UN SDGs and their targets [21]. They presented a novel methodological framework that assigned a score to each relevant target of SDGs for every category of building material depending on how much that material contributed to achieving the relevant SDG target. In their study, mud and lime were classified as “local building materials” and stabilised earthen blocks were classified as “low embodied energy building materials”. Their findings suggested how each category of building material could help achieve SDGs generally and also that both categories are able to achieve multiple SDGs. A wide variety of building materials can be classified under each category, as shown in [21].

In essence, their framework, which allows a detailed investigation of how each building material can contribute towards achieving SDGs, was utilized as a guiding framework for this study. Their work was also extended, to study the relationship between earthen-building techniques and SDGs and their targets and its alignment to self-recovery in post-disaster contexts. Hence, the two research objectives that this study seeks to address are:

1) How have earthen construction techniques been adapted to mitigate hazards, and how can these techniques be adopted for disaster-resilient recovery planning?
2) Can earthen construction techniques contribute towards achieving theUN SDGs?

Based on these objectives this study is divided into two phases, where the first phase examines the opportunities of earthen construction for disaster resilience based on case studies of various vernacular systems practiced across the globe. This phase concludes with discussions on the advancements in this technology, and the presentation of a conceptual framework showing how disaster resilience can be achieved by adopting a vernacular housing approach. The second phase of the study investigates the contribution of earthen techniques towards achieving various UN SDGs utilizing a scoring framework, where literature review-based information forms the basis of scoring. The overarching goal of the present study is to aid in understanding the resilience capacities and capabilities of achieving UN SDGs from earthen construction practices.

2 Methods of Earthen Construction

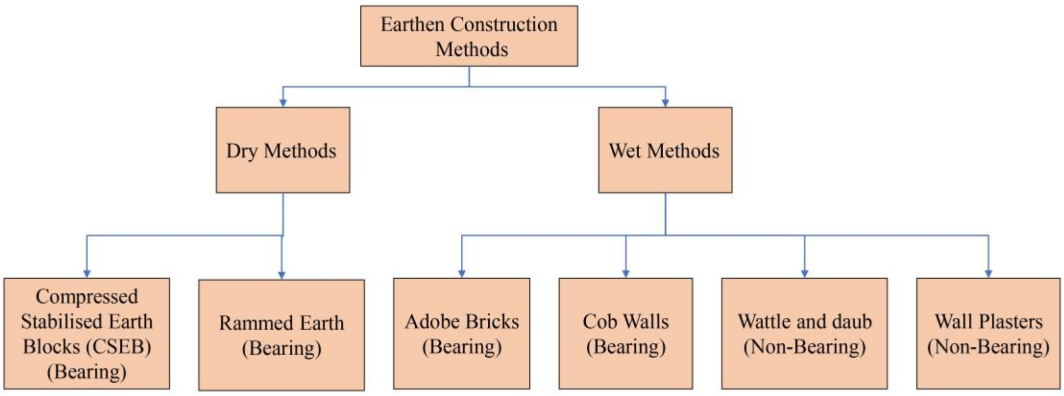

Fig. 1. Types of Earthen construction

Earthen techniques can be classified into dry and wet methods, as depicted in Fig. 1, based on water content, implementation type, and structural role of the earth elements [22]. Wet methods, such as adobe bricks (sun-dried bricks), cob walls, and wattle and daub methods, have higher water requirements and are implemented in a wet plastic state [23-25]. The wattle and daub method shown in Fig. 2 (b) has earthen plastering over a wattle structure made of cane or bamboo [26,27]. Compressed Stabilized Earth Blocks (CSEBs) and rammed earth are regarded as dry methods with a lower water requirement, implemented at a dry state, and found as load-bearing walls. CSEB preparation involves a block-making machine, as shown in Fig. 2 (d). The construction of rammed earth walls, as shown in Fig. 2 (a), involves the ramming of earth in a wooden structure [28]. Wet methods are affected by poor dimensional stability and shrinkage cracking, leading to a strength reduction over time due to the surrounding environmental conditions [29]. But, for dry methods, the increased density through compaction leads to lower porosity, thereby reducing the issues related to dampness [30]. Also, the various shortcomings of wet methods can be overcome by focusing on stabilisation with cement, lime, or agricultural waste in dry methods [31-35]. Therefore, modern techniques like CSEBs and rammed earth offer ample opportunity for advancements and applications in the future.

(a) Rammed earthen walls at a construction site, Calicut, Kerala, India

(b) Wattle and Daub walls built in Keystone Foundation, Kotagiri, Tamil Nadu, India

(c) CSEB blocks stacked in the production unit at Auroville Earth Institute, Pondicherry, India

(d) Production of CSEB blocks using Auram Press 3000 machine (manually operated machine) at Auroville Earth Institute, Pondicherry, India

Fig. 2. Some earthen techniques practiced at different locations in India

3 Earthen Methods and Resilience

Various studies show that conventional adobe construction, such as the Arg-e-Bam earthen architecture, failed during multiple earthquakes in Iran, especially during the 2003 Bam earthquake [36,37]. Similarly, the adobe dwellings in southern parts of Peru in the cities of Ica, Lima, and Huancavelica were reported to have faced significant damage during the 2007 earthquake (magnitude of Mw 8.0), which claimed 593 lives, completely destroyed 48,208 dwellings, and left 45,500 uninhabitable [38]. The Kahramanmaraş earthquake (2023) in Turkey (magnitude of Mw 7.7), which claimed over 50,000 lives was also attributed to the collapse of adobe buildings on the population [39]. Of the 100 adobe buildings studied, 25% were destroyed, 49% were heavily damaged, 15% were moderately damaged, and 11% were only slightly damaged with the primary causes being the low strength of adobe material, the use of heavy earthen roofs, non-compliance with earthquake-resistant design principles, and inadequate support for load-bearing walls [39].

Thus, the commonly adopted earthen techniques are inherently weak, with brittleness and low strength. Poor workmanship and lack of sufficient connections between structural sections also increase the overall vulnerability of these buildings under earthquake loads [36,40]. In such situations, various systems have adopted ways for load transfer mechanisms using timber and proper wall connections to prevent out-of-plane failure by overturning [19,41]. Similarly, delamination of wall leaves and in-plane shear failures can also be identified as major causes of failure [30,19]. All these causes have been illustrated in **Fig. 3**.

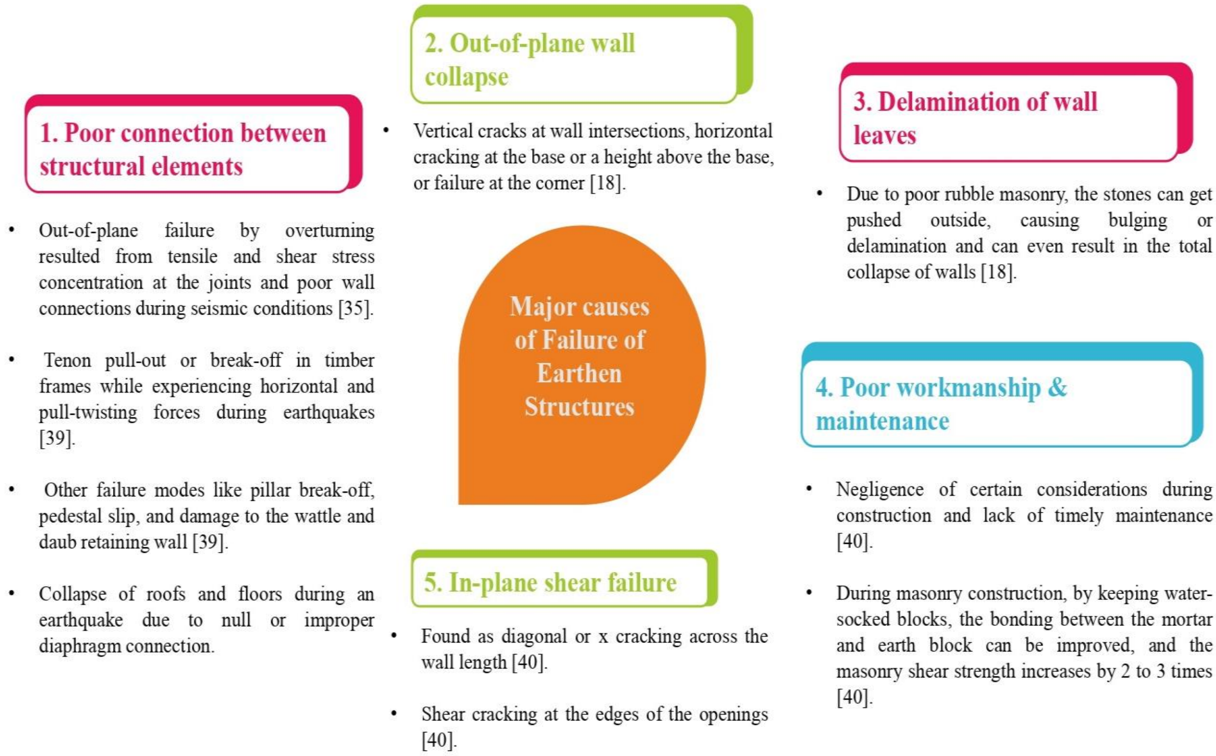

Fig. 3. Major causes of failure of earthen structures

During all the prevailing situations, a loss of structural integrity can be seen, which has been tried to confront with different mitigation strategies adopted in various parts of the world. Most of these cases use timber for reinforcements, framing, or providing band structures. This usually brings a “box behavior” where proper connections are also ensured between the various elements [42, 43] and flexibility to withstand seismic forces. This quality of timber elements to absorb energy and compliment the strength of earth materials makes it very versatile, in reducing the risk of collapse during disasters. This has been experimentally proven by various researchers and has been enumerated in **Table 1**. Some cases have also been shown in **Fig. 4**. Therefore, all these cases show a traditional approach towards an engineering design for disaster resilience.

Table 1. Case studies of earthen construction practices with disaster-resistant features

Sl. No.	Case	Technique Used	Observations
1	Bahareque construction, El Salvador [27]	● Wattle and Daub. ● Chemically treated timber for frame. ● Wall mat made of bamboo. ● Used steel plate connections. ● Replaced mud plastering with sand-cement mortar mix.	● Authors were able to successfully come up with an “engineered” design of vernacular housing practice. ● Out-of-plane shake-table tests, and cyclic shear tests for the wall panels to study in-plane seismic behaviour, and flexural tests for the canes were conducted based on which timber studs were provided.
2	Himalayan vernacular	● Horizontal timber bands (runners).	● Improved geometric configuration by simple and regular design of plan and

	masonry buildings. with earthquake-resistant features [17]	● Wooden framed structures composed of both vertical and horizontal components, either with or without diagonal braces.	elevation. ● Improved structural integrity on wall-to-wall and wall-to-diaphragm (using timber wedges) connections. Framed structures can provide good confinement against the infill, and similarly, bands also provide stability against out-of-plane loading. ● Good structural redundancy due to multiple load paths and wall deformability due to timber members. ● Timber members interrupt crack paths and reduce crack widths. ● The low tensile strength and low cohesion of the mud mortar result in the sliding failure of the infill.
3	Earthquake-resilient vernacular design in mid-hill regions of Nepal [44]	● Stone or brick masonry with mud mortar. ● Round in structure. ● Timber elements are provided as openings, struts, and slabs.	● Observed cracks due to uneven settlement.
4	Himis houses in Turkey [45-47]	● Timber-framed structure, with frame interiors divided into smaller compartments using horizontal, vertical, or diagonal elements. ● In-fills are provided using adobe, brick, or stone based on availability.	● During the past earthquakes of 2010 Kovancilar, 1995 Dinar, and 1999 Izmit, Himis houses performed better than concrete houses. In some other cases (2003 Bingol earthquake) infill collapse was observed. ● One of the main causes of a frame's high ductility and energy dissipation is nail connections. The pulling-out of the nail connections is the damage mechanism found during the reversed cyclic lateral load testing, regardless of the timber type used, the size and geometry of the frame, or the type of infill or cladding. ● Infill and claddings provided increase the load-bearing capacity and stiffness of the frames.
5	Dejii-Dewari of Kashmir valley [48, 49]	● Large wooden structure formed of vertical and horizontal cages with infill as adobe or sun-dried bricks.	● Similar to the Himis type in Turkey. ● Spacing between the timber studs is close enough to prevent shear crack propagation.
6	Quincha of Peru [26, 50]	● Wattle and daub.	● Authors conducted Finite element model analysis, and results showed adequate safety for the moderate seismic zones of the Latin American Region. ● Similar to Bahareque. ● One of the disadvantages is the development of cracks and fissures on the daub surface. ● Rainwater can seep through cracks, causing the mud coating to expand and loosen. It can lead to the growth of insects and the rotting of the wattle structure.
7	Adobe Construction in Chile [51]	● Adobe construction. ● Walls were found to have a common slenderness	● Seismic strategy counterforts were seen as a continuity of walls in the exterior in perpendicular directions to avoid the

	ratio of 1:7.	overturning to outside. ● Wooden connection elements known as Las trabas were seen at wooden element-to-wall connections and roof-to-wall connections. ● The strategy most adopted is placing a wooden ladder-like arrangement at a certain level, usually at the lintel or mezzanine where it is placed continuously. ● Survived the 2015 earthquake with a magnitude of 8.4 Mw.

(a) Wattle structure of the bahareque construction made with a cane while constructing [27]

(b) Adobe filling for the timber frames for the walls of Himis houses [45]

(c) A reconstruction program in the Pakistan-Kashmir region reviving the technique of Dhajji dewari, in which the small spaces between the timber studs are filled with stones and cob mixer [52]

(d) An old church building of adobe construction provided with counterforts in Barraza, Chile [51]

Fig. 4. Some of the traditional earthen construction practices worldwide, adopted with disaster-resilient features

On comparing with other building typologies, non-engineered earthen structures are more vulnerable during disaster events, as reported during the 2017 Tripura earthquake [53]. This can also be due to their prior conditions of reduced strength and durability due to soaked conditions of rain and other environmental conditions [53]. Also, the high-frequency earthquake vibrations combined with the conditions of termite damage and clay degradation conditions of the earthen structures lead the walls to lose cohesion and collapse [37]. Therefore, these kinds of pre-existing conditions of clay degradations, termite attacks, and damages due to rainwater intrusion all can be viewed as the limitations of non-engineered earthen techniques, which increased the severity of the damages. The causes of damage also include the presence of numerous shrinkage cracks and fissures, both horizontally and vertically, since their inception, along with inadequate structural detailing in the connections between the walls and the roof, as well as between adjoining walls [53].

3.1 "Engineered for Disaster Resilience": Traditional Methods

From the case studies discussed in Table 1, the following disaster-resilient practices from the traditional systems were gleaned,

a) Timber reinforcement in masonry structures: The housing practices in the Himalayan region have popularized the inclusion of horizontal timber runners (ring beams), which deliver good structural integrity [17]. They are usually placed at the lintel or roof levels. They consist of a pair of longitudinal parallel planks connected with transverse members in a ladder-like shape [19]. These beams prevent overturning by providing out-of-plane strength and stiffness. Besides these, the insertion of timber elements within the masonry can be seen as a strengthening method due to their ductile properties.

b) Timber-framed Structures: The cases of Bahareque construction in El Salvador, Himis houses in Turkey, and Deji-Dewari of Kashmir Valley and Quicha of Peru, all suggest the adoption of timber-framed construction practices. Discussing a similar case in Zhaohua, China, the majority of the historic timber structures are of timber load-bearing frames, wattle and daub walls with bamboo and added grass fibres to enhance the connection, use of wood retaining walls along with small grey tile roofs [41]. After the Wenchuan Earthquake 2008, which reported an earthquake intensity of 7 degrees, nearly 60% of the historic timber structures were subject to relatively minor damage [41].

c) Addition of natural fibres and manure: Plant fibres are also added in various regions to improve ductility and contribute more towards enhancing tensile strength [54,55]. Optimal fibre length and percentage addition have greater significance, where a greater length and high content adversely affect the compressive strength. Researchers found that an optimum fibre (Hibiscus cannabinus) content between 0.3 - 0.5 wt. % and 30 mm length improved the mechanical and physical characteristics of adobe blocks [56]. Improved mechanical properties are associated with the non-propagation of fractures resulting from the fibres present in the clay matrix [57]. Similarly, cow dung has been used with various earthen techniques in many settings as it causes microstructural changes by reacting with kaolinite and fine quartz, forming insoluble silicate amine, which holds the isolated soil particles together [57]. Additionally, the substantial fibre content of cow dung strengthens the material by stopping fissures in the adobes from spreading.

d) Counteracting horizontal load: Buttressing is another common economical and traditional method provided as a counter-support for strengthening the wall against lateral thrust [58]. These are commonly found in regions of South America like the Andean highlands [58]. It is crucial to fasten buttresses to diaphragms or tie beams or to the walls and cross ties are one way to carry out such a connection.

3.2 "Engineered for Disaster Resilience": Current Technological Adaptation

Strength and durability are the key factors determining the lifespan and performance of materials and buildings. Earthen buildings are more susceptible to wearing action, where these buildings require continuous maintenance. For the Bhuj earthquake (2001) Rehabilitation project, in the State of Gujrat, India, approximately 2,000 Cement-Stabilised Rammed Earth (CSRE) dwelling units were constructed in a circular (with thatch roof) and rectangular (flat RC roof) shapes within two years [59]. This has proven to be a model program, satisfying the various objectives of a reconstruction program including speedy selection of the housing design and construction practice, reduction in repairs and maintenance costs, site-specific planning, and ensuring the sustainability of the project goals [60]. The construction of these dwelling units also followed the guidelines of IS 4326 (1993), which required constructing sill, lintel, roof RCC bands, and vertical reinforcements for earthquake resistance. Studies of various technological adaptations are seen in the methods of CSEB and rammed earth. Some of the key areas of research are described below.

a) Improved stabilisation methods: The soil in different regions has a different composition. The percentage of clay composition is a determining factor in the final performance of the material. Higher clay content can result in higher shrinkage [54]. Researchers have utilised various soil parameters like linear shrinkage (LS) and plasticity index (PI) to identify favorable soil for rammed-earth construction [61]. Burroughs (2008) identified the soil types with (1) LS < 6.0% and PI <15 %; and (2) LS between 6.0 – 11.0% and PI 15-30 % and sand content < 64% as the two favorable cases with higher stabilisation success rate for the rammed earth construction [61]. Therefore, the modification of the soil is usually carried out by the addition of sand or gravel to improve structural stability.

Similarly, one of clay's essential characteristics is its compaction capacity. Soil mix characteristics like water content and dry density are important in obtaining the required performance [62,63]. Increased water content, greater than 20%, and a lower maximum dry density below 1.76 g/cm^3 are caused by increased clay content [54]. This causes higher shrinkage, becoming inappropriate for usage. Other than these approaches based on mix design, the addition of materials with comparatively high tensile strength, such as fibres like jute fabric provided with adhesives or plasters, can increase the seismic performance in rammed earth buildings [64-66]. Intermediate layers of lime or gypsum mortar are also found in certain regions of Spain, reported to be a solution to prevent humidity and dampness to a certain extent [67].

b) Reinforcement and anchoring: Reinforcement options like inserting steel-reinforcement bars, particularly at corners, will also strengthen the earthen walls [65]. In out-of-plane lateral bending, rammed earth walls exhibit low flexural strength, particularly in the vertical direction, thus, providing rebar reinforcements in walls, increasing the flexural strength of the rammed earth walls [68]. Similarly, Tripura and Singh (2018) found that CSRE columns with steel reinforcement under axial loading conditions in earthen constructions, the load-carrying capacity of the column increases with an increase in lateral reinforcement ratio. They also concluded that steel reinforcement has a better performance than bamboo [69].

Numerical studies are also widely used to analyze the seismic performance of RE walls. Finite Element Analysis (FEA) a computer simulation technique, has been used to prove that providing vertical steel reinforcements at two extremities of the wall can enhance the horizontal load-carrying capacity of the walls by 25% (load at which the first crack appears) compared to an unreinforced RE wall [32]. Similarly, Matte et al. (2015) conducted a structural analysis and found that it is feasible to design one-story CSEB masonry dwellings that can withstand wind loads from category 4 Hurricanes (as per the Saffir-Simpson Hurricane Wind Scale) and EF3 Tornadoes (as per Enhanced Fujita Scale), provided that a rigid horizontal diaphragm is used [70]. At higher wind loads, the most rational strategy is to use internal reinforcement and anchor the diaphragm and the roof to the walls and the walls to the footings [70]. Erdogmus et al. (2015) designed a single-family dwelling unit for high-wind resistance using Compressed and Stabilized Earthen Masonry (CSEM) and paid special attention to the provision of an appropriate load path to survive significant wind-related uplift forces [71]. They suggested providing anchor bolts between CSEM and roof trusses, and a bond beam on top of the CSEM wall section to ensure sufficient material strength for truss anchors [71]. From all these studies, it can be concluded that reinforcement and anchoring increase the resistance of the earthen structures against various disaster conditions like earthquakes and cyclones.

3.3 Conceptual Framework

Although the aforementioned case studies through a review of extant literature have shown how disaster-resilient features are adopted in various architectural systems, in many parts of the world, earthen techniques are still practiced without the integration of such features, thereby increasing the disaster vulnerability in these regions. EL Salvador witnessed two earthquakes (with magnitudes (Mw) of 7.7 and 6.6) on January 13 and February 13, 2001, which severely damaged and caused the collapse of 200,000 adobe homes and claimed 1100 lives [72]. Similarly, the Peruvian provinces of Arequipa, Moquegua, and Tacna also experienced the destruction of 36,000 houses, of which 25,000 were made of adobe, causing a loss of 81 lives that same year due to an earthquake of magnitude 8.4 Mw[73].

This kind of vulnerability even exists with architectural systems like the Pa Chim (rammed earth) construction in the seismic regions of Bhutan [74]. Here, the Pa Chim technique has been provided without proper connections between orthogonal walls [74]. Researchers have observed that cracks were commonly found in dwelling units due to the presence of putlog holes, out-of-plane wall collapses, buckling, delamination, and dislocations of roof connections [75]. Such a situation has also been found within the monasteries built with rammed earth in the Lahaul and Spiti region of Himachal Pradesh, India [76]. Researchers have noticed the absence of various standard code recommendations like buttresses for walls, seismic bands, and wall-to-wall connections [76]. These structures also lack roof-to-frame connections, wall-to-foundation connections, and roof-to-wall and wall-to-floor connections [76]. In all these cases, researchers have highlighted the necessity of expert engineering consultations to improve the disaster-resistant capacities of these buildings [72,74].

It can thus be concluded that a self-recovery approach for disaster recovery planning can adopt the vernacular housing techniques as it provides choices and control in design and implementation for the dwellers [77]. However, unfortunately, the rebuilding takes place with the same mistakes being repeated leading to the same vulnerabilities that caused serious destruction in the first place, without any improvements [77]. Therefore, it is important to include technological modifications while adopting earthen construction techniques as a bottom-up approach to disaster resilience. The vernacular housing methods need to be adapted or engineered to sustain disaster shocks during the planning stage [16].

With this in mind, a conceptual model is presented in **Fig. 5** demonstrating two key components for adopting vernacular housing techniques: (1) engineered for disaster resilience and (2) socio-economic aspects. Under the component "Engineered for disaster resilience", materials selection and mix design, design of various elements, provision of reinforcements, and connection designs, as discussed earlier, have been included. Various rehabilitation projects like the case of the Bhuj earthquake (2001) have successfully undertaken disaster recovery planning and implementation with earthen dwelling units designed as earthquake-resistant. Housing design related to layouts, dimensions, functional usage, and climate responsiveness also becomes a component that requires engineering consultation during the planning of disaster-resilient vernacular housing programs [60].

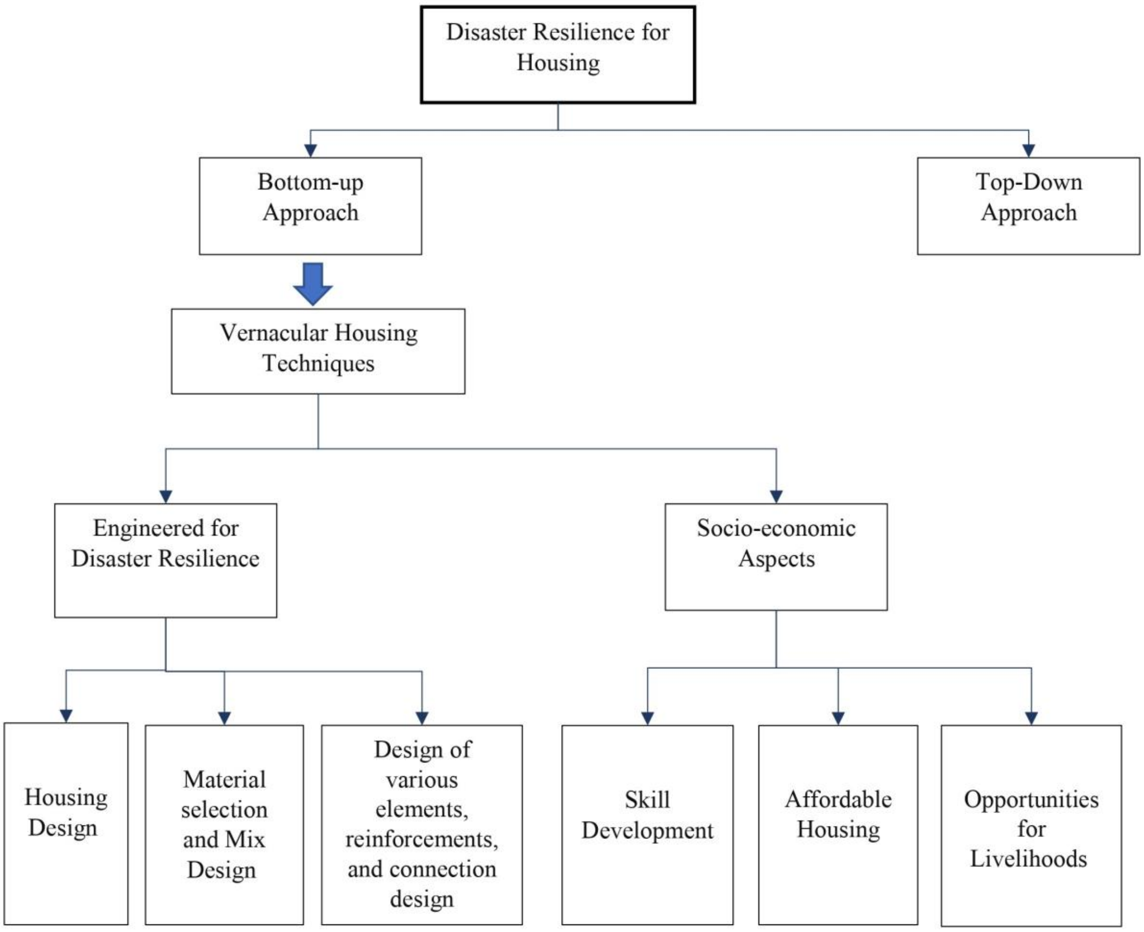

Fig. 5. Conceptual framework showing Disaster resilience with vernacular housing approach for recovery planning

Vernacular architectural practices come in the bottom-up approach in which community members are encouraged to take up the reconstruction projects with the government or organizational support. Thus, the socio-economic aspects become another key component in this approach. Therefore, the local artisan, including unskilled labor, shall be trained with the newer technological adoptions for capacity building, and it shall offer possibilities for livelihood [59]. Housing restoration to a greater standard, based on local participation and expertise, can potentially aid in long-term catastrophe risk reduction [78]. External agencies can facilitate co-creation, in which people can be successfully involved and help generate social innovation [79]. Many researchers have implemented a "co-design" approach in which people are collaboratively involved in the design and development of the improved solution according to their needs [80-82]. This conceptual model can be viewed as the basis for formulating the required solution and understanding the persistent challenge. Various participatory methods can be employed to propose an intervention [83,84]. External agencies can be involved in finding the solution, facilitating, and bringing the skill development towards resilient construction by adopting the self-recovery approaches.

4 Earthen Structures and SDGs

4.1 Evaluating the contributions towards achieving SDGs.

There are 17 UN Sustainable Development Goals (SDGs) ranging from the eradication of poverty and hunger to the promotion of peace and justice among societies [85]. Even though there exist various SDGs concerning efficiencies in resource management, the proper link between building materials and the UN SDGs and their targets has not been extensively explained. Omer and Noguchi (2020) did a categorical classification of building materials and investigated each categorical contribution to the SDGs by proposing a framework [21]. The same framework is used in this current study, in order to assess the contribution of the earthen methods toward the achievement of SDGs. In this framework, scores are assigned depending on how much these techniques contribute to the relevant SDG target, as shown in **Table 2**.

Table 2. The contribution scoring chart and explanation [21]

Building Material Contribution Score	Contribution Name	Contribution Explanation	Contribution Example
+3	Visible	Direct involvement in reaching the goal/target.	Earthen materials pose comparatively lower embodied energy than conventional masonry, visibly contributing inextricably to achieving target 7.3 of SDG 7 through energy efficiency.
+2	Reinforcing	Facilitates the accomplishment of the goal/target.	Earthen walls can be reused after demolition; thus, it promotes the circular economy. This can be viewed as a reinforcing contribution to target 8.4 of SDG 8.
1	Enabling	Minimal contribution in reaching the goal/target.	Bringing wider acceptance of the earthen materials promotes a sustainable lifestyle resulting in more sharing of knowledge for sustainable development. Thus, it enables the achievement of the target 4.7 of SDG 4.
0	Invisible	No Contribution/ trade-off.	Earthen Materials and Gender Equality, SDG 5.
-1	Constraining	Limiting the accomplishment of the goal/target or causing trade-off.	-

Source: Adapted from Omer and Noguchi (2020)

The scoring matrix presented in **Table 2** shows a five-point scale ranging from -1 to +3, representing various magnitudes of constraining, invisible, enabling, reinforcing, and visible, respectively. If there is no contribution, either positive or negative, that is known, a score of zero is assigned. A score of -1 is assigned for a negative correlation, causing a trade-off on the SDG by the earth materials. And, the positive scoring ranges between +1 to +3 depending upon the visibility, link, and magnitude of the contribution concerning the various targets of SDGs as discussed further. Awarded scores for the relevant targets are shown in **Table 3**.

4.2 Goals, Relevant targets, and contribution of Earthen methods towards the achievement of SDGs

For all 17 SDGs together, there are 169 targets [85]. Of the 17 SDGs, 12 SDGs that can be linked with building materials and construction methods are discussed in this study. 25 targets falling under these 12 SDGs were selected for discussion and can be related to earthen construction practices. All these SDGs and the selected targets are shown in Table 3. A qualitative discussion investigating the linkages between the relevant targets of the SDGs and earthen construction practices was carried out further, which forms the evidence base for scoring as per the rules in Table 2.

Table 3. Contribution of earth materials and techniques for SDGs and their relevant targets

SDG No.	Sustainable Development Goal (SDG)	Target No.	Target	Literature	Contribution Score
	End poverty in all its forms everywhere	1.4	Equal rights to ownership, basic services, technology, and economic resources	[86-88]	+3
		1.5	Build resilience to environmental, economic, and social disasters	[59,89]	+3
	End hunger, achieve food security and improved nutrition, and promote sustainable agriculture				0
	Ensure healthy lives and promote well-being for all at all ages	3.4	Reduce mortality from non-communicable diseases and promote mental health	[90,91]	+1
		3.9	Reduce illnesses and deaths from hazardous chemicals and pollution.	[92-94]	+1
	Ensure inclusive and quality education for all and promote lifelong learning	4.7	Education for sustainable development and global citizenship	[95,96]	+1
	Achieve gender equality and empower all women and girls				0
	Ensure access to water and sanitation for all	6.4	Increase water use efficiency and ensure freshwater supplies.	[97-100]	+2
	Ensure access to affordable, reliable, sustainable, and modern energy for all	7.3	Double the improvement in energy efficiency	[101-104]	+3
	Promote sustained, inclusive, and sustainable economic growth, full and productive employment, and decent work for all	8.4	Improve resource efficiency in consumption and production	[101,105,106]	+2
	Build resilient infrastructure, promote inclusive and sustainable industrialisation, and foster innovation	9.1	Develop sustainable, resilient, and inclusive infrastructures	[107]	+3
		9.4	Promote inclusive and sustainable industrialisation	[108,109]	+3
	Reduce inequality within and among countries				0

Make cities and human settlements inclusive, safe, resilient and sustainable	11.1	Safe and affordable housing	[88,107,110]	+3
	11.4	Protect the world's cultural and natural heritage	[18,111]	+3
	11.5	Reduce the adverse effects of natural disasters	[17,59,112]	+3
	11.6	Reduce the environmental impacts of cities	[93,102]	+2
Ensure sustainable consumption and production patterns	12.2	Sustainable management and use of natural resources	[106,113-118]	+3
	12.4	Responsible management of chemicals and waste		+3
	12.5	Substantially reduce waste generation		+3
	12.8	Promote a universal understanding of sustainable lifestyles	[119]	+2
Take urgent action to combat climate change and its impacts	13.1	Strengthen resilience and adaptive capacity to climate-related disasters	[17,59,112]	+3
	13.2	Integrate climate change measures into policy and planning	[101,102,120,121]	+3
Conserve and sustainably use the oceans, seas, and marine resources				0
Sustainably manage forests, combat desertification, halt and reverse land degradation, halt biodiversity loss	15.3	End desertification and restore degraded land	[115,122,123]	+1
	15.5	Protect biodiversity and natural habitats	[122,124]	+2
Promote just, peaceful, and inclusive societies				0
Revitalise the global partnership for sustainable development	17.7	Promote sustainable technologies to developing countries	[86,125-127]	+2
	17.9	Enhanced SDG capacity in developing countries		+2
	17.16	Enhance the global partnership for sustainable development	[109,128]	+1

Source: Authors' creation adapted from UN SDGs and Omer and Noguchi (2020)

4.2.1 SDG1, End poverty in all its forms everywhere:

Socio-economic factors play a major role in receiving acceptance for the earthen construction techniques [86]. Studies reported that low-income households are forced to continue in earthen houses, due to their economic conditions [87]. The traditional construction methods require frequent maintenance and are susceptible to termite infestations while modern construction techniques like CSEB and Rammed Earth offer better performance against the weather and termites [87]. Since these techniques utilise locally available materials, a cost reduction is expected, and is regarded as an affordable housing solution [88]. Hence, even when the traditional earthen methods remain as an "image" linked to poverty, integrating new knowledge of enhancing these with modern techniques, can achieve Target 1.1 of SDG 1, providing equal rights, facilities, and resources to all [87]. Similarly, Target 1.5 is to build resilience to environmental, economic, and social disasters. In this study, the resilience capacities of earthen structures through stabilisation techniques, reinforcement, and anchoring methods, and various other traditional approaches have been discussed earlier [59,89]. These outline their ability to help achieve Target 1.5.

4.2.2 SDG3, Ensure healthy lives and promote well-being for all at all ages:

Target 3.9 of SDG 3 highlights the necessity of reducing the harmful effects of various pollutants. Whilst indoors, there can be several ozone-producing devices like laser printers, photocopiers, and ion generators [92,94]. Researchers have found that clay for wall plastering has a relatively higher ozone reactivity in indoor conditions [93]. Hence clay can be used as a Passive Removal Material (PRM), to reduce indoor pollution without significantly forming chemical by-products or using more energy [93]. Similarly, Target 3.4 focuses on the promotion of mental health. Samarasinghe & Falk (2022) conducted interviews among earthen homeowners in New Zealand and concluded that earthen homes can improve mental health, a sense of satisfaction, and creativity among dwellers. Various studies have also shown increased satisfaction among the dwellers due to the ability of earthen constructions to control humidity [90,91]. All these prove that the earthen techniques can contribute effectively towards health and well-being goals.

4.2.3 SDG4, Ensure inclusive and quality education for all and promote lifelong learning:

Most studies of education for sustainable development are focused on environmental educational themes or global citizenship themes [95]. At the same time, education plays a greater role in the capacity-building of individuals' ability to tackle environmental and development concerns—which are closely linked to sustainable development [96]. While considering the ecological factor of sustainable material selection, the energy expenditure for production, which includes energy for manufacturing and transportation, is an indicator. This Primary Energy Intensity (PEI) is very low for earth materials compared to concrete [106]. Thus, constructing with earthen materials is regarded as an inherently sustainable lifestyle and education and skill training on earthen practices will promote sustainable development, specifically towards achieving Target 4.7, education for sustainable development.

4.2.4 SDG6, Ensure access to water and sanitation for all:

The construction sector consumes 16% of the world's water resources [97]. Therefore, water consumption in the building sector has a greater significance and has an impact on the world's water resources. Using rammed earth requires comparatively less water than that for concrete and brick manufacturing [98]. Similar to embodied energy, water embodied in materials through the production, extraction, and manufacturing of construction materials has been studied by various researchers [99]. Concrete has been identified with a higher embodied water coefficient of 11 KL/m^2, while conventional clay bricks have an embodied energy coefficient of just 1 KL/m^2 [100]. A comparative study on embodied water is necessary to understand the capability of modern earthen techniques in reducing water consumption. Thus, water use efficiency can be observed with the modern construction practices of earthen structures and can be viewed as a reinforcing strategy to achieve Target 6.4 of SDG 6. Furthermore, as the concepts of embodied water are unexplored in the earthen techniques’ domain, scholars may pursue this line of research in the future.

4.2.5 SDG7, Ensure access to affordable, reliable, sustainable, and modern energy for all:

Earthen construction techniques have the advantage of utilising excavated soil from the foundation in addition to the raw source, thereby reducing the production cost [101]. Studies show that utilisation of on-site soil reduces the energy demand by 62% to 82% compared to concrete masonry units [102], [103]. This results in the achievement of higher energy efficiency. Researchers have also found that the earthen blocks stabilised with cement only require one-fourth of the energy consumed by burnt clay bricks [103]. The total embodied energy of cement-stabilised rammed earth walls (0.4 – 0.5 GJ/m^3) is also found to be lower than the burnt clay brick masonry (2 – 3.4 GJ/m^3) and concrete slabs (0.80–0.85 GJ/m^3) [104]. Such a comparison of embodied energy between the various construction materials identifies earth materials as a higher energy-efficient solution for construction. Therefore, earthen materials have a vital contribution to make towards the achievement of Target 7.3 which is to double the improvement of energy efficiency.

4.2.6 SDG8, Promote sustained, inclusive, and sustainable economic growth, full and productive employment, and decent work for all:

The production of earthen dwellings involves simple processes [101]. This requires fewer skills and local community members can be trained with minimal efforts, thus offering additional employment opportunities and enhancement in earnings. Researchers have also observed that the paradigm shift towards the circular economy from a linear model is inevitable in the construction industry for the conservation of resources [105]. The earthen materials can be reused or recycled even at end stage of a structure, resulting in a circular model [106]. Thus, earthen techniques strengthen the successful transition towards a circular economy and reinforce the achievement of Target 8.4 by improving resource efficiency in production and consumption.

4.2.7 SDG9, Build resilient infrastructure, promote inclusive and sustainable industrialisation, and foster innovation:

Modern earthen methods, such as rammed earth production in Australia, have shown adaptability to industrial processes with material supply chains and technical consultation and design for thermal insulations, cement stabilisation, and steel reinforcement [108, 109]. Nowadays, various water-repellent additives have been developed for earthen walls [108]. This adaptability towards industrial processes, including the machine-based production of CSEB blocks, can be viewed as a visible positive contribution towards target 9.4 of SDG 9. They can be produced locally using natural materials, semi-skilled labor, and minimal transportation, making them an affordable and sustainable option [107]. Thus, modern earthen methods can contribute much towards the achievement of Target 9.1 of SDG 9 as an affordable and sustainable technique.

4.2.8 SDG11: Make cities and human settlements inclusive, safe, resilient, and sustainable:

SDG 11 is more focused on cities. However, earthen techniques, traditionally associated with rural settlements, are gaining attention due to climate change and their cost-effectiveness and energy efficiency. Concerning the rising cost of conventional construction practices, these techniques contribute significantly to the achievement of Target 11.1 as affordable housing solutions [88,107,110]. However, the number of earthen homes is decreasing globally due to demographic shifts and cultural conflicts, especially in developing nations [18]. In many countries like Afghanistan, the vernacular architecture is rooted in earthen methods, and the importation of other techniques could result in a cultural conflict [111]. Therefore, development efforts in this area could safeguard this architectural practise and make a visible contribution towards Target 11.4. Similarly, target 11.5 is focused on reducing the effects of natural disasters, and studies have proven the better performance of earthen dwellings provided confinements, runners, and reinforcements against seismic conditions [17,59,112]. Regarding target 11.6 on reducing the impacts of environmental pollution, it is noted that many earth techniques like Cob can reduce air acidification by 89 to 95 % and air particulate pollution by 96 to 98 % when compared with masonry units [93,128]. Thus, these techniques have a reinforcing contribution towards the achievement of target 11.6, as illustrated in Table 3.

4.2.9 SDG12: Ensure sustainable consumption and production patterns:

Resource efficiency involves reducing the use of primary and non-renewable resources, producing high-quality goods with less waste, and preserving the long-term worth of products [113]. Studies show that earthen techniques, such as rammed earth stabilised with cement or lime, require lower embodied energy than conventional methods [114]. Also, savings in logistics as the material can be locally resourced and the reusability makes this technique a green technology [106]. Even the demolition waste disposal of earth materials also has no serious environmental hazard involved [115]. In addition, many industrial by-products can be utilised for stabilisation, providing opportunities for waste management [116-118]. All these can be viewed as a visible contribution towards the achievement of the 12.2, 12.4, and 12.5 targets of SDG 12. 'Sustainable lifestyle' covers a broad variety of actions covering resource conservation, choosing 'green' technologies, and individual behaviors during various situations [119]. As a 'green' technology, proper education is needed to raise public awareness and promote earthen construction practices. Thus, earthen construction practices have a reinforcing contribution towards the achievement of target 12.8.

4.2.10 SDG13, Take urgent action to combat climate change and its impacts:

Traditional methods like cob can reduce Global Warming Potential (GWP) by 75-82% compared to conventional concrete masonry units [102]. Similarly, for CSEB and rammed earth, a GWP of 0.39 kg CO_2 eq./block and 47.5 kg CO_2 eq./m^3 were found, respectively causing a 50 % reduction in potential environmental impact [120]. Cement production causes greater CO_2 emissions, therefore, minimal cement usage or using alternate cementitious materials can reduce the embodied carbon [101,121]. Hence, the adoption of earthen techniques can contribute positively towards the achievement of target 13.2, making it a climate mitigation measure. The disaster resilience capacity of earthen techniques has been discussed earlier. Incorporating the steel reinforcement has been found to improve its seismic performance, and there are cases of applications during post-disaster rehabilitation programs [59,112]. All these can be viewed as visible contributions towards the achievement of target 13.1.

4.2.11 Goal 15, Sustainably manage forests, combat desertification, halt and reverse land degradation, and halt biodiversity loss:

Rapid infrastructure development has caused significant pressure on biodiversity and ecosystems where a growing portion of open areas and farmland is being used for building [122]. This has also led to the depletion of fertile land and serious land degradation. Conventional construction practices, heavily reliant on mining and quarrying, cause destruction to natural habitats and indirectly affect biodiversity [124]. However, the life cycle inventory analysis of earthen materials shows that they can be either reused or recycled after demolition [106]. Thus, it reduces the pressure on natural resources and could contribute towards the achievement of target 15.5. Depositing waste in landfills remains the major waste disposal method in the construction industry from a global perspective [123]. This eventually results in land degradation. However, as earthen materials can be reused after demolition, and even the disposal of earthen materials has no environmental hazard involved [115] it can indirectly contribute to towards achieving Target 15.3.

4.2.12 Goal 17, strengthen the means of implementation and revitalise the global partnership for sustainable development:

Innovation in the building materials sector is crucial for the attainment of SDGs in all nations. To transform earthen materials from "poor man's materials" to workable ones, technology transfer through capacity-building programs is necessary [125,126]. The growing need for affordable housing presents an opportunity for earthen techniques in developing countries [127]. However, construction professionals often hesitate to specify and select earth materials due to their limitations in knowledge of technologies, highlighting the need for capacity building among them [86]. Such initiatives will all have a reinforcing contribution to the achievement of targets 17.7 and 17.9 of SDG 17. Researchers suggest that advancements have to be made at the policy level for popularizing earthen constructions, synthesising available technical data and conducting environmental assessments [109]. Regulatory collaboration and policy discussions that bring various stakeholders together are necessary to encourage earthen materials and techniques in mainstream construction [128]. This will have an enabling contribution to the achievement of target 17.16 of SDG 17.

Of the 17 SDGs, 12 SDGs were discussed in detail above. Four SDGs, namely, SDG 2 (zero hunger), SDG 5 (gender equality), SDG 10 (Reduce inequality), and SDG 16 (peace, justice, and strong institution) were identified with null contributions concerning building materials from the works of literature (Omer and Noguchi 2020). In the current study, these SDGs were provided with zero scores since no positive or negative contributions were found. Omer and Noguchi (2020) found that locally sourced building materials cause a trade-off for SDG 14 (life below water), for the construction activities in the coastal area which may carry out excavations and use the local resources. However, the present study identifies earthen methods not practiced in the coastal regions. Therefore, these methods do not have any positive or negative contribution towards SDG 14.

Similarly, in contrast to the various trade-offs shown in the study of Omer and Noguchi (2020) for the general material case of locally sourced building materials, the earthen materials were identified with positive contributions due to various reasons as discussed for each SDG earlier. This study found that the trade-offs marked by Omer and Noguchi (2020), were overcome by the following reasons; (1)

the efficiency of material and energy usage, (2) the promotion of a circular economy by reuse and recycling, (3) the adoption of disaster-resilient features, (4) affordability, (5) no pollution and (6) no land degradation since demolition waste of earthen materials can be treated as degradable landfill. Therefore, this study does not identify any trade-offs for earthen construction practices. But based on the qualitative positive contribution towards the achievement of relevant targets for each SDG, scores were assigned and shown in **Table 3**.

4.3 An overview of contributions towards achieving SDGs

This study investigated various attributes that can contribute to the achievement of various UN-SDGs while adopting earthen construction techniques. **Fig. 6** is the diagrammatic representation of various observations. Factors such as affordability, vernacularity, disaster resilience through technology adaptation, lower Global Warming Potential (GWP), possibilities of sustainable industrialisation, reusability, recyclability, and higher energy efficiency can be regarded as the attributes leading toward achieving a visible positive contribution. Similarly, factors such as lesser water demand for earthen blocks, transmission from a linear economic model to a circular one, the outlook of sustainable living, and opportunities in developing nations can be identified as reinforcing attributes toward the achievement of various SDGs and their relevant targets, as shown in **Table 4**.

Fig. 6. Attributes of earthen construction techniques for achieving various targets of UN-SDGs

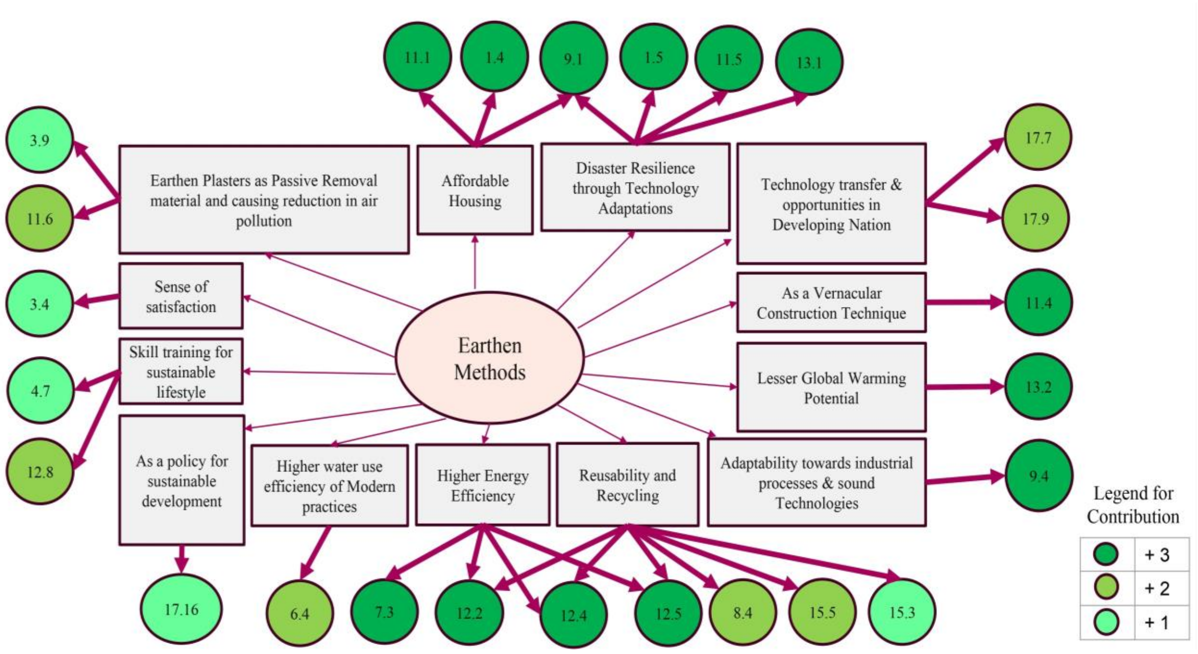

Table 4. SDGs and the relevant targets achieved by adopting earthen techniques

Contribution Type	SDGs	Targets
Visible (+3)	1, 7, 9, 11, 12, 13	1.4, 1.5, 7.3, 9.1, 9.4, 11.1, 11.4, 11.5, 12.2, 12.4, 12.5, 13.1, 13.2
Reinforcing (+2)	6, 8, 11, 12, 15, 17	6.4, 8.4, 11.6, 15.5, 12.8, 17.7, 17.9
Enabling (+1)	3, 4, 15, 17	3.4, 3.9, 15.3, 4.7, 17.16
Invisible (0)	2, 5, 10, 14, 16	
Constraining (-1)		

This study also identifies a minimal contribution for relevant targets of certain SDGs. Earthen materials as pollution reductant render and the sense of satisfaction for earthen dwellings were a few attributes identified as minimal contributions. This study identifies that one of the major reasons for the degradation of the land due to the construction industry is the waste generated due to landfills. For the earth materials, the excavation of soil is involved. But the reusability of earth materials after demolition and non-polluting even in the case of open disposal gives a slight edge to earthen techniques and is also identified with a minimal contribution towards an end to desertification. Similarly, education and skill training in sustainable housing practices, policy advancements, and multi-stakeholder engagement for this technology and practices can be seen as enabling contributions towards the achievement of certain SDGs and their relevant targets. Even though this study was able to successfully use the framework by Omer and Noguchi (2020) for a qualitative investigation, the analysis based on scoring can vary depending on different cultural contexts and different researchers' biases. We acknowledge this limitation. However, despite these limitations, this study makes a unique contribution to theory and practice.

4.4 Future Scope

The major challenge associated with earthen techniques is to increase its acceptance in the mainstream construction domain. As a sustainable construction practice capable of achieving various UN-SDGs, there needs to be knowledge transfer and capacity building among the society which has to be brought through policy initiatives. However, the universality of earthen construction techniques as resilient recovery planning is questionable and case-to-case specific, depending on regional and climatic conditions. This study points towards the need for further exploration of resources, strategies, and policy planning for disaster self-recovery using locally available technologies.

5 Conclusion

The disaster self-recovery approach, based on vernacular construction techniques, has received greater attention since the restoration program can be carried out with localised skills and knowledge, can use the available resources, and needs little outside assistance. Earthen methods are techniques that have been used for thousands of years in various parts of the world. While the widely practiced techniques were wattle and daub, cob walls, and abode earlier, many recent advancements have been brought in the modern-day practices of earthen techniques like CSEBs and Rammed Earth. As a sustainable housing practice, earthen methods also have the capability to contribute much towards various UN SDGs. This study was able to successfully utilise the methodological framework put forward by Omer and Noguchi (2020) to investigate the relationship between earthen-building techniques and the relevant targets of various SDGs. This study conducted a literature review, investigating the opportunities of earthen construction techniques for disaster resilience and the contributions of earthen construction techniques towards achieving UN SDGs. The major findings of this study are the following,

- During disasters, the major cause of failure is the loss of structural integrity and the various case studies presented in the study proved that, in many parts of the world, certain methods have been adopted to incorporate a disaster-resistant design.
- In many other parts of the world, like the *Pa Chim* (rammed earth) construction in Bhutan, earthen methods are practiced without any features incorporated. These dwellings are constructed without any proper element-to-element connections. This has resulted in increasing the vulnerability due to disasters in these regions. No standards or codes have been followed in certain cases.
- While adopting any vernacular earthen techniques as a housing solution for disaster resilience, this study highlights the importance of its engineering consultations and experimentations during the planning stage to improve traditional housing to be a more appropriate solution in many respects.
- Various strategies ranging from stabilisation methods, reinforcements, and anchoring techniques have been developed by researchers in this domain to improve the resistance of earthen constructions against various disasters.
- It is important to adopt such new technological knowledge and enhancement measures to improve the longevity of the structure, since these structures are more susceptible to being affected by the surrounding environmental conditions.
- Recovery planning for disaster resilience shall adopt a participatory "co-design" approach, where the persisting challenges can be precisely observed from the communities, can include the locals in the decision-making processes, and bring the skill development towards resilient construction practices.

- A conceptual framework is presented for highlighting the importance of technological adaptations and capacity building in communities, while adopting a bottom-up approach.
- Of the 17 SDGs, earthen techniques can directly or indirectly contribute to at least 12 SDGs. A higher positive contribution was observed for the relevant targets of SDGs 01, 07, 09, 11, 12, and 13.
- Even though Omer and Noguchi (2020) found various trade-offs for the general material case of locally sourced building materials (the category in which the earthen materials were included), this study proves that earthen materials can overcome these trade-offs due to the following reasons:
    - Efficiency of material and energy usage.
    - Promotion of a circular economy by reuse and recycling.
    - Ability to adopt disaster-resilient features.
    - Affordability.
    - No pollution
    - Minimal environmental impact as a landfill after demolition.

This study on contributions to the various SDGs highlighted the importance of earthen techniques to be encouraged as a sustainable lifestyle. All these studies on interconnections between earthen materials and SDGs and the resilience capacities of the earthen construction practices based on literature review would provide primitive information for the policymakers, practitioners, and developers to formulate strategies upon implementation.

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CRediT authorship contribution statement

Harisankar R: Investigation, Methodology, Writing – original draft. **Arjun Siva Rathan R T**: Conceptualization, Methodology, Supervision, Writing – review & editing. **Sudha Arlikatti**: Conceptualization, Methodology, Writing – review & editing.

Conflicts of Interest

The authors declare that they have no conflicts of interest to report regarding the present study.

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