Innovative Infrastructure Solutions (2023) 8:39
https://doi.org/10.1007/s41062-022-01010-8

STATE-OF-THE-ART PAPER

A state-of-the-art review on sustainable low-cost housing and application of textile reinforced concrete

Sophia Immanuel[1] · **K. Baskar**[1]

Received: 22 August 2022 / Accepted: 24 November 2022 / Published online: 2 December 2022

Abstract

This article reviews the various housing schemes implemented in India post-independence. This year marking the 75 years of independence, the demand for affordable housing for economically weaker sections and low-income group are at stake in the country. In achieving "Housing for all" in the rapidly urbanizing Indian context, Textile reinforced concrete (TRC) technology promises to be environmentally and economically "affordable" consuming significantly fewer quantities of building materials with high embodied energy. Textile reinforced concrete is the most durable, lightweight, and highly ductile structural component with its non-corrosive textiles replacing the conventional steel reinforcement used, and it can be the most feasible solution to the problem of implementing affordable housing in urban India. TRC has been an excellent solution for the retrofitting and strengthening of existing infrastructures paving its progressive research direction of using this as a load-bearing structural component. With a substantially lower carbon footprint than conventional RCC structures, TRC offers better potential for sustainability. Furthermore, this article proposes a futuristic direction to enhance the research on the application of TRC as a structural component for prefabricated low-cost housing.

Keywords Affordable housing · Sustainable · Low-cost materials · EWS · TRC · PMAY-U

Introduction

Urban sprawl and migration from rural to cities have resulted in severe housing scarcity in metropolitan India, especially among the economically weaker sections of the society [1]. The "Summit on Sustainable Development" in New York in September 2015 with 193 United Nations member nations gathered with a solid motive to eradicate poverty by 2030 in developing countries and to build a sustainable future considering the 17 sustainability global goals. By 2030, one of the most important goals was to ensure everyone would have access to adequate, secured, reasonably priced housing with all the basic amenities and to rehabilitate the slums. As per the RBI report, by 2025, the Indians residing in cities are estimated to exceed 543 million. By 2020, urban regions will have contributed to more than 70% of India's Gross Domestic Product (GDP). In terms of Foreign Direct Investment (FDI) inflows, construction is the fourth largest industry. "*Housing for All*" a government initiative in India, is anticipated to attract 1.3 trillion US dollars in investments in the housing industry by 2025 [1].

In India, an approximated deficit of around 18 million housing units were identified, of which 99% belong to the economically weaker sections of society [2]. Hence, the policymakers in India foresaw this worldwide goal and set a lofty deadline of 2022 for achieving it in the country. The Indian government, along with the Reserve Bank of India (RBI), has taken several measures to help low-income families with various schemes and initiatives so that poverty in India is wholly eradicated.

"*Affordable housing*" is one such initiative of the government in which these housing units make them more accessible to the country's poorest citizens. Housing regulations, government incentive schemes, and an interest subsidy scheme under the Pradhan Mantri Awas Yojana (PMAY) were all positive steps in this direction [3]. This sector has enormous demand but very minimal supply [4]. The United Nations financed the research project on *Mainstreaming Sustainable Social Housing in India*

✉ Sophia Immanuel
sophiaimmanuel2011@gmail.com

K. Baskar
kbaskar@nitt.edu

1 Department of Civil Engineering, National Institute of Technology, Tiruchirappalli, India

Project (MaS-SHIP), which is quite like the PMAY-U, it aimed to examine the social implications on the development of housing units in urban India. Hence, this research on affordable housing is even more critical since it has the potential to address the problems, meet the tremendous demand in this low-cost housing sector, and bridge the supply–demand gap. The building phase was at complete halt during the covid-19 epidemic, resulting in a significant delay in constructing houses for EWS communities. Following covid, the cost of conventionally used construction materials has reached an all-time hike, necessitating the need to adopt a low-cost alternative material that functions well in all weather conditions and can be prefabricated and deployed on-site as soon as possible. Most of the Housing models projected have steel reinforcement which is costly and exhibit corrosion well before the targeted service life of the structures. In alternative to this, a thin and light weight structural elements using Non-Corrosive Textile reinforced composite panels (TRCP) [5] which eliminates thicker cover requirement can be a promising solution for affordable housing. TRC allows the design of very thin-structured concrete elements with high strength in compression and tension [6].

This article proposes the most effective solution incorporating TRC made with innovative sustainable high performance fine-grained cementitious matrix and textiles embedded in the matrix as shown in Fig. 1, which are not only cost effective but also would perform well in any kind of exposure. Techniques for large scale production and deploying its effective application in various places in our country. The key objective of low-cost housing construction approaches is to lower the cost of construction by employing good alternate materials and effective techniques and methods, which is what this paper outlines. This article also discusses the necessity for affordable housing, obstacles to its creation, and a feasible low-cost housing construction technique using Textile Reinforced Concrete.

Fig. 1 Textile reinforced concrete casting process and hardened component [7]

Housing schemes in India: an overview

Government of India has significantly introduced various housing schemes in India following Independence which are outlined in this section. It reviews the design of these initiatives to see if the strategy defining such design has satisfactorily answered housing poverty in the cities [8]. The housing policy of India must change in response to the extent the urbanization has evolved. The failure of several housing initiatives by the Government of India that have been tried over the last eight decades has been attributed to the lack of an integrated approach in addressing the housing poverty and the reason for the still existing slums. Construction of Low-Cost housing units or the facilitation of such construction through financial aid has been the dominating technique for addressing housing poverty [9, 10]. Such actions do not really accomplish anything to stop the spread of slums. Additionally, the tactics being used do not fit the nature of the urban poverty the nation is experiencing. Under PMAY-U, 1.3 crores of new Low-cost Housing for Economically Weaker section (EWS) were sanctioned to be completed by March 2022 but currently only 61.77 Lakhs houses were only possible to be constructed within the stipulated time. Using a technology that not only is sustainable but cost effective with minimum CO_2 footprint is what is feasible for the remaining housings to be constructed for EWS. In Fig. 2, Various Housing schemes implemented in India post-independence is briefly highlighted using a flowchart.

Need for low-cost housing in India

There has been a significant imbalance in the supply–demand of urban housing in India, according to the Technical Group (TG-12) Report on Estimation of Urban Housing Shortage [11]. Housing units for the EWS sectors of society are perpetually scarce in all developing countries worldwide.

It is challenging to determine the precise extent of the housing shortage in metropolitan cities due to unchecked growth, fast migration, and a lack of reliable statistics. For 66.30 million urban families, a technical team established by the Ministry of Housing and Poverty Alleviation (MHPUA) estimated a deficit of 24.71 million housing units at the finish of the 10th five-year plan. According to the group's estimates, most of the deficit was in the EWS category, where the gap was estimated as 88 percent; LIG accounted for 11 percent; and MIG/HIG groupings, where the anticipated shortfall was only 0.04 million housing units. The group estimated that the total housing demand

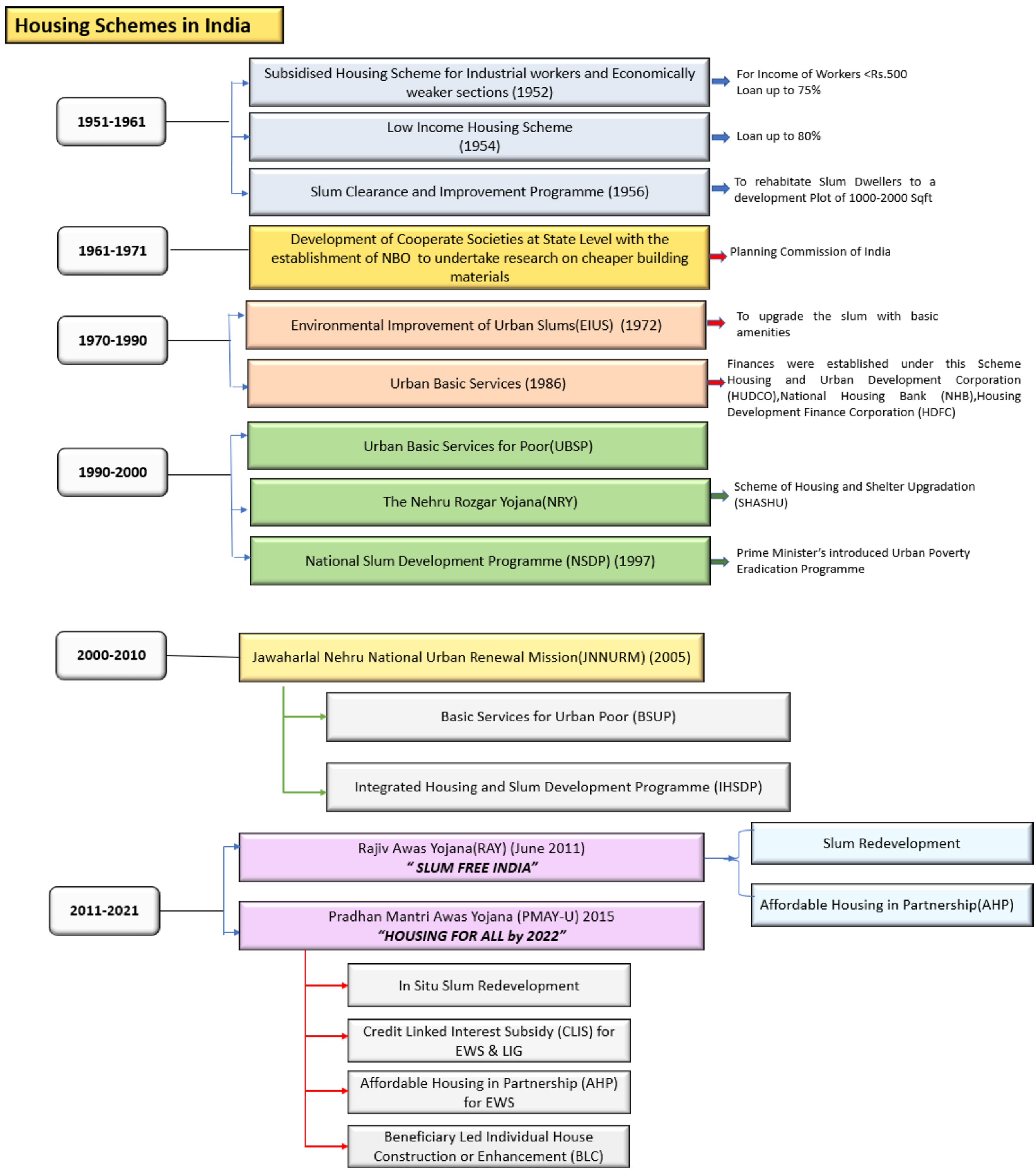

Fig. 2 Various housing schemes from 1950 to 2022 [9, 10]

in urban centers during the 11th Five Year Plan (2007–12), including backlog, will range from 26.53 million housing units for 75.01 million families.

It is stated by several researchers that 30 million homes would be needed by the year 2020 to satisfy the national aim of providing affordable shelter for all, if the current trend of increasing the backlog of housing continues. Technical Committee also critically examined the housing shortage in each category separately and found that the EWS category had the highest housing shortage, with

99.9% of all EWS households experiencing a shortage, followed by LIG with 10.5 percent and MIG/HIG with only 0.2 percent of households experiencing a shortage. It is observed that 96% of India's entire housing deficit was attributable to the Economically weaker sections (EWS) and low-income group (LIG) as stated in Table 1 from MHUP annual report 2012.

The McKinsey Report [12] predicts that by 2030, 68 cities in India will have a population of one million or higher, up from 42 now, with 40% of the country's people residing in urban regions as depicted in Fig. 3. It predicts that from 19 million housing units in 2012, the demand for affordable housing will go up to 38 million units in 2030.

The housing unit requirement for EWS with a max carpet area of 30 sq.m is given in Table 2 is possible only with low-cost building materials which will be durable with low maintenance costs, Eco-friendly with low Carbon footprint, and Economical.

The number of houses finished under PMAY-U has increased by three times since April 2017, demonstrating the central government's relentless effort for affordable Housing. The current status of the PMAY-U scheme is presented in Table 3.

Within the framework of this programs, the government intends to build 2.03 lakh crore housing units. According to the latest data given by the MoHUA in August 1 2022, approximately 21,566 Projects have been approved for the building of 122.69 Lakhs homes under this initiative, of which 102.59lakhs homes are already under construction and 61.77 Lakhs homes have been completed [13]. PMAY-U's current report also mentions that 16 Lakhs new houses will be constructed using new technology.

Table 1 Shortage of Housing in Urban India as reported by the Ministry of Housing and Urban Poverty (MHUP) report [11]

Types of housing units	Shortage (in 2012)
People residing in substandard housing (Katcha Houses)	0.99
People living in obsolescent houses	2.27
People residing in overcrowded localities	14.99
Poverty-stricken homeless people	0.53
Total Housing requirement	*18.78*
I. Economically weaker Sections(EWS)	10.55 (56%)
II. Low income group (LIG)	7.41 (40%)
III.Medium and high-income group (MIG + HIG)	0.82(4%)

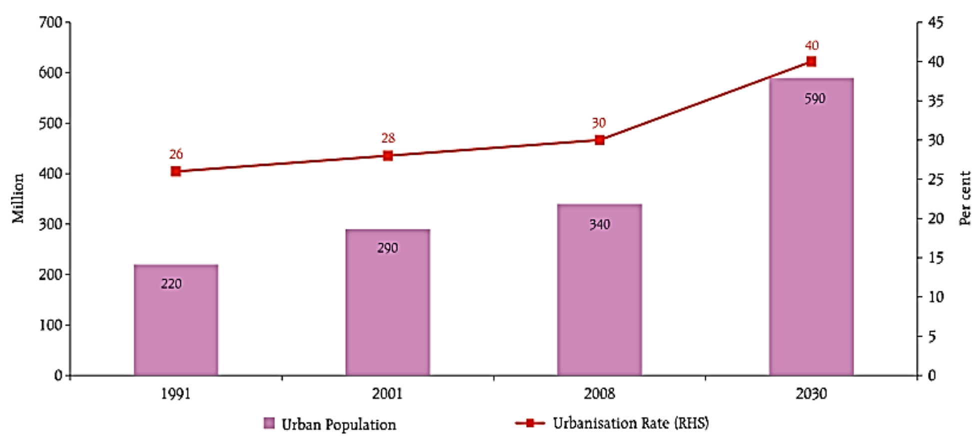

Fig. 3 Urbanization rate in India from 1990 to 2030 [12]

Table 2 Under credit-linked subsidy scheme (CLSS)

Category of beneficiaries	Income (per annum)	Interest subsidy (%)	Loan amount (₹ in lakhs)	Carpet area (sq.m.)
Economically weaker section (EWS)	Up to ₹ 3 lakhs	6.5	6	30
Low income group (LIG)	₹3–6 lakhs	6.5	6	60
Middle income group (MIG –I)	₹6–12lakhs	4	9	120
Middle income group (MIG–II)	₹ 12–18 lakhs	3	12	150

Table 3 Current status of PMAY-U "Housing for all by 2022". *Source*: Compiled from PMAY(U)-HFA'22 progress report, MoHUA (GoI), 2022 (1 crore = 100 lakhs; 1 lakh crore = 0.1 million)

Project Proposal considered	21,566 projects
Project costs	₹ 8.31 Lakhs Cr
Central assistance approved	₹ 2.03 Lakhs Cr
Central assistance released	₹ 1.20 Lakhs Cr
Houses sanctioned	₹ 122.69 Lakhs
Houses grounded	₹ 102.59 Lakhs
Houses completed	₹ 61.77 Lakhs

corros *As of August 1, 2022,

**Included incomplete houses of earlier NURM (National Urban Renewal Mission)

Sustainable materials for low-cost housing

Utilizing materials that are readily accessible locally helps reduce the negative impact on the environment of the infrastructure being built in the locality. The suitability of sustainable construction materials and building structures can be determined by their adherence to variability in climate conditions and natural catastrophic threats. Advancements in technologies and information sharing with local populations are sought in every situation. Local people can be made aware of these materials and may be trained and educated on low-cost housing construction to create more sustainable building materials [14].

The Building Materials and Technology Promotion Council (BMTPC), Ministry of Housing and Urban Poverty Alleviation (MHUPA), Government of India (GoI), has been in charge of studying, assessing, validating, promoting, and endorsing innovative construction technologies for acceptance to be implemented for low-cost mass housing schemes across the nation. BMTPC has recommended the following technologies, including [15, 16].

There are numerous technologies that can be used to provide affordable housing. It is challenging to recommend a particular technology for use throughout the entire country. Because of this, it is crucial to conduct research in each area to determine the best technology to utilize given the context, location, climate, local requirements, available resources, tenant preferences, cultural considerations, time, cost, sustainability, and other factors. To select the optimal technology and accomplish sustainable development goals, it is crucial to conduct a trade-off analysis between several factors. The demand for housing will necessitate the construction of millions of houses worldwide. Technology and sustainability were not discussed in further detail in the housing efforts. These details may significantly affect an aim of massive accumulation. To reduce embodied energy, each project should be approached as a unique circumstance and the appropriate technology should be selected based on its unique requirements.

Embodied energy has a substantial impact on the overall life cycle energy of naturally ventilated and partially air-conditioned buildings. Additionally, the element of thermal comfort, which is directly related to energy, is really what keeps the tenants in any type of housing. Thus, thermal comfort does have a big impact on how well housing plans work. Passive design strategies, for example, may in some cases be effective in attaining thermal comfort and lowering operational energy in tropical regions. In some cases, however, passive design is unable to offer the required comfort for independent life. Therefore, research should also point in that direction. more cost-effective cooling and heating options that are also more energy efficient. As a result, many considerations should be considered when choosing a technology, including whether prioritizing the criteria will help with decision-making in conflict situations. Sustainability in building can only be achieved if these needs are considered at the planning stage.

In Fig. 4, bamboo dominates a variety of uses when evaluating environmentally acceptable building materials. In spite of its relatively low fire resistance, bamboo has demonstrated its effectiveness as a material for reinforcing. In particular the north-eastern regions of India, bamboo continues to prove to be a cost-effective alternative in composite forms and with the use of various protective coatings. Mud blocks and coir-based solutions are becoming more effective in South India. The coir industry is currently booming in the twenty-first century, with a diverse range of products being developed, from coir concrete pavements to coir polymer composite boards and panels for doors and walls. These materials are not long-lasting and eventually deteriorate.

Figure 5 depicts the modular housing technologies that the BMTPC [14] recommends. Utilizing waste materials, researchers have developed bricks such Calcium Silicate Bricks, Lime Fly Ash Bricks, and Aerocon Blocks for Walls that are more lightweight and efficient than regular bricks. The conventional in situ construction method, which requires months to complete, has been superseded with precast construction thanks to technological advancements. Precast technologies allow for the rapid construction of housing units [19–22]. Complex geometrical designs are achievable with precast and pre-engineered technologies thanks to the use of optimized materials, which is not possible with traditional methods. Both quantity and quality are fully considered utilizing hollow core, waffle, and pre-stressed torn precast slabs has enhanced strength and durability while reducing material consumption, cost, and geometrical requirements. In comparison with the cost of reinforcement used in above structures and sustainability as the major concern, the use of textiles is quite economical with high performance.

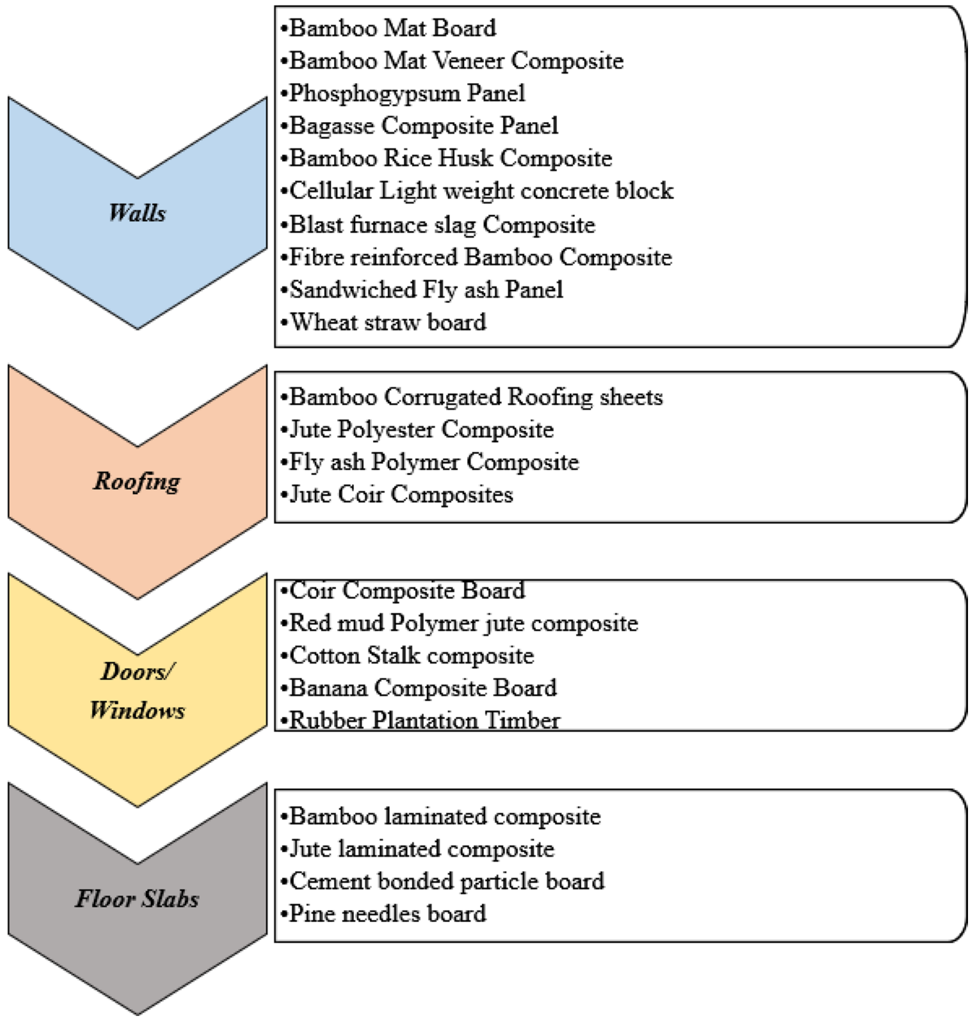

Fig. 4 Various eco-friendly, energy efficient, cost-effective composite products for Low-Cost Housing (BMTPC) [14, 15, 17–25]

Out of the eighteen technologies mentioned most of them are lightweight, but the thickness of the walls or slabs is very similar to the conventional RC structures. Most of these techniques use steel reinforcement subjected to corrosion during its lifetime. Hence, the use of technologies that survives to a greater extent is the need for affordable Housing in India. Housing units with durable modern technology, earthquake resistant, stable in waterlogged areas during monsoon and flood, withstand high temperatures during summer, and has good freeze and thaw resistance during peak winter is the most critical solution for the construction industry in India. Researchers are working on still more advanced technology to design the structural components based on crack-resistant design. Bridging the crack in the structure under various loadings utilizing fibers and textiles instead of steel will help prevent catastrophic failure of structural systems, promising the life safety of the people residing.

Performance criteria for affordable housing technologies in India

In Table 4, the building technologies currently adopted in India for Affordable housing in various regions is compared based on its physical properties, structural performance and considering sustainability and durability aspect. It is observed that some of the low-cost technologies like Aerocon Panels [28] and EPS Panels [29] which are widely used perform low when durability is concern, cracks are developed within a decade of the structure built. The failure mechanism of EPS panels are through shear failure, even though cost is really low but in long run they do not perform well. Low-cost housing does not mean to compromise on the quality of construction.

Bricks made of Flyash [30–32], compressed mud blocks [33–35] were extensively used for rural housing

Fig. 5 Modular housing technologies recommended & approved by BMTPC [8, 15, 19, 21–27]

in various districts in India. Reuse of waste materials inspired researchers to develop new building materials out of wastes. Ferrocement technology was quite popular in 20th century for its quicker construction and less requirement of shuttering for construction of panels, water tanks, STP tanks, etc. Textile reinforced concrete incorporated ferrocement concrete concepts by replacing the wire meshes with textile layers [36].

TRC is now utilized extensively for nonstructural components like exterior paneling and facades, and research into its application in sandwich panels is still underway. Numerous prototypes have lately been created, but due to the difficult design processes, their practical use is restricted. Additionally, there was a lack of assurance that such a material could be used as a structural element due to the absence of production and testing standards. The modeling of intricate components as TRC shells, bridges, and decks will be made simpler if the existing problems are solved, guaranteeing that this material finds more uses.

TRC as a feasible solution for low-cost housing

Adoption of cutting-edge and creative building technologies is primarily required to shorten construction time, minimize construction costs, and guarantee construction quality. A new era in affordable housing would be ushered in by the Government of India's Technology Mission under PMAY to source the most cutting-edge and cost-effective global technology.

Sustainable construction techniques are increasingly being used in the modern day as a prime driving criterion for advancement in the building and construction industry [46]. The spectrum of sustainability features provided by TRC [47, 48] is extensive. It has the potential to produce components using a substantially lesser material as well as a longer service life in comparison to the traditional concrete which is still being used in our country [49]. TRC

Table 4 Properties of building technologies used currently in India [6, 7, 37–45]

SLNo	Properties	Bamboo	Concrete Blocks	Ferrocement Panels	Aerocon Panels	Fiber Cement Composites	Fly Ash Bricks	Compressed Mud Blocks	Rice husk bricks	EPS Panels	Cellular Foam Concrete Panel	TRC Sandwich Panels
1	Structural	Good in Shear, High flexibility than steel and lower modulus of elasticity	High Strength and be tailored as per mortar mix	Lightweight High strength Low density High crack resistance of mortar	Lightweight, Dry wall connections Easy to handle and place	Lightweight, High strength to weight ratio, Corrosion resistance, Crack resistance	Eco-friendly, Saves energy, High strength,	Local mud used, Economic and energy efficient	Pozzolanic, Economical, Corrosion resistance increases	Lightweight Low shear resistance, Cracks very early	Lightweight Foam concrete	Lightweight, High strength to weight ratio, High performance, High Ductility, Crack Resistant design, Corrosion free, Minimum Cover requirement (thin structural element)
2	Thermal	Good resistance	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	Moderate	Good	Excellent	Excellent
3	Water Resistant	Moderate	Good	Excellent	Excellent	Good	low	Low	Low	Excellent	Moderate	Excellent
4	Buildability	Moderate	Good	Good	Good	Moderate	Good	Good	Moderate	Good	Excellent	Excellent (Any complex geometries)
5	Durability	Low	Moderate	Good	Good (but not crack resistant)	Good	Low	Low	Very low	Good	Excellent	Longer Service life Crack resistant

can also be used to upgrade the mechanical performance of the already existing old, deteriorating structures in order to increase their ability to tolerate higher static and dynamic loads [50].

For more than a century, steel has been employed as reinforcement in concrete. However, steel reinforcement is vulnerable to corrosion, which reduces the effective cross-sectional area of the rebar and, in severe exposure conditions, causes the concrete to spall and collapse structurally. It was demonstrated that substituting textile reinforcement for steel reinforcement can boost the longevity and dependability of buildings [51]. High-performance fine-grained mortar and strong textile materials make up Textile Reinforced Concrete (TRC). The textiles are multi-yarns with a high tensile strength that are often constructed of polymer, carbon, basalt, or alkali resistant (AR) glass. The maximum aggregate size that may be utilized in TRC depending on the dimensions of the structural components and yarn distance. Typically, TRC aggregate has a thickness of less than 2 mm. The positives of TRC are its high tensile strength, pseudo-ductile behavior, and corrosion and acid attack resistance. The TRC composite is also suitable for the fabrication of lightweight structural components as well as for rehabilitating and restoring aging structural elements due to its superior mechanical properties and durability features [50, 52].

Properties of the fiber mesh as reinforcements

Synthetic fibers such as carbon, alkali-resistant glass, E-glass, aramid, polypropylene, and natural fibers like basalt and sisal as shown in Fig. 6 are adopted to develop lightweight TRC structural components. These fibers have high mechanical characteristics compared to metallic fibers like steel which are described in Table 5. Textiles of these fibers are available in woven, non-woven or in knitted forms as shown in Fig. 7 [49]. Several coatings, including epoxy

Fig. 6 Various fibers used as reinforcement in the TRC [52, 53]

Table 5 Properties of various fibers [5, 54, 55]

Fiber	Tensile strength (MPa)	Modulus of elasticity (GPa)	Ultimate strain (%)	Density (g/cc)
AR glass	2500	70	3.6	2.78
Carbon	3500–6000	230–600	1.5–2.0	1.60–1.95
Aramid	3000	60–130	2.1–4.0	1.4
Polypropylene	140–690	3–5	25	0.9–0.95
Basalt	3000–4800	79.3–93.1	3.1	2.7
Sisal	600–700	38	2–3	1.33
Steel	1200	200	3–4	7.85

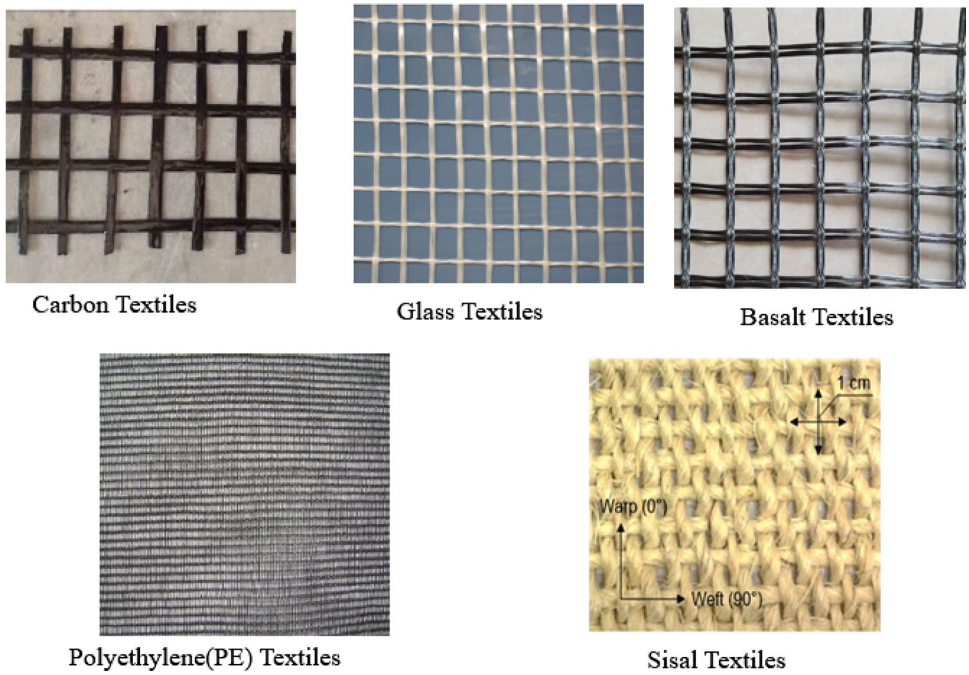

Fig. 7 Configuration of various textile used as reinforcement in the TRC [54–58]

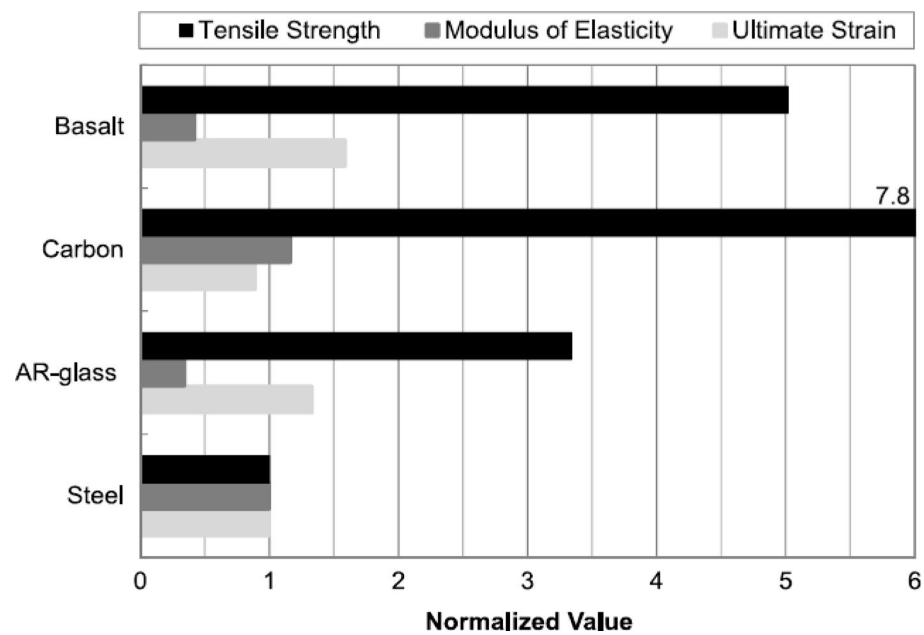

Fig. 8 Comparison of normalized mechanical properties of all Textiles [59, 60]

resin coated, styrene butadiene rubber (SBR) coated, and alkali resistant coating, which preserves these textiles from deteriorating within the alkaline fine grained cementitious matrix.

Considering the facts that have been reviewed and displayed in Fig. 8, the normalized values highlights the merits and demerits of each reinforcing textile. Carbon textiles have lower ultimate strain in contrast to all textiles but have higher tensile strength and elastic modulus. The steel reinforcement bar has the second-highest modulus of elasticity, the third-highest strain, and the lowest tensile strength (at yield). Compared to steel's yield strength characteristics, alkali-resistant glass textiles have better tensile strength and ultimate strain but a significantly lower E-modulus. Steel reinforcement despite having an E-modulus close to 1 basalt fiber yarn tensile strength which is 5 times higher than steel and a significantly higher ultimate strain than the yield strain of steel [60].

Precast application of TRC

The positives of TRC technology include highly polished surfaces, reduced product thickness owing to lightweight structures [38], the potential for free-form architecture, and enhanced mechanical and durability properties. It has a high strength-to-weight ratio, hence its ability to manufacture into complex shapes and geometries can be tailored for its mechanical properties according to specific needs. Properties of textile include its non-corrosive, high fracture toughness [61], low thermal conductivity, and high fatigue performance [62–64]. TRC is used in the production of precast structural components and in the rehabilitation and repair of reinforced structures.

Prefabricated TRC components utilize less concrete, have lower manufacture, transportation, and construction costs, and have less wastage [52]. Hence, they are employed for both architectural and structural components. For the creation of facades, employ fabrics like carbon or AR glass [62]. In India, lot many of architectural structures have incorporated the use of TRC facades which are crack-resistant and innovative designs with aesthetically pleasing forms. In the fabrication of prototype ventilated facade components [65], using a mix of continuous AR-glass threads and textile meshes embedded in self-compacting high-performance fiber-reinforced micro concrete Precast pedestrian bridges utilized TRC. The first TRC Bridge, with an 8.6 m span, was constructed in Oschatz, Germany. For the same, four layers of fine concrete with AR glass yarns embedded as reinforcement within the matrix were used. Then a 17 m long TRC Bridge in Kempten, Germany built to allow vehicles to cross over with maximum weight of 3.5 tons. Later,

Fig. 9 TRC Bridge '*Rottachsteg*' in Kempten, Germany [60]

Fig. 10 First segmental TRC Bridge in Oschatz, Germany [66]

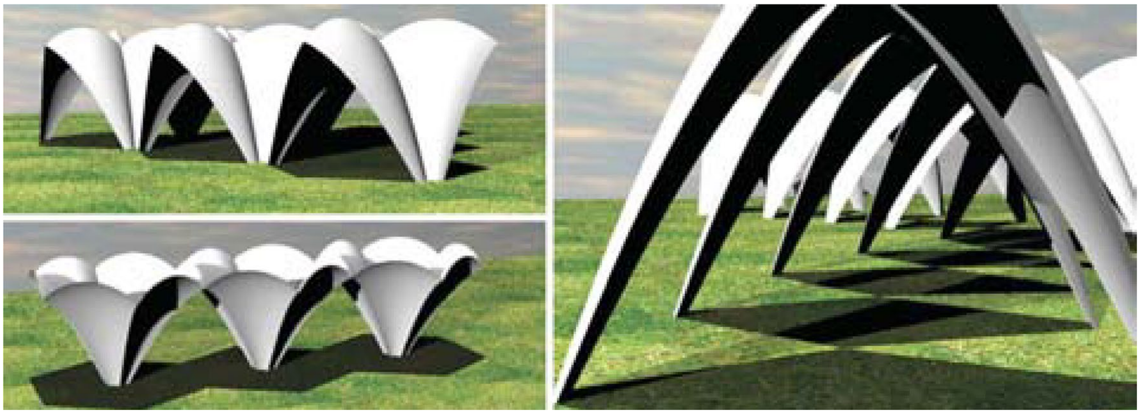

Fig. 11 Shell elements for TRC Pavilion [60]

Fig. 12 TRC shell elements with six cast elements [60]

in 2010, the longest TRC Bridge with 97 m span length was constructed using AR glass textiles in Albstadt, Germany (Figs. 9 and 10).

Free-form structural elements are becoming the most remarkable trends in modern architecture which could be possible only using TRC. Pavilion Building at RWTH Aachen University paved the way for TRC to be utilized as Structural Component [47, 60] (Figs. 11, 12, 13, 14 and 15).

Modular precast TRC sandwich wall panels have been used to construct low-cost housing in Germany and many other countries like Japan, China, and Italy. This technology applies to many regions of the world and is particularly attractive in places where steel and timber are limited [50]. Cast-in-place construction using Textiles as reinforcement with fully integrated molds is attractive for developing

Fig. 13 TRC hypar-shells at RWTH Aachen [60]

Fig. 14 Roof of the bicycle stand made of laminated TRC barrel vault shells at RWTH Aachen [60]

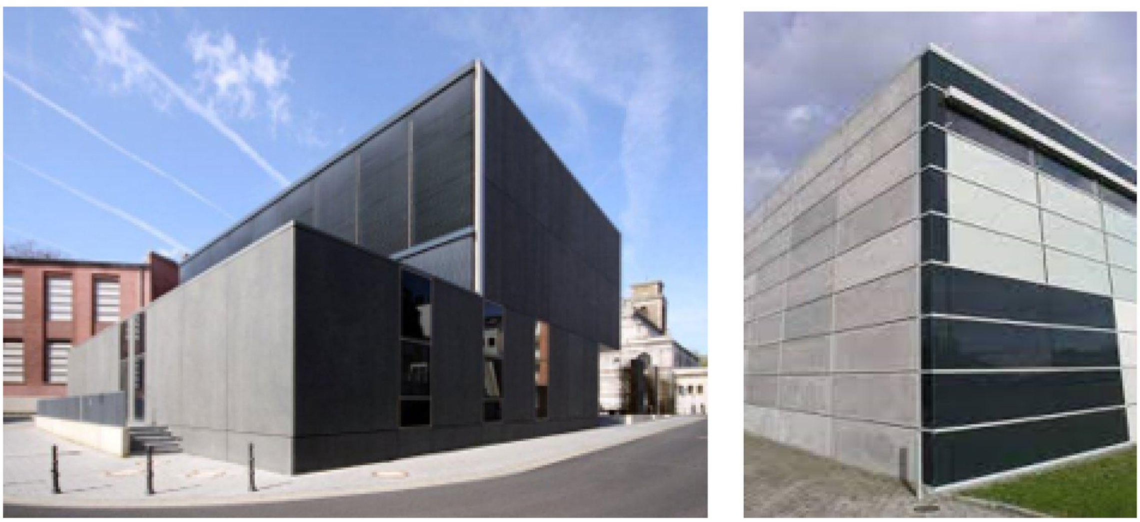

Fig. 15 TRC facades with AR glass Textiles at RWTH Aachen University [65]

energy-efficient, economical, and sustainable infrastructure in India [49, 67, 68].

Conclusion and way forward

Prime Minister Awas Yojana (PMAY), which promises to provide "*Housing for All"* within a constrained timeframe by 2022, has presented several difficulties to engineers, decision-makers, and administrators everywhere. Due to these difficulties, several cutting-edge technologies have emerged in the building sector to accomplish mass housing plans and schemes like PMAY. The critical criteria that drive the development of innovative technologies for low-cost housing are speedy construction, economical cost, ease of construction, quality of construction, and sustainability as a significant concern. Even in current conventional construction practices, structural and functional requirements plays a critical factor for all currently existing and developing technologies; each one is unique due to its conditions to adapt to various geographic, climatic, and other exposure situations. However, major factors that determine which specific form of technology will be used to achieve low-cost mass housing programs were suggested by various researchers. Through this effort, it has also become clear that current technologies are more focused on individual building components than the entire building system in one go.

The main area of this research work is to identify the problem of slow implementation of urban housing in India and propose a feasible solution to it. It aims to help the Government of India PMAY-U scheme to complete its unaccomplished tasks of "Housing for all" at the earliest by incorporating alternative, affordable, low-cost construction materials with higher durability and climatic resistance. This article reviews many modern building technologies adopted in various states in India with locally available raw materials. The study report attempts to offer a feasible and sustainable solution to the housing requirements issue based on its findings, it is evident that Precast lightweight textile reinforced concrete panels will be the best promising choice.

Textile-reinforced composites have drawn a lot of interest as strong, durable, high-performance, lightweight materials for various cutting-edge applications, including aerospace, construction, etc. Textile composites will be used more often in a wider range of applications because of recent advancements in fiber and matrix systems, interface modification techniques, and nanotechnology. In future, textile materials are anticipated to play a significant role in reinforcing sophisticated composite materials In view of all the above applications, for low-cost modular Housing for EWS communities in India, Textile Reinforced Concrete (TRC) is the most effective and feasible solution. With the review of various literatures, it is been observed that very limited research is carried out to adopt TRC as a structural component for infrastructure development. Hence, our current research focuses on developing structural components of TRC and proposing its use for rural housing in India.

Author contributions SI, Ph.D. scholar at NIT, Trichy, has written the original draft. Prof. KB has reviewed and supervised the draft.

Funding Sophia Immanuel reports financial support for the Ph.D. fellowship (MHRD) is provided by the National Institute of Technology Tiruchirappalli for carrying out this research.

Declarations

Conflict of interest The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Ethical approval This article does not contain any studies involving human participants directly performed by any authors. The data mentioned are from the Government of India Portal used for these studies. This is purely a review paper. Hence it reviews various technologies implemented in India and proposes a new solution to the problem.

Informed consent None.

References

1. Gandhi S (2012) Economics of affordable housing in Indian cities: the case of Mumbai. Environ Urban ASIA. https://doi.org/10.1177/097542531200300112
2. Sarkar A, Dhavalikar U, Agrawal V, Morris S (2016) Examination of affordable housing policies in India. Business and Management Horizons. https://doi.org/10.5296/bmh.v4i1.9508
3. Sengupta U (2013) Affordable housing development in India: a real deal for low-income people? Int Dev Plan Rev. https://doi.org/10.3828/idpr.2013.17
4. Agarwal A, Jain V, Karamchandani A (2013) Lead sponsors: Michael & Susan Dell Foundation and Mahindra Lifespaces Sponsors: Department for international development and Ambuja cement co-sponsors: Muthoot Housing Finance and Dewan Housing Finance corporation limited state of the low-income housing market encouraging progress & opportunity to realize dreams of millions
5. Portal NW (2015) Usability of textile reinforced concrete: structural performance, durability and sustainability
6. Djamai ZI, Bahrar M, Salvatore F et al (2017) Textile reinforced concrete multiscale mechanical modelling: application to TRC sandwich panels. Finite Elem Anal Des. https://doi.org/10.1016/j.finel.2017.07.003
7. Zhang Z, Provis JL, Reid A, Wang H (2014) Geopolymer foam concrete: an emerging material for sustainable construction. Constr Build Mater 56:113–127
8. Gavali HR, Bras A, Faria P, Ralegaonkar RV (2019) Development of sustainable alkali-activated bricks using industrial wastes. Constr Build Mater 215:180–191
9. D'Souza R (2019) Housing poverty in urban India: the failures of past and current strategies and the need for a new blueprint
10. Ahmad S (2015) Housing poverty and inequality in urban India. In: Economic studies in inequality, social exclusion and well-being
11. Housing MOF, Alleviation UP, Organisation NB (2012) Government of India ministry of housing and urban poverty alleviation national buildings organisation www.mhupa.gov.in. Group (New York)
12. Sankhe S, Vittal I, Dobbs R, et al (2010) India's urban awakening: building inclusive cities, sustaining economic growth. McKinsey Quarterly
13. Kundu A (2022) Housing for all: from rhetoric to a reality check on slum statistics for operationalization of flagship missions in India. In: Accessible housing for South Asia
14. Bredenoord J (2017) 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. https://doi.org/10.4172/2168-9717.1000187
15. BMTPC and Mohua (2018) Compendium of prospective emerging technologies for mass housing. Building Materials & Technology Promotion Council
16. Keswani K (1997) The contribution of building centres to low-cost housing in India. Build Res Inf. https://doi.org/10.1080/096132197370606
17. Roshan R, Sivapriya SV (2020) Understanding sustainable strategies in low-cost housing. Int J Hous Mark Anal. https://doi.org/10.1108/IJHMA-05-2019-0050
18. Mastrucci A, Rao ND (2019) Bridging India's housing gap: lowering costs and CO_2 emissions. Build Res Inf. https://doi.org/10.1080/09613218.2018.1483634
19. Torres-Sanchez C, Huang C, Steel G (2016) Optimization of assembly instructions for a low-cost housing solution. Inf Des J. https://doi.org/10.1075/idj.22.1.04tor
20. Kulshreshtha Y, Mota NJA, Jagadish KS et al (2020) The potential and current status of earthen material for low-cost housing in rural India. Constr Build Mater. https://doi.org/10.1016/j.conbuildmat.2020.118615
21. Sinha S, Mishra S, Kumar P, Saurabh S (2020) Sustainable low-cost housing using cost effective construction technology "Rat trap bond masonry" and "Filler roof slab" in Bihar. Int J Eng Res Technol. https://doi.org/10.37624/ijert/13.7.2020.1780-1785
22. Kumar S (2002) A perspective study on fly ash-lime-gypsum bricks and hollow blocks for low cost housing development. Constr Build Mater. https://doi.org/10.1016/S0950-0618(02)00034-X
23. Jasvi AH (2015) sustainable use of low cost building materials in the rural India. Int J Res Eng Technol. https://doi.org/10.15623/ijret.2015.0425077

24. Singh MR, Naskar SD (2020) Smart construction: case of '3-S' Prefab technology for sustainable mass housing. In: Lecture notes in civil engineering
25. Raj PV, Teja PS, Siddhartha KS, Rama JSK (2020) Housing with low-cost materials and techniques for a sustainable construction in India-a review. Mater Today Proc 43:1850–1855
26. Garg AA, Yalawar A, Kamath A, Vinay J (2014) Effect of varying cement proportions on properties of compressed stabilized earth blocks (CSEB) - a sustainable low-cost housing material. In: International conference on sustainable civil infrastructure, ASCE India Section, October 17–18, 2014, Hyderabad, India
27. Khadka B (2020) Rammed earth, as a sustainable and structurally safe green building: a housing solution in the era of global warming and climate change. Asian J Civ Eng. https://doi.org/10.1007/s42107-019-00202-5
28. Tarafdar SS (2016) Facade: sustainable facade materials lead to green buildings. Athena Information Solutions Pvt Ltd
29. Mamat R, Rahim JA, Hamzah SH (2015) Behaviour of unreinforced expanded polystyrene lightweight concrete (EPS-LWC) wall panel enhanced with steel fibre. J Eng Sci Technol 10
30. Lavanya B, Kuriya PD, Suganesh S et al (2020) Properties of geopolymer bricks made with flyash and GGBS. IOP Conf Ser Mater Sci Eng 872:012141
31. Senthil K, Rupali S, Pratap A, et al (2020) Behaviour of concrete brick and flyash brick on infilled frame under cyclic loading. Ecol Environ Conserv 26:
32. Sisodia H, Sharma P (2017) A review on utilization aspects of natural and artificial fiber in flyash brick. Int J Mech Eng Technol 8:
33. Vinod BR, Shobha R, Vikas C et al (2021) Compressed stabilized mud block using alccofine and sodium meta silicate. Eng Sci Int J. https://doi.org/10.30726/esij/v7.i4.2020.74020
34. Subramanian GKM, Balasubramanian M, Jeya Kumar AA (2021) A review on the mechanical properties of natural fiber reinforced compressed earth blocks. J Nat Fibers 19:7687–7701
35. Vinayak M, Nitish M, Siddarth Gowda HM, et al (2021) Studies on properties of compressed mud blocks. In: Lecture notes in civil engineering
36. Naaman AE (2010) Textile reinforced cement composites: competitive status and research directions. In: International RILEM conference on material science
37. Chowdhury S, Roy S (2013) Prospects of low cost housing in India. Geomaterials. https://doi.org/10.4236/gm.2013.32008
38. Hegger J, Will N, Chudoba R, Scholzen A (2015) Classification of approaches to dimensioning and assessment of lightweight Trc structures. In: FERRO-11–11th international symposium on ferrocement and 3rd ICTRC-international conference on textile reinforced concrete
39. Colombo IG, Colombo M, di Prisco M, et al (2018) TRC sandwich panel for energy retrofitting exposed to environmental thermal actions. In: American Concrete Institute, ACI Special Publication
40. D'Orazio M, Stipa P, Sabbatini S, Maracchini G (2020) Experimental investigation on the durability of a novel lightweight prefabricated reinforced-EPS based construction system. Constr Build Mater 252:119134
41. Wayal A, Kumthekar MB (2019) Aerocon blocks and panels: sustainable and cost effective material for speedy construction. SSRN Electron J. https://doi.org/10.2139/ssrn.3366741
42. Jaiganesh K, Dinesh S (2017) An investigation of using aerocon block and M-sand in constructing low cost housing. IOSR J Mech Civ Eng. https://doi.org/10.9790/1684-1403017075
43. Chithambaram SJ, Kumar S (2017) Flexural behaviour of bamboo based ferrocement slab panels with flyash. Constr Build Mater 134:641–648
44. Mali PR, Datta D (2018) Experimental evaluation of bamboo reinforced concrete slab panels. Constr Build Mater 188:1092–1100
45. Sreadha AR, Pany C (2020) Review on fabrication of bamboo composite materials reinforced concrete. J Sci Tech 5(3):258–279
46. RILEM TC 232-TDT (2016) Test methods and design of textile reinforced concrete. Mater Struct 49:
47. Scholzen A, Chudoba R, Hegger J (2015) Thin-walled shell structures made of textile-reinforced concrete: part I: structural design and construction. Struct Concr 16(1):106–114
48. Döbrich O, Gereke T, Cherif C (2016) Modeling the mechanical properties of textile-reinforced composites with a near micro-scale approach. Compos Struct 135:1–7
49. Alexander AE, Shashikala AP (2020) Sustainability of construction with textile reinforced concrete-a state of the art. IOP Conf Ser Mater Sci Eng 936:012006
50. Mesticou Z, Bui L, Junes A, Larbi AS (2017) Experimental investigation of tensile fatigue behaviour of textile-reinforced concrete (TRC): effect of fatigue load and strain rate. Compos Struct 160:1136–1146
51. Karaduman NS, Karaduman Y, Ozdemir H, Ozdemir G (2017) Textile reinforced structural composites for advanced applications. In: Textiles for advanced applications
52. Butler M, Lieboldt M, & Mechtcherine V (2010). Application of textile-reinforced concrete (TRC) for structural strengthening and in prefabrication. In: Proceedings of the international conference on advanced concrete materials (ACM), Stellenbosch, South Africa (pp. 125–134)
53. Stolyarov O, Quadflieg T, Gries T (2015) Effects of fabric structures on the tensile properties of warp-knitted fabrics used as concrete reinforcements. Text Res J 85(18):1934–1945
54. Guo S, Ren J, Yang T et al (2022) Influences of surface treatment on the mechanical performances of carbon and basalt textiles-reinforced concretes under harsh environments. Compos B Eng 246:110195. https://doi.org/10.1016/J.COMPOSITESB.2022.110195
55. Garcia D, Larrinaga P, San-Jose JT, Garmendia L (2010) Ummantelung des Betons mit Basalttextilmatten bewehrtem Mörtel/confinement of concrete with basalt textile reinforced mortar. Restorat Build Monum 16(4–5):341–352
56. Du Y, Zhang X, Zhou F, Zhu D, Zhang M, Pan W (2018) Flexural behavior of basalt textile-reinforced concrete. Constr Build Mater 183:7–21
57. Shamseldein A, ELgabbas F, Elshafie H (2022) Tensile behavior of basalt textile-reinforced mortar (BTRM). Ain Shams Eng J. https://doi.org/10.1016/j.asej.2021.05.003
58. Alan Strauss Rambo D, Umbinger de Oliveira C, Pícolo Salvador R et al (2021) Sisal textile reinforced concrete: improving tensile strength and bonding through peeling and nano-silica treatment. Constr Build Mater. https://doi.org/10.1016/j.conbuildmat.2021.124300
59. Zhu D, Liu S, Yao Y et al (2019) Effects of short fiber and pre-tension on the tensile behavior of basalt textile reinforced concrete. Cement Concr Compos. https://doi.org/10.1016/j.cemconcomp.2018.11.015
60. Scheerer S, Chudoba R, Garibaldi MP, Curbach M (2017) Shells made of textile reinforced concrete -applications in Germany. J Int Assoc Shell Spatial Struct. https://doi.org/10.20898/j.iass.2017.191.846
61. Udhayaraman R, Subramanian H, Mulay SS, Venkatachalam S (2022) Multi-scale approach-based studies on the damage-healing and fracture behavior of plain woven textile composite. Mech Adv Mater Struct. https://doi.org/10.1080/15376494.2020.1809037
62. Engberts, E. (2006). Large-size facade Elements of textile reinforced concrete. In ICTRC'2006–1st International RILEM conference on textile reinforced concrete (pp. 309–318). RILEM Publications SARL

63. Junes A, Larbi AS (2016) An indirect non-linear approach for the analysis of sandwich panels with TRC facings. Constr Build Mater 112:406–415
64. Colombo IG, Colombo M, di Prisco M, Salvalai G, & Sesana MM (2018). TRC sandwich panel for energy retrofitting exposed to environmental thermal actions. In: 2nd international workshop on durability and sustainability of concrete structures, DSCS 2018 (pp. 1–10). American Concrete Institute, ACI Special Publication
65. Hegger J, Zell M, & Horstmann M (2008). Textile reinforced concrete–realization in applications. In: proceedings: international fib symposium tailor made concrete structures: new solutions for our society (pp. 357–362)
66. Karaduman NS, Karaduman Y, Ozdemir H, & Ozdemir G (2017). Textile reinforced structural composites for advanced applications. In: Textiles for advanced applications, 87
67. Peled A, Mobasher B, & Bentur A (2017). Innovative applications of textile reinforced concrete (TRC) for sustainability and efficiency. In: Textile reinforced concrete (pp. 451–464)
68. Laiblová L, Pešta J, Kumar A, Hájek P, Fiala C, Vlach T, Kočí V (2019) Environmental impact of textile reinforced concrete facades compared to conventional solutions—LCA case study. Materials 12(19):3194