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An Investigation of Perceptions on the Suitability of Rammed Earth in the Construction of Affordable Housing Units in Zambia

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Abstract
Housing is one of the basic necessities of mankind known to affect human health and well being. Since 1964, Zambia has been struggling with the provision of housing in urban areas. Zambia's urban population rose by 52% from 5,173,450 to 7, 844,628, between 2010 to 2022. The current housing deficit is estimated at over 2,000,000 housing units compared to 860,000 units estimated in 1996. This study aimed at exploring the use of stabilised rammed earth in the construction of affordable housing units in Zambia.
A mixed method approach requiring both qualitative and quantitative analysis was adopted, with data collected by using a questionnaire and laboratory testing. In establishing public perception on the use of rammed earth, 104 respondents were sampled. Further, in assessing the properties and suitability of rammed earth units for housing construction, soil samples were collected from four different locations within Lusaka Province
The study revealed that there was lack of legislation on rammed earth construction, and mixed public perceptions on the use of rammed earth. Whilst there was some considerable level of agreement on its advantages mainly in terms of lower cost of construction, thermal, fire as well as moisture resistance, the respondents on the other hand were of the view that the structural strength for houses constructed with rammed earth was poor compared to ones constructed using concrete blocks. The study established that 41.7% of respondents had knowledge on construction techniques associated with rammed earth. Further, laboratory testing of rammed earth cubes stabilised with 3%, 6% and 10% cement displayed increased compression strength of 2.2MPa, 2.96MPa and 3.12MPa respectively compared to 1.4MPa for unstabilised cubes at day 28.
From the research, a legal framework which supports the use of stabilised rammed earth in housing construction in Zambia should be established. Further, there is need to sensitize the general public on the advantages of using stabilized earth blocks to address the housing deficit and provision of affordable housing.
***Keywords**: Affordable Housing, Perceptions, Stabilized Rammed Earth*

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I. INTRODUCTION

Housing is one of the most important necessities of mankind known to affect human health and wellbeing (Emsley et al 2018). According to Okeyinka (2019), housing is a basic necessity that holds a singular importance in the general strategy of development for its socio-economic characteristics. Housing is a socio necessity of life and a second basic need to man after food (Okeyinka, 2017). The Zambian government and its social partners in conformity with this view have placed housing among its top priority (ILO, 2018). Zambia's population stood at 19,610,769 with urbanization rate at 4.3% confirming that Zambia is one of the most urbanised developing countries in Africa (MHID, 2020; ZSA, 2022). Zambia has been struggling with the provision of affordable housing since attainment of its independence in 1964 (Hadjri, et al 2007; UNCAD, 2015; Phiri, 2016). The Zambian government's desire to provide affordable housing for its citizens is emphasised in the Eighth National Development Plan (8NDP 2020-2024) which states that "To increase access to decent and affordable housing for all, the Government will facilitate the provision of affordable housing finance, provide incentives for private sector participation, and promote investments in research on alternative building materials and technologies. Consequently, during the Plan period, the housing deficit is expected to reduce from 1,539,000 in 2021 to 1,378,000 housing units in 2026." Earth has always been accepted as a building material for durable houses in the informal sector with 64% (1,600,000) of the housing units in 2010 being constructed of earthen material (Phiri, 2016), This confirms that earth as a building material is the most affordable and sustainable material to provide shelter since earth is an abundant resource (Zami and Lee, 2010). This research aimed at investigating the Perceptions on the suitability of rammed earth in construction of affordable urban housing units in Zambia.

II. DEFINITION OF RAMMED EARTH

Rammed earth is a construction technique where a well selected and graded mixture of wet soil is compacted between formwork to form a monolithic building structure (Jaquin et al, 2018; Birznieks, 2013; Maniatidis & Walker, 2003; Dabaieh, 2014; Cheah et al, 2012). Rammed earth construction can be categorized into both traditional rammed earth construction and modern rammed earth construction.

TRADITIONAL RAMMED EARTH

According to Beckett and Ciancio (2015), "traditional rammed earth, structures are formed through the compaction of raw material into formwork, which is then removed to allow the material to dry, granting it its considerable strength". The compaction is done in layers of 100 to 150mm by pneumatic tapper or hand rammers. The density of the soil is altered during mechanical compaction improving soil principal properties such as compressive strength, shearing resistance, shrinkage and swelling (Abdelkader, 2013).

STABILISED RAMMED EARTH

Stabilization of soil is the process of modifying the soil properties in relation to its strength, texture, voids and water resisting properties, so as to obtain permanent properties compatible with a particular application (Zievie et al. 2016). Stabilisation fulfils several objectives that are necessary to achieve a lasting structure from locally available soil, including better mechanical characteristics (improved wet and dry compressive strength); better cohesion between particles (reducing porosity which reduces changes in volume due to moisture fluctuations); and improved resistance to wind and rain erosion [Beckett & Ciancio (2015)]. There are three techniques for stabilising soil namely Mechanical, Physical and Chemical (ICS - UNIDO, 2008; Houben, 1994). Mechanical stabilisation refers to compaction of the soil which changes its density, mechanical strength, compressibility, permeability, and porosity (Amu, 2008). Physical stabilisation is where the texture of the soil is altered through the control of the grain fraction mix, heat treatment, drying, freezing or electrical treatment while the addition of chemicals to alter the properties of the soil is referred to as chemical stabilisation. This happens via a physical-chemical reaction between the grains of soil and the materials added, or through the addition of a matrix that binds or coats the grains (Amu, 2008).

Literature from a wide range of previous scholars recommends the proportion of cement in stabilised soils to be between 4% and 15%, with the range 6% to 10% being the most commonly specified (Bryan, 1988; Walker, 2000; Burroughs, 2008) resulting in the compressive strength between 1MPa to 15MPa (Standards Australia HB195, 2002). The amount of cement required is determined by the type and grading of the soil. Soils ideal for cement stabilisation should have minimal clay to produce desired results.

In Zambia, rammed earth housing structures have different names depending on where they are constructed. In Isoka District of Muchinga province, rammed earth is called "Sindile" while in most parts in Eastern Province it is called "Nyumba Yamudindo" and is mostly practiced in rural areas.

III. MATERIALS AND METHOD

The study was conducted in two parts to measure perceptions on the use of rammed earth in the construction of affordable housing units and laboratory tests were conducted to clarify and justify the results of the survey. The Survey (Part A) involved the administration of a structured questionnaire to measure perceptions on the use of rammed earth in the construction of affordable housing units to randomly selected participants from the Zambia Institute of Architects (ZIA), Engineering Institution of Zambia (EIZ), Zambia Institute of Planners (ZIP), Surveyors Institute of Zambia (SIZ) based on their specialised expertise and close involvement in the Zambian construction sector, contractors registered with National Council for Construction (NCC) Grade 4 Category B as well as occupants of earthen structures, as the target population of the proposed research. The population comprised 68 practicing Architects, 704 Civil and structural practicing Engineers, 115 practicing Planners, 362 contractors registered with NCC and 10 occupants of earthen structures from the three urban towns (Lusaka, Kitwe and Chipata), as summarised in Table 1.

The laboratory experiments (Part B) were conducted to establish the characteristics of the soil for stabilised rammed earth, ideal soil mixing methods, compression strength and residual strength in accordance with BS1377-2, 2022. Soil samples were selected for laboratory experiments using stratified random assignment based on their physical and chemical characteristics as recommended in the literature. Suitable sites were selected, and sample soils collected at a depth of 1m to 1.5m, to avoid vegetative matter in the soil. The preferred sub-soils were first subjected to smells test and elimination of soil samples with humus or decomposed matter in the field and further classified by performing laboratory tests to ultimately determine their suitability as a material for the manufacture of Rammed Earth cubes. The tests included moisture content, sieve analysis and compression strength of soil samples. The water content was determined by moisture content test and by performing a "ball test" according to Walker et al., 2005. 64 Cubes measuring 150mm x 150mm x 150mm were made from the sample soils. Portland cement was added to the mix in varying contents of 3%, 6% and 10%, by dry weight of soil sample. The material for all test samples was compacted using a 2.5kg tapping cylindrical rammer in three layers of 50mm in accordance with BS 1377-2, 2022. The cubes were cured in accordance with Walker et al, 2005 and subjected to compression tests at various stages. The results from the laboratory experiments were used to refute or justify some of the perceptions on durability and compression strength of stabilised rammed earth from the respondents during the survey.

IV. RESULTS AND DISCUSSION

The 104 respondents in the questionnaire survey comprised of Architects (41), Engineers (27), Planners (12) and Grade 4 category B contractors (18) and occupants of earthen structures (6) as shown Table 1. The survey revealed that rammed earth (Table 2) had good thermal comfort (83%) and fire residual strength (82%). This agrees with Kraus, 2012 who stated that among the most perceived favourable attributes of rammed earth is that it has good thermal resistance, good fire residual strength, as well as low life cycle costs. Likewise, the results agree with literature that among the factors considered to be least favourable consequently hindering the adoption of rammed earth material for housing construction include challenges to do with constructability (68.4%), lack of legislation (45%), perceived as material for the poor (68%) as well as perceived high initial costs of investment (Maini, 2005, Hadjri et al., 2007). The houses constructed using rammed earth had poor sale or resale value compared to houses constructed with other convectional materials (73%), as shown in Figure 1. With regards to knowledge among professionals, the study revealed that there is lack of knowledge among architectural professionals (82%), as shown in Table 3. This agrees with literature that there is a lack of knowledge, skills, and understanding among professionals, government, donors, and users which is affecting the widespread use of stabilised rammed earth. Lack of information regarding the acceptable chemical composition of soils as a construction product, as well as lack of skilled labour in stabilised earthen construction, are some of the factors hindering the adoption of rammed earth in construction of housing (Castells and Laperal, 2007; Houben et al., 1995; Jagadish, 2007). Similarly, on non-availability of legislation (82%), the results agree with literature that lack of building codes, standards, quality control criteria, and policies guiding usage of stabilised rammed earth as a building construction material hinders the adoption of rammed earth for construction of urban housing (Hadjri et al. 2007). This aligns with Mulenga (2018) who affirms that lack of standards and code of practice has negatively affected sustainable construction methods.

Table 1: Summary of population sizes, sample sizes and response rates

Population Category	Population Size	Sample Size	Successful Response
Architects	68	47	41
Engineers	704	131	27
Contractors (Grade 4B)	362	108	18
Planners	115	66	12
Earthen House Occupants	10	10	6
Total	1259	362	104

Table 2: Perception on the use of Rammed Earth for Housing Construction

Description	**Ratings by the respondents**					**Total**
Characteristic	Very poor	Poor	Average	Good	Very good	%
Thermal	16.6%	0%	0%	41.7%	41.7%	100%
Fire residual strength	9%	0%	9%	18.%	64%	100%
Microclimate	0%	9%	28%	45%	18%	100%
Economically	9%	0%	36.4%	36.4%	18.2%	100%
Availability	0%	8.3%	33.3%	16.7%	41.7%	100%
Sustainability	9%	18.2%	0%	36.4%	36.4%	100%
Structural strength	45.7%	22.7%	17.7%	10.2%	3.7%	100%
Labour intensive	0%	16.7%	16.7%	41.7%	25%	100%
Knowledge by professionals	0%	41.7%	50%	8.3%	0%	100%
Housing for the poor	0%	8.3%	16.7%	25%	41.7%	100%
Maintenance costs	0%	9%	18.%	27%	46%	100%
Lack of legislation	46%	36%	9%	9%	0%	100%

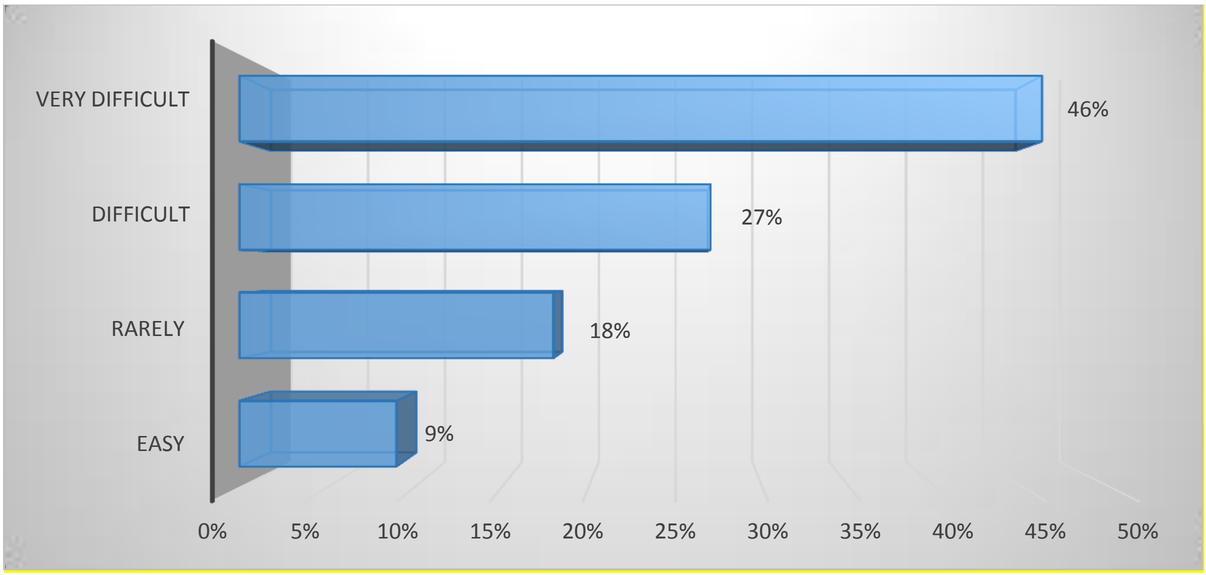

Figure 1: Marketability of rammed earth housing units against conventional housing units

Table 3: Responses on specification and usage of construction material during design and construction

Construction materials	Have used the material	Not used the material	Total
Rammed earth	18%	82%	100%
Wattle	70%	30%	100%
Adobe (clay) sun dried bricks	100%	0%	100%
Adobe (clay) burnt bricks	65%	35%	100%
Adobe (clay) compressed blocks	90%	10%	100%
Sandbag	33%	67%	100%

Table 4:Soil composition

Sample	Gravel	Sand	Silt/ Clay
A	35	12	53
B	4	16	80
C	1	12	87
D	1	21	78

Table 5: Optimum Moisture Content and Maximum Dry Density

ID	Soil Sample	Optimum Moisture Content(%)	Maximum Dry Density (Kg/m^3)
1	Sample A	**15.38**	**1836**
2	Sample B	17.48	1700
3	Sample C	18.81	1684
4	Sample D	16.75	1714

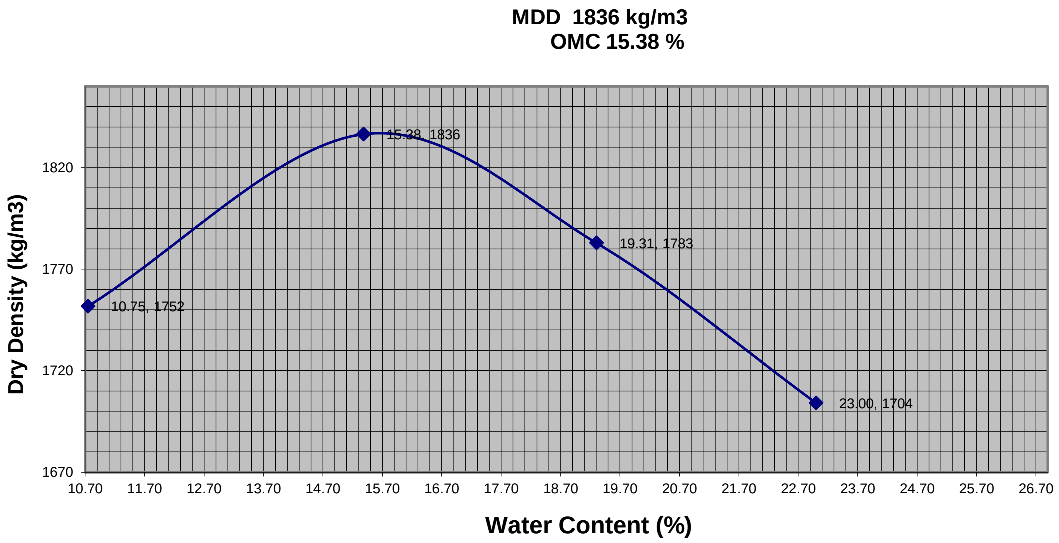

Figure 2:Relationship between Maximum Dry density and Moisture content for sample A

Table 6: Compression strength results at 7, 14, 28 and 56 days

ID	Days	Compression Strength (MPa)			
		7	**14**	**28**	**56**
A_1	0%	0.35	1.22	1.4	1.6
A_2	3%	1	1.57	2.2	2.9
A_3	6%	1.2	1.65	2.96	3.1
A_4	10%	1.3	2.96	3.12	3.7

Table 7: Compression Strength results after fire tests

Specimen	% Cement Stabilization in Soil Mix	Compression Strength (MPa) before Fire @ 28days	Compression Strength (MPa) After fire
A_1	0	1.4	7.8
A_2	3	2.2	4.6
A_3	6	2.96	3.5
A_4	10	3.12	3.2

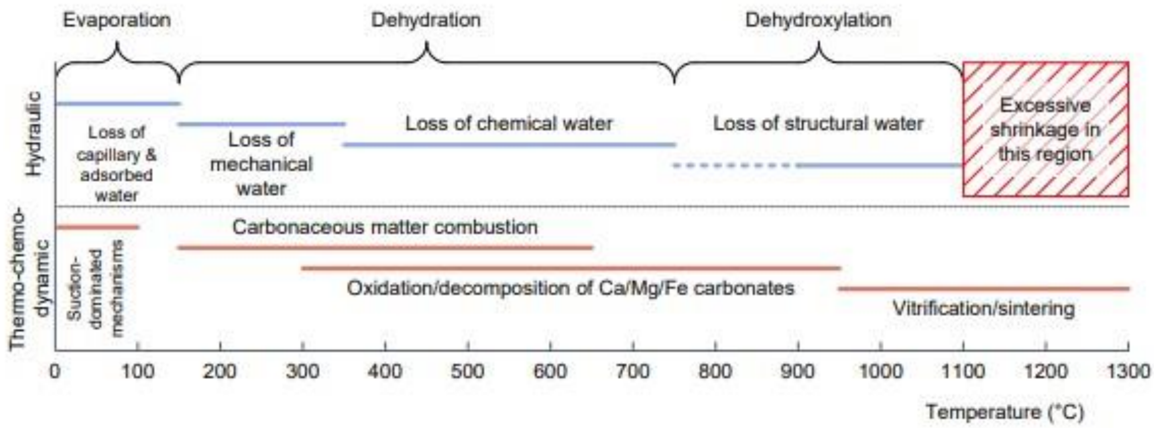

Figure 3: Key hydraulic and thermo - chemo process and associated temperature ranges during typical clay brick firing. (Source: Beckett, Kazamias and Law, 2019)

Table 8: Moisture absorption by immersion

Sample weight before and after immersion in water					
Specimen	**Treatment**	**Before**	**After**	**Variance**	**Moisture absorption (%)**
A_1	0%	6602	-	-	-
A_2	3%	6538	7563	1025	16.8
A_3	6%	6506	7361	855	14
A_4	10%	6690	7358	668	9.8

Table 9: Summary of Construction cost for a 101.5m^2 concrete block to stabilised rammed earth house.

	ITEM	**COST (ZMW)**	
		Concrete Block	Stabilised RE
1	Substructure	49,842.00	32,400.00
2	Concrete works in ring beam / lintols	25,000.00	10,000.00
3	Superstructure	24,430.00	59,500.00
4	Wall finish	15,030.00	0.00
5	Paint work	12,815.00	0.00
6	Sub-total	127,117.00	101,900.00
	TOTAL MATERIAL COST	127,117.00	101,900.00
	Add FOR		
7	Labour & Equipment at 20% of total cost	25,423.40	20,380.00
8	Transport costs at 10% of total cost	12,711.70	10,190.00
	TOTAL ESTIMATE COST	**165,252.10**	**132,470.00**

Figure 4: Weighing of the specimen before emersion in water and after immersion in water

The results from the laboratory experiments rebut the physical and chemical results from the survey. The percentage of particle size in the soil samples was determined using wet sieve analysis in accordance with the recommended proportions according to BS1377-2:2022, ASTM D2487-17, SANS 201- 2008 and Walker et al.,2005, for the samples to be considered for further analysis as shown in Table 4.

Proctor tests were conducted to ascertain/confirm the moisture content required or each sample at which the compacted sample achieved the greatest dry density (Table 5 and Figure 2). The unconfined compressive strength results (Table 6) revealed that the stabilised rammed earth cubes satisfy the desired minimum threshold of 1.5 MPa in accordance with international standards such as SADC ZW HS 983: 2014 at 1.5 – 2MPa, NZS 4298:1998 at 1.5MPa and ASTM International E2392 / E2392M - 10e1 (2010) at 2.06MPa if stabilized with a minimum of 3% cement. This agrees with literature that cement stabilization of rammed soil samples improves strength, resistance to water and reduces shrinkage of the rammed earth walls. Numerous studies have been conducted on the strength, durability and shrinkage characteristics of stabilised soils which indicate a strong linear correlation between compression strength and cement content (Walker, 2000; DTi, 2003; SADC ZW HS 983, 2014). On fire residual strength (Table 5), the results revealed that rammed earth retained the desired strength. This agrees with Nshimiyimana et al., 2022 who affirmed that rammed earth could withstand relatively high temperature without risking the loss of their mechanical performance. However, after exposing the rammed earth to fire, the samples with less or no cement content yielded even more strength than those with more cement content. This aligns with Beckett, Kazamias and Law (2019) and Johari et al., (2010) who affirm that unstabilised rammed earth cubes gain strength when exposed to elevated temperatures above 100 ºC due to loss of water and thermo chemo-dynamic as shown in Table7 and Figure 3.

The unstabilised and stabilised cubes were immersed in water for 24hrs. The un-stabilised specimen disintegrated under water immersion as shown in Figure 4 confirming that un-stabilised Rammed Earth walls, unless protected, were not durable in the presence of water. The specimens with a higher cement content had a lower rate of moisture absorption compared with specimens with lower cement content which had a higher rate of moisture absorption as shown in Table 8. The stabilised cubes remained intact. while the unstabilised disintegrated under water immersion

In comparing the unit cost per square meter (m^2) of constructing a wall in a housing unit using stabilised rammed earth against concrete block work, this study built a rate and found that the cost of using stabilised rammed earth was 25% lower compared to that of using concrete block (Table 9).

These results agree with Bui et al., (2009) that the cost effectiveness and durability of houses made of rammed earth may provide a solution to the problem of expensive housing, advancing that soil can be sourced on-site at zero or almost zero cost. The transportation cost of the construction materials when the main bulk component (earth) is sourced on-site is significantly reduced. More so, rammed earth walls do not require painting or other wall treatments, resulting in minimum on-going maintenance cost (ibid).

However, it is important to note that even though the forming systems for the two materials are similar and take the same man-hours to erect, layering and compacting rammed earth into the form takes considerably more labour and equipment than pouring and vibrating concrete, or laying of concrete blocks. The only savings possible are a reduction in aggregate and cement costs which are achieved by developing a design mix that utilizes a major portion of either on-site or other free mineral soil and a minimum rate of stabilization.

The results confirm the assertion that the Zambian housing sector is associated with numerous challenges in the provision of affordable and sustainable housing units thereby impacting negatively on access to affordable housing. Further, the findings showed that stabilised, rammed earth can be employed in the construction of sustainable and affordable housing units, thereby improving the delivery of affordable housing.

V. CONCLUSION

The public perception on the use of rammed was mixed, with some considerable level of agreement on its advantages associated with lower cost, thermal, fire as well as moisture resistance. On the other hand, the respondents were of the view that the market value for a house constructed with rammed earth is lower compared to one constructed with concrete; housing constructed with rammed earth was aimed at the poor and those who were not doing well economically. Furthermore, another factor perceived to be a drawback in the adoption of rammed earth was the lack of legislation as well as standardization. A further factor was the perceived challenges or difficulties associated with constructability.

The test results for compressive strength, fire residual strength as well as moisture resistance all fell within the recommended thresholds by various standards, suggesting that stabilized rammed earth material is suitable for construction of walls in housing.

The study found that the construction cost of rammed earth was cheaper in Lusaka compared to that of concrete blocks. However, it was observed that even though the forming systems for the two materials were similar and took more or less the same man-hours to erect, layering and compacting rammed earth into the form takes considerably more labor and equipment than laying of concrete block. The identified cost savings were in terms of aggregates, formwork and cement costs including a significant less impact on the embodied energy and embodied carbon dioxide emission of a building as compared to conventional concrete block (Venkatarama Reddy and Prasanna Kumar, 2010).

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