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ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/rbri20

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To cite this article: Hisham Hafez, Deena El-Mahdy & Alastair T.M. Marsh (2023): Barriers and enablers for scaled-up adoption of compressed earth blocks in Egypt, Building Research & Information, DOI: 10.1080/09613218.2023.2237133

To link to this article: https://doi.org/10.1080/09613218.2023.2237133

Published online: 20 Jul 2023.

BRI BUILDING RESEARCH & INFORMATION
https://doi.org/10.1080/09613218.2023.2237133

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RESEARCH ARTICLE

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Barriers and enablers for scaled-up adoption of compressed earth blocks in Egypt

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ABSTRACT

Compressed earth blocks (CEBs) are a low-cost, low-carbon construction product, which are well-suited for masonry infill in the Global South. A knowledge gap remains around the technical and socio-economic barriers to CEB adoption. A combined survey and interview study was carried out among architects, CEB manufacturers, and academics within Egypt: firstly, to explore technical and socio-economic barriers to greater adoption of CEBs for masonry infill, and secondly, to identify potential enablers. Many technical challenges still exist, despite the fact that building codes for CEB in Egypt were introduced in 2019. The majority of respondents agreed that socio-economic barriers are more significant than technical barriers. These included CEBs being unfamiliar to most architects and builders, and that most clients perceive CEBs as 'low-quality' or 'inaesthetic'. Most respondents believed that CEBs can achieve ≥25% market share for masonry in Egypt. However, CEB press supply is likely to be a major barrier to scale-up. Suggested enablers included tailored marketing suggestions for low-/middle-income and high-income clients, and deciding at the earliest possible design stage whether to manufacture CEBs on-site or off-site. Mapping the enablers across stakeholders showed that more research is needed to understand the views of CEB press manufacturers and government officials.

ARTICLE HISTORY
Received 15 May 2023
Accepted 11 July 2023

KEYWORDS
Compressed earth blocks; stabilized earth construction; survey-based methods; socio-economic barriers; global south

Introduction

Egypt, like other Global South countries, faces a challenge in meeting the forecasted housing demand by 2050 with low-cost solutions that do not exacerbate climate change. The current population of Egypt is 106 million; by 2050, the population is projected to grow to 160 million (Nabawy et al., 2021). The urban population is 40% (Marzouk et al., 2021), but this is concentrated within only 10% of the country's area. To meet the forecasted increase in population between 2022 and 2050, an additional 13 million housing units will be required – 43% of these are expected to be urban and the remaining 57% to be rural (Appolloni & D'alessandro, 2021). Historically, load-bearing walls in Egypt have typically been made of adobe bricks and natural stone. Adobe, a term referring to sun-dried mud bricks, has been used ever since the Ancient Egyptian era (Morgenstein & Redmount, 1998). Today, the majority of new housing projects in Egypt use reinforced concrete as a structural system and a wall infill of either fired clay bricks or concrete masonry blocks. Comparing these two masonry materials, the embodied carbon of hollow concrete blocks (971 MJ/m^3 of masonry, for 10% cement blocks) is much lower than that of fired bricks (2141 MJ/m^3 of masonry) (Reddy and Jagadish, 2003). Whilst concrete blocks may seem preferable to fired bricks in terms of embodied energy and carbon, they have drawbacks in other aspects of sustainability. Concrete houses can have poor thermal comfort in Egypt (Gado et al., 2010); given trends of rising global surface temperatures, overheating of housing is an increasingly important public health concern (Hales et al., 2007; Mastrucci et al., 2019). Therefore, it is crucial for new housing to minimize the risk of overheating. There is also concern that the use of conventional contemporary construction materials, including concrete, is eroding the cultural identity of oasis towns in Egypt by replacing traditional earth-based materials and construction techniques (Gado et al., 2010). These considerations drive the search for low-cost, low-carbon infill brick solutions to replace the use of fired clay bricks and concrete blocks in Egypt and other Global South countries.

Compressed earth blocks (CEB), made using manual or automated presses to form a standardized block, have been developed in recent decades. The compression process gives higher strength and durability compared

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to Adobe (Adam & Agib, 2001). Stabilizing agents, such as cement or lime, are often added to further improve strength and durability (Reddy et al., 2022). The presence of unfired clay in CEB helps to regulate both indoor temperature and humidity, contributing to thermal comfort for occupants (Fahmy et al., 2022). CEB production does not require skilled labour, as the production process goes through three simple phases; soil preparation, compression, and curing (Riza et al., 2011). CEB can therefore be viewed as a desirable middle ground between adobe and fired bricks for infill masonry – they have greater strength and durability than adobe but with lower embodied energy and better hygro-thermal performance than fired bricks. The Egyptian Center for Housing and Building Research released a building code for compressed stabilized earth blocks (CSEB) in 2019 (HBRC, 2019). Nonetheless, CEBs are still an immature construction technology in Egypt, and the overall share of the masonry market is believed to be very small. In order to help facilitate and accelerate the wider adoption of CEBs in Egypt, it is necessary to understand the barriers towards CEB construction.

The barriers to adoption of earth construction in general can be grouped into five categories: economical, organizational, political, social, and technical (Pelé-Peltier et al., 2023). There is a degree of consensus in the literature around the barriers to earth construction that are commonly found across different sub-groups of earth building and across different regions. These generic barriers can be broadly summarized as: the variability and local availability of suitable soils; concerns over durability performance; extra costs relative to other materials; lack of suitable codes and standards, lack of skills and education, and negative perceptions of earthen buildings (Pelé-Peltier et al., 2023). Given that barriers and drivers can vary widely across different socio-economic and geographical contexts, it is recommended that studies on barriers to earth construction focus on a specific context; another recommendation is that studies should focus on a specific earth construction technique, as several barriers are technique-specific (Pelé-Peltier et al., 2023). Surveys and/or interviews have been the main research methods used to investigate context-specific barriers. Whilst some survey and/or interview-based studies have taken a global scope (Ben-Alon et al., 2019; Zami & Lee 2011), the majority have focused on individual countries (or regions within countries), including: Asia (Zare Shahabadi et al., 2019);(Kulshreshtha et al., 2020); South America (Dorado et al., 2022); North America (Hughes et al., 2017); Oceania (Samarasinghe & Falk, 2022); Europe (Morel et al., 2021); (Zami, 2022), and Africa (Gado et al., 2010); (Hadjri et al., 2007); (Zami, 2015); (Nambatya, 2015) (Zoungrana et al., 2021). There have only been two survey or interview-based studies in Egypt, in the English language literature. Gado et al. (2010) interviewed residents of four oases in the Western Desert about their experiences of, and attitudes to, living in earthen buildings. Interviewees were aware of the thermal comfort and financial advantages of earthen housings, but these were outweighed by their negative social perceptions of traditional earthen housing. As a result, new construction in the oases favoured fired bricks or limestone blocks, either as load-bearing walls or as infill in concrete frame structures. Interviewees also indicated that earthen architecture was key to the cultural identity and economic viability of the oases as tourist destinations and was open to new technologies that would make earthen buildings look more modern. Hanafi (2021) surveyed residents in six villages in Egypt about their attitudes to CEBs – maintenance requirements and poor aesthetics were the main disadvantages identified, although the results were not sufficiently disaggregated to yield findings that were more specific. Despite known reservations around earth-based materials, CEBs are still a promising masonry product for Egypt (Abdel Gelil & Abo Eldardaa, 2023), as they provide a finish and aesthetic which can be very similar to fired bricks.

The only known survey and/or interview-based studies on CEBs are by Dorado et al. (2022), Zoungrana et al. (2021), Hanafi (2021), Hughes et al. (2017) and Nambatya (2015). Dorado et al. (2022) carried out surveys and interviews with a range of stakeholders in Argentina to identify barriers to the adoption of CEBs manufactured off-site. Several of the identified barriers were CEB-specific, including: a difficult commercial environment for machinery manufacturers arising from fluctuating demand and overseas imports; unreliability in the quality and availability of off-site manufactured CEBs, and transportation difficulties arising from the weight of CEBs. Hughes et al. (2017) investigated attitudes and barriers towards CEB in residential construction in the North Carolina Piedmont, an area of the USA with suitable soils but no significant history of CEB construction. Contractors without prior experience of using CEBs had an overall more negative perception of CEBs than those with prior experience. Capital investment in CEB production equipment and access to training were recommended as barriers in need of greater attention. Nambatya (2015) investigated barriers to the adoption of on-site manufactured Interlocking Stabilized Soil Blocks (ISSBs), a variety of CEB used in Uganda. Low acceptability by clients and scepticism by local authorities were identified as major non-technical barriers. CEB-specific concerns raised by interviewees included the per-brick cost compared with fired bricks; the risks around using less mortar with interlocking blocks; catering needs for on-site artisans; difficulties in training workers; accidents when operating manual block presses, and remediation of excavation pits. Zoungrana et al. (2021) focused on the social barriers to CEB use in Burkina Faso. Most interviewees had negative perceptions of CEB – these were based on a close association between CEB and adobe, and also the degradation of large numbers of CEB buildings from public building programmes spanning the 1980s to 2010s. However, a small minority, representing elites, had positive associations with CEB that were attributed to their low environmental impact and thermal comfort. Even within a small number of studies, these findings show the range of different barriers to wider adoption of CEB.

To advance the knowledge base around motivations and barriers to earthen construction, more detailed investigation is needed which is contextually specific to a given region and building method, and which focusses on potential enablers identified by practitioners as well as barriers. The aim of this study is to identify the motivations and barriers relating to CEB construction in Egypt and also to identify potential enablers to those barriers. The research questions were:

a) What are the motives for the wider adoption of CEB in the Egyptian construction market?
b) What are the most impactful barriers across technical, social, and economic categories?
c) How can enablers help to overcome the identified barriers?

Methods

A two-stage survey and a subsequent set of interviews were used. This combined approach has been used in previous studies on this topic (Hadjri et al., 2007; Samarasinghe & Falk, 2022; Zami, 2022). As the schematic diagram in Figure 1 shows, the data from Survey 1 were used to inform the complementary questions in Survey 2, and the data from both informed the interview questions.

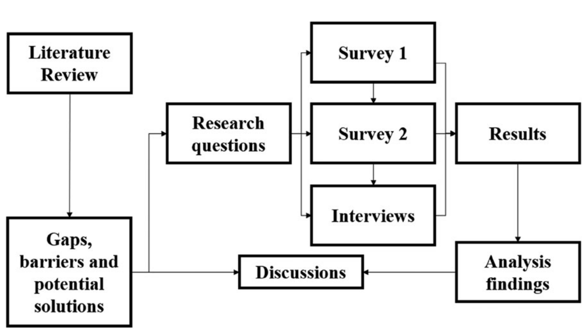

Figure 1. A schematic of the methodology followed in this study and different data collection methods used.

Respondent sampling approach

The experts from whom data was collected were selected to fulfil three main characteristics: (1) they work in Egypt; (2) they work in a relevant profession (academic, architect, or brick producer), and (3) they have previously worked with CEB. Thirty experts were initially contacted – this pool was a non-probability convenience sample, selected from the authors' professional contacts. While this sampling technique has limitations around its generalization to a wider population (Harries et al., 2020), it is appropriate for the intended purpose of the study given the small expected total number of CEB experts in Egypt. Out of the 22 accepted respondents who filled in the first survey, only 17 responses were accepted for the second stage survey as 5 of the received responses were incomplete. The 5 most experienced respondents were selected for interviews. As Zami (Zami, 2015) pointed out, it can be challenging to obtain expert responses where a given country's contemporary earth construction sector is nascent, and there is only a small pool of experts. Nonetheless, this number of respondents falls within the typical range of previous survey-based studies on a single country (e.g. n = 20, Hanafi (2021); n = 22, Hadjri et al. (2007); n = 22, Zami (2022); n = 30, Hughes et al. (2017)).

Data collection

The first survey was prepared based on the insights from the literature and distributed to the selected sample of experts as an online form. The survey was designed to fulfil three objectives. The first was to validate the initial hypothesis that there is a need for CEB as an infill block solution in the current Egyptian market for housing projects. The experts were also asked to estimate the current and potential proportion of CEB use in this market. The second objective was to validate, through the experts' answers, whether the technical, economic, or social barriers indeed exist in the Egyptian context to the production and/or use of CEB, and then to state ≤ 3 specific barriers within each category. The final part addressed the third objective, to identify potential enablers, and consisted of two questions about the experts' suggestions for overcoming the stated barriers.

After analyzing the suggested barriers and enablers from the first survey stage and following the recommendations from previous studies (Hughes et al., 2017; Zami, 2022), a second survey was distributed to validate the ranking of the barriers synthesized from the first survey stage. The top three technical, social, and economic barriers identified from Stage 1 were presented and respondents were asked to rank them 1st–3rd in order of significance.

In the first stage survey, the experts proposed several enablers to overcome different barriers. However, the short nature of the answers in the survey responses meant that the statements did not fully explain how exactly the proposed enablers would work. Given that barriers are known to be highly interlinked, it was decided to explore these proposed enablers in greater detail. A structured interview including ten open-ended questions gathered further detail about how the selected experts would implement their enablers to overcome the stated barriers. The templates and answers for the two surveys and interview questions are available upon request.

Results and discussion

Participants' profiles

The respondents to the first survey stage (n = 22) were mainly architects (n = 16) and a smaller group of academics (4) and CEB manufacturers (n = 2) (Figure 2a). The emphasis on practitioners, as opposed to researchers, followed recommendations from the literature (Zami, 2022). The majority of respondents to the first survey stage had >5 years of experience in the field (n = 13) (Figure 2b). There are no explicit guidelines or recommendations as to a suitable number of respondents, or minimum levels of experience, for surveys into barriers to non-conventional construction materials; nonetheless, the distribution of experts by profession and experience is deemed satisfactory for this study, given that the Egyptian CEB sector is still immature and small.

Production modes: on-site and factory-based

There are two main modes of CEB production: on-site, using soil extracted from the construction site to produce bricks to then be used on-site; and, factory-based, using a centralized production facility, from where bricks are then transported for sale and use (Reddy et al., 2022). It is not known what the market share is in Egypt between on-site and factory-based production of CEBs – however, it is believed that the majority of production is on-site. These two modes of CEB production offer different opportunities and barriers (Maïni & Davis, 2018); (Dorado et al., 2022), so it is valuable to explore the expert views on this before interpreting the survey results.

There was a consensus among the interviewees about the ideal situation: that a large enough number of CEB factories are distributed geographically, such that transportation distances of CEBs to sites are sufficiently small – expert 3 specified 10 km as the maximum feasible threshold. Especially to a client (based on insight from a developer, expert 5), the quality and short lead time offered by industrial hydraulic presses in factory production is indispensable, and more important than cost. However, such full market penetration is far from being reality and until then, there will be a mix of both modes of production. Accordingly, experts agreed that on-site production would be dependent on the availability of good quality soil on site, the accessibility to transport raw materials to the site (extra soil if needed and stabilizers), as well as access to suitably trained manual labourers.

Market need for CEB in Egypt

The results from the first survey stage showed a unanimous agreement that new types of building blocks are needed in the Egyptian construction market, and that

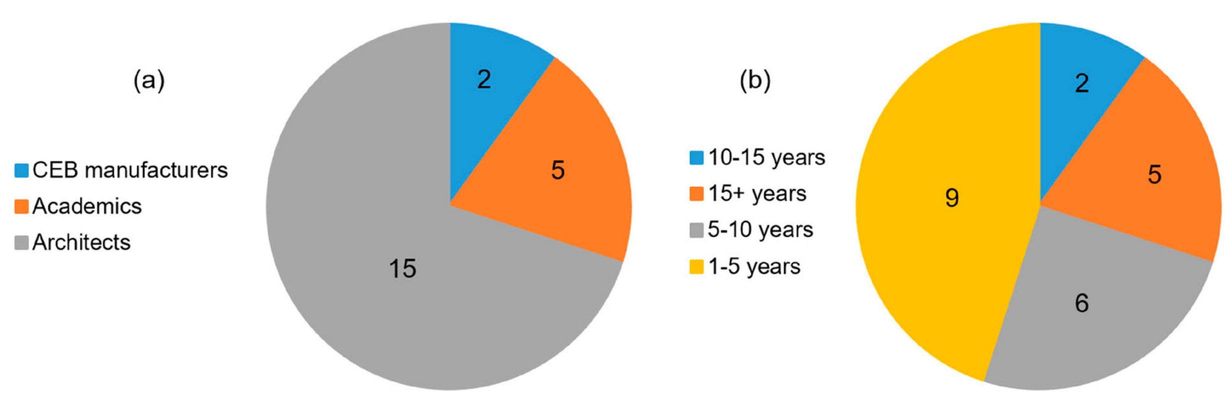

Figure 2. Breakdown of the number of respondents (out of the total of 22) to the first survey stage by: (a) profession, and (b) years of experience.

CEB could be a suitable candidate. When asked about the incentives behind using CEB for walling infill, the answers were limited to the low carbon footprint, enhanced indoor air quality and thermal insulation that CEB provide. The answers resonate with a 'textbook' answer applicable to all earth construction techniques as cited in previous surveys (Samarasinghe & Falk, 2022); the reason behind this could be the limited number of executed projects with CEB in Egypt which would allow for more in-depth and CEB-specific answers. 20 out of the 22 experts agreed that the current CEB market share of building blocks in Egypt is 0-10%. However, 14 of the respondents believed this could grow to 25% market share, while four voted it could grow up to 50% market share. Whilst information about the scale of the CEB market in other countries is limited, CEB is generally acknowledged to be a minority construction product in most countries (Dorado et al., 2022); 50% market share would therefore represent a dramatic rise in the adoption of CEB in relation to current market share, both in Egypt and other countries. It would also represent an abrupt change in adoption of earthen housing in general, which has remained approximately constant or in decline across several Global South countries in recent decades (Marsh & Kulshreshtha, 2022).

To assess the potential implications of the projected expansion of CEB as a masonry product in the Egyptian market by 2050, three scenarios were generated, aligned with the range of respondents' predictions: low adoption (5% market share), medium adoption (25% market share), and high adoption (50% market share). The total estimated demand for masonry units up to 2050 was estimated using projections for additional housing demand of 13 million housing units (Appolloni & D'alessandro, 2021), an average household size of 80 m^2 (UN-Habitat, 2016), an average material intensity for masonry units of 150 kg/m^2 of floor area (Arehart et al., 2022), and a linear rate of housebuilding. The expected total demand for masonry units in Egypt up to 2050 was estimated at 156 Mt. Accordingly, the expected demand for CEB is 7.8 Mt for the low adoption scenario (5% market share), 39 Mt for the medium adoption scenario (25% market share) and 78 Mt for the high adoption scenario (50% market share). The growth in annual CEB production for these scenarios' projections, assuming a linear growth in CEB adoption up to the predicted value in 2050, is shown in Figure 3a.

The benefits of CEBs in comparison to fired clay bricks and/or concrete blocks are often advocated on the scale of individual blocks (Reddy and Jagadish, 2003) or individual buildings (Praseeda et al., 2016); however, there is rarely critical scrutiny of the implications for resource consumption and capital investment of up-scaling CEB production on a national scale. The total CEB demand to 2050 was predicted to be in the range of 7.8 Mt–78 Mt – the raw material extraction required for these quantities is still small compared with the scale of raw material extraction for cement and concrete production in Egypt. For comparison, annual cement production in Egypt is predicted to reach ~80 Mt/year by 2050 (Vanderborght et al., 2016). Nevertheless, these projections still represent a large overall volume of material extraction, which has environmental implications. CEB production has been criticized for poor post-extractive remediation practices, in which malarial pools can form in extractive pits (Sanya, 2012). This issue, and others regarding the local impacts of earth extraction, will depend on the distribution between on-site production and centralized factory production. The rapid up-scaling of CEB production required to meet these projections (Figure 3a) carries risks. Poor quality control in large-scale CEB programmes in Burkina Faso led to widespread building degradation, which damaged public perceptions around CEB in that country (Zoungrana et al., 2021).

The availability and financing of production equipment is key to expanding production (Helmy, 2022), and is a known barrier for greater adoption of local construction materials in African countries (Dosumu & Aigbavboa, 2020). Given the maximum service life of an automated, hydraulic press machine is 10 years, then assuming 240 working days/year with 2000 blocks produced per day and a block mass of 8 kg/block, the maximum capacity of production per machine is approximately 0.04 Mt (Rigassi, 1985). This estimate indicates that >2000 industrial-scale hydraulic presses will be needed to satisfy the high-demand scenario (Figure 3b). The significance of this projection is that given the high inflation rate in Egypt in 2022 (Helmy, 2022), the investment required to purchase these presses might pose a serious challenge. There are no precedents of manufacturing hydraulic presses in Egypt, but the typical price of imported presses ranges between $15k and $20k[1] – this represents substantial CAPEX given an average Egyptian startup only earns $50k/year (ElBarkouky, 2022). The typical CAPEX for a manual press is ~10% that of a hydraulic press (around $1,300) but their maximum service life is believed to be limited to a maximum of 2 years.[2]

Technical barriers

In the first survey stage, only half of respondents (11 out of 22) voted that there are technical barriers to using CEB. The barriers stated varied widely: absence of

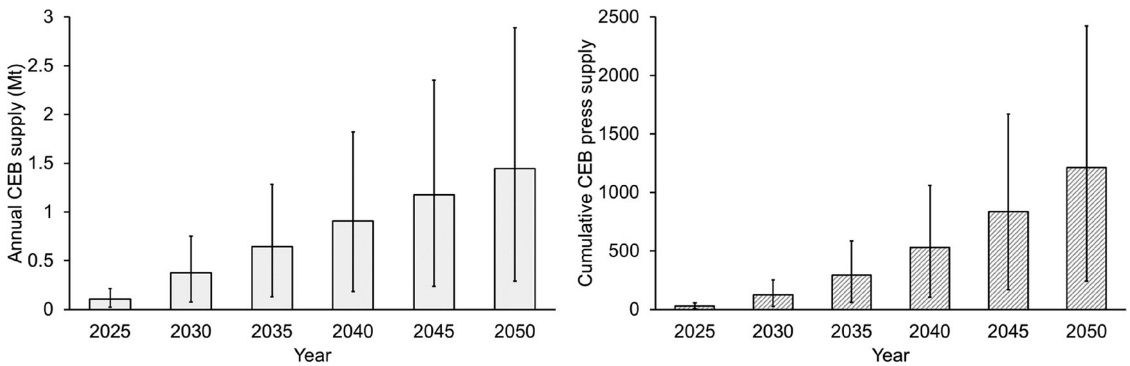

Figure 3. Projected ranges for (a) annual CEB supply, and (b) cumulative supply of hydraulic press machines, based on a linear increase of CEB supply up to different projected adoption rates in 2050. The bars represent 25% market share of CEB for masonry by 2050 (i.e. 'medium adoption' scenario), the upper whisker represents 50% market share by 2050 (i.e. 'high adoption' scenario) and the lower whisker represents 5% market share by 2050 (i.e. 'low adoption' scenario).

building codes, limited heights of buildings, heavy bricks, material durability, slow production, and the ability to find suitable soil. The barriers were all stated in previous surveys (Pelé-Peltier et al., 2023) and came without surprise except for the absence of building codes. Issues around standards for earth construction (Reddy et al., 2022), and unconventional construction materials in general (Harries et al., 2020), have previously been explored in the literature. A previous study on CEB in Argentina identified imprecise building regulations as a barrier, as well as a lack of regulations for the production and quality assessment of CEB themselves (Dorado et al., 2022). Despite the respondents highlighting the absence of building codes as a barrier, the Egyptian code for building with CEB was released in 2019 (Hanafi, 2021). For the Egyptian context, the survey results indicate that the main issue is awareness of the standards, rather than the absence of standards.

In the second survey stage, experts were asked to rank the top three technical barriers facing the use of CEB in non-load bearing walls, as identified through the first survey stage. The top-ranked barrier was that the material is heavy. The density of CEB (1.8 gcm^{-3}) can be ∼20% higher than for fired clay bricks (1.4 gcm^{-3}) and hollow concrete blocks (1.5 gcm^{-3}) (Galán-Marín et al., 2015). On-site CEB production with manual presses has the advantage that the presses can be set up in different areas of a site, to minimize the distances for transporting blocks on-site (Reddy, 2015).

In the second survey stage also, the experts were asked to rank the top three technical barriers to the production of CEB, as identified through the first survey stage. The top-ranked barrier was around aspects of the block press itself, including availability, maintenance and speed of production. The second and third-ranked barriers were a tie between 'proper material availability on site' and 'availability of skilled labor' (Figure 4). The answers are not consistent with the findings from academics such as Gallipoli et al. (2017), for whom quality control is the priority for CEB production. The variability in soil quality and availability of appropriate soil on site are familiar issues in the literature (Wright & Thorpe, 2015). However, the soil

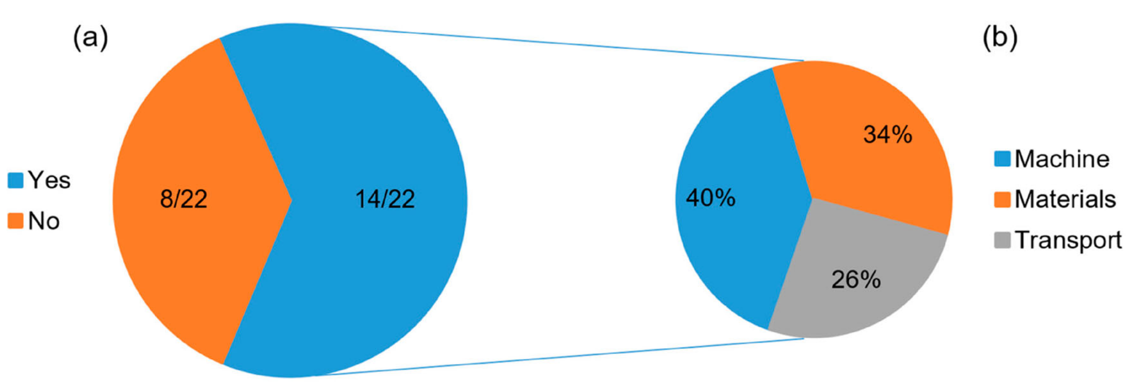

Figure 4. Percentages of responses for (a) whether or not there are economic barriers? (b) What are the main risk elements in CEB production when it comes to cost?

availability issue is more relevant to on-site production as opposed to factory production – in the first survey, on-site production was voted by the majority (16/22) as more suitable for CEB production than factory production. Finally, when asked about any other potentially more important technical barriers besides the aforementioned three, some experts saw potential issues around compatibility of CEBs with building services such as plumbing, electrical fixtures, and fittings, as well as with finishing layers such as paints and coatings.

Economic barriers

Seventeen out of the twenty-two respondents agreed that there are economic barriers facing the realization of CEB in the Egyptian market (Figure 4), while unanimously agreeing that for CEB to be competitive, it needs to be sold at a lower market price than fired clay bricks. Studies have typically found the costs of CEB buildings to be cheaper than comparison concrete block buildings (Adegun & Adedeji, 2017). However, the picture is more mixed when a fired clay brick building is used for comparison. For a prototype CEB house in Egypt, the total cost of CEB walling was less expensive than comparable walling using reinforced concrete columns and fired brick infill (Abdel Gelil & Abo Eldardaa, 2023). In contrast, in Argentina in 2021, the cost of materials per unit area of walling was 18.36 USD/m^2 for CEB, compared to 13.49 USD/m^2 for fired clay bricks (Dorado et al., 2022). Part of this uncertainty arises from the greater range of production efficiency for CEBs, compared to fired bricks. An average-sized fired brick kiln produces around 100,000 bricks/day (Ibrahim et al. (2022)). For CEB production, production capacity is limited by the capacity of the press machine, which ranges between 8000 blocks/day for hydraulic presses (Elkabbany, 2013) and 800 blocks/day for manual ones (Elkabbany, 2013). Costs per block, and per unit area, are crucial for CEB, but actual costs data remains a weak area of knowledge given the CEB sector in Egypt is still immature.

In the second survey stage, experts were asked to identify the aspect of CEB production and use that is most important in determining its overall cost as a building solution. Production process was chosen by 7 out of the 17 respondents of the second survey as the most important cost element – this included the cost of the press machine as well as the operational costs of using it. Sourcing raw material was in second place with five responses, and transportation of the blocks was third with three responses – this viewpoint is believed to be based on factory-based production, which might change if the suggested ideal mode of production is on-site. However, the split votes were relatively even between the three choices, indicating a diversity of views among the experts. There is no precedent relevant to Egypt in the literature to compare to these findings, since costs are market specific.

Social barriers

Eighteen out of twenty-two respondents agreed that there are social barriers to the use of CEBs. The most widely-chosen specific barriers were: client perception of the material being for the poor; poor aesthetics, and prejudice towards the durability of the material. The association of earthen construction with poverty is consistent with reports from some communities in Egypt about young women who refuse to marry men who do not own a concrete house as a sign of wealth (Gado et al., 2010). This viewpoint is also found across other African countries (Adegun & Adedeji, 2017), and is partly attributed to a sustained decline in the proportion of housing built using earth in Global South countries (Marsh & Kulshreshtha, 2022). However, the association between earthen construction and poverty does not necessarily apply to wealthy elites and/or foreign residents, for whom environmental consciousness has greater prestige (Zoungrana et al., 2021). This echoes a wider split between the Global North, which is broadly believed to have more positive associations with earth construction, and the Global South for which there is a general association between earth housing and poverty (Marsh & Kulshreshtha, 2022). Beliefs around CEB durability are an interlink between the social and the technical – previous studies have that durability issues are not totally 'imagined', but rather depend on context-specific material properties and exposure conditions (Danso et al., 2015; Zami & Lee, 2011).

Summary of CEB barriers

The three most important barriers identified by the experts in each of the three categories are listed in order of importance in Table 1. Although these barriers have all been mentioned before in the literature (Dorado et al., 2022; Pelé-Peltier et al., 2023), there are no precedents in the literature to rank them. When asked about the relative importance of the three categories of barriers, the majority of respondents voted for social (n = 10), then economic (n = 6), and finally technical (n = 4) as shown in Table 1. Whilst research around non-technical barriers and enablers for earth construction is relatively neglected (Morel et al., 2021), these findings

Table 1. A summary of the three categories of barriers and the top three of each barrier category facing the integration of CEB in the Egyptian market.

Priority	Social barriers 1	Economic barriers 2	Technical barriers 3
1	1.1 Client perception of the material being for the poor	2.1 Machinery cost	3.1 Availability, maintenance and speed of production of the press machine
2	1.2 Poor aesthetics of CEB	2.2 Material cost	3.2 Proper material availability on site
3	1.3 Prejudice towards the durability of the material	2.3 Transportation cost	3.3 Availability of skilled labourers

show that practitioners in Egypt are clearly aware of social and economic barriers' importance.

Potential enablers to overcome barriers

Experts' suggestions on potential enablers to overcome the identified barriers were initially gathered through the survey and then explored in more detail through interviews with the five selected experts. Technical enablers were identified to address barriers around CEB durability (and clients' perception thereof) and awareness of codes.

Technical enablers

Regarding durability concerns, debate in the literature has focused on the question of whether to use chemical stabilizers (e.g. cement and lime) or not. Some have argued that durability should not be an issue in a well-designed, well-built, and well-maintained earthen structure, and hence that stabilization is unnecessary and not worth the additional embodied carbon (Van Damme & Houben, 2018). Others have argued that whilst stabilization is not essential in theory, stabilization is often desirable in practice, both to ensure material resilience and to give sufficient confidence in the material to clients (Marsh et al., 2020). There is very little literature data on this latter issue of client confidence; the interview responses help give information for this. There was a consensus among the experts interviewed that it is necessary to use stabilizers (e.g. cement, lime) in CEBs to gain the confidence of clients and minimize waste of CEBs in storage and/or use. Accordingly, as expert 3 emphasizes, there would be no real technical concern over the durability of stabilized CEB in comparison to fired clay bricks and/or concrete blocks. Thus, the specification of appropriate stabilization by architects and/or CEB producers is identified primarily as a technical enabler for CEB in Egypt; but since stabilization is also key to reduce the losses in handling and storing the CEB (Bogas et al., 2019) it could also be seen as an economic enabler.

Regarding codes, all five experts agreed that the Egyptian HBRC code (HBRC, 2019) validates the technical viability of CEB as a masonry product. This viewpoint agrees well with perspectives from other Global South countries: in a previous survey, the majority of respondents from India, Iran, and Malaysia stated that national guidelines were either very influential or extremely influential for enabling more earthen construction (Niroumand et al., 2017). As described from the first stage survey results, not all practitioners are yet aware of the HBRC code. Therefore, another technical enabler will be for stakeholders promoting CEB to increase architects' awareness of, and access to, the HBRC code.

Economic enablers

Economic enablers to reduce the cost of CEB buildings were identified for the production process of CEBs, and the design of the CEBs themselves. Experts 1 and 3 recommended that CEB producers adopt centralized, factory production of CEB using hydraulic presses – this would reduce CEB unit costs due to three main reasons. Yet, the use of CEB using hydraulic presses – this would reduce CEB unit costs in a factory setup is believed to have a larger cost reduction potential mainly due to three main reasons. Firstly, the ability to mass-produce CEB would result in greater production efficiency, reducing the contribution of baseline operating costs towards the unit cost of a CEB (expert 1). Whilst no data is available for Egypt, a Sri Lankan study found hydraulic press production to yield a per unit area walling cost 8.5% cheaper than when using a manual press (Maïni & Davis, 2018). Secondly, employing a consistent team of skilled labourers in the factory would avoid the additional costs associated with on-site production, in which different sets of workers are trained for each project – this can take up to 10% of a project's duration (expert 3). Thirdly, in comparison to manual presses used for on-site production, hydraulic presses waste less material and produce stronger blocks which are less likely to break during the curing/storage stages of production (expert 3).

The survey stage of this study identified that the price of CEB is critical to uptake – respondents unanimously agreed that for CEB to be competitive, it needs to be sold at a lower market price than fired clay bricks. Yet, there may be advantages of on-site production that would be lost with a move to centralized factory production. For example, the additional training required for on-site CEB production – viewed from the perspective of architects (as experts 1 and 3 are) for a single project, this additional training represents an additional cost. But, viewed from a community or region-based perspective, such training could be viewed as a beneficial externality, whose value is not captured by that project – the training brings new skills and experience to construction workers in that area. Whilst it is difficult to measure the exact nature and scale of any economic benefits resulting from training programmes have the potential to reach tens of thousands of people when scaled up (Bredenoord & Kulshreshtha, 2023). The broader economic value of training is also important when considering the sustainability of construction in a more holistic manner. For example, Sanya (2012) developed an architectural sustainability framework based on thirteen criteria to assess the sustainability of designs using different materials, including CEBs, for a classroom block in Uganda. Applying Sanya's framework to the Egyptian context, on-site CEB production would likely perform better than centralized factory CEB production for the criteria of 'decentralizing resources and power' and 'job creation for locals', yet more poorly on the criterion of 'affordability'. In addition, a self-help housing model can substantially reduce labour costs for CEB construction (Abdel Gelil & Abo Eldardaa, 2023). More availability of project-based data for CEB construction in Egypt is necessary, to enable holistic assessments of CEB as a product. Centralized factories exist in some countries with a more mature CEB sector (e.g. Argentina (Dorado et al., 2022)), yet none are known to exist in Egypt. Whilst comparing on-site and centralized production for the Egyptian context is hypothetical at this moment in time, it is nonetheless valuable to explore the potential impacts of both production routes if CEB production does indeed scale up to the quantities predicted by the experts in Figure 3.

Regarding the design of CEBs, experts recommended that CEB producers carry out innovations to make CEB lighter. For example, the suggestion by expert 4 to include larger holes and/or lighter soils/fillers Holes have been incorporated in several varieties of CEBs, including as a way to incorporate reinforcement in CEB masonry walls (Bredenoord & Kulshreshtha, 2023). This enabler is already technically feasible, although research would be needed around the maximum size of holes that could be used without compromising CEBs' mechanical properties. The issue of block mass is particularly relevant in determining the overall cost of a CEB structure, in comparison to other types of blocks. The larger mass of a CEB block results in an increase in structural deadload (estimated up to 25%); in turn, this increases the steel and concrete volumes required in the structure, increasing the overall cost of the building. The interlocking CEB type (ISSB) could be a good trade-off since it eliminates the need for mortar, which reduces the associated self-weight and costs. However, complexity in production and unfamiliarity to masons is a barrier to the adoption of ISSB (Nambatya, 2015).

The schematic flow chart in Figure 5 shows the different project-specific technical and economic enablers identified through the interviews across the relevant project stages. The enablers are seen to be limited only to pre-handover stages which is reflective of the early level of maturity of the CEB market in Egypt. The decisions listed in the Figure are also all limited to the role of the design team or the architects, who were the majority of the selected interviewees. However, project-specific recommendations on later stages such as the use and maintenance of the CEB walls were added to Figure 5 based on the authors' experience.

Social enablers

Social enablers were focused on how to overcome the two main social barriers identified through the surveys: the lack of awareness of CEB amongst both the architects and the users, as well as the negative perceptions towards CEB. The enablers to overcome lack of awareness of CEB are grouped in the paragraphs below, according to the actors who are recommended to carry out each enabler. For the role of architects, experts recommended a key role for famous architects. Famous architectural studios should include CEB within the selection for their interior designs (expert 2). Influential architects should make a short video or a documentary promoting the prototypical CEB buildings, such as the one built in the Housing and Building Research Center of Egypt (Elkabbany, 2013), through internet forums and social media platforms (experts 1 and 3). Architects specializing in earth construction should aim to either build their whole office out of CEB or at least have a permanent exhibition of CEB use in their offices for clients to see (expert 4). There are precedents for high profile architects promoting their work in earthen construction – for example, Herzog and de Meuron for their Ricola Herb Center in Switzerland (Herzog & de Meuron, 2013). However, these examples are mostly limited to the Global North. In the Global South, there are numerous examples of high-profile earthen buildings, but these are not always designed by architectural practices

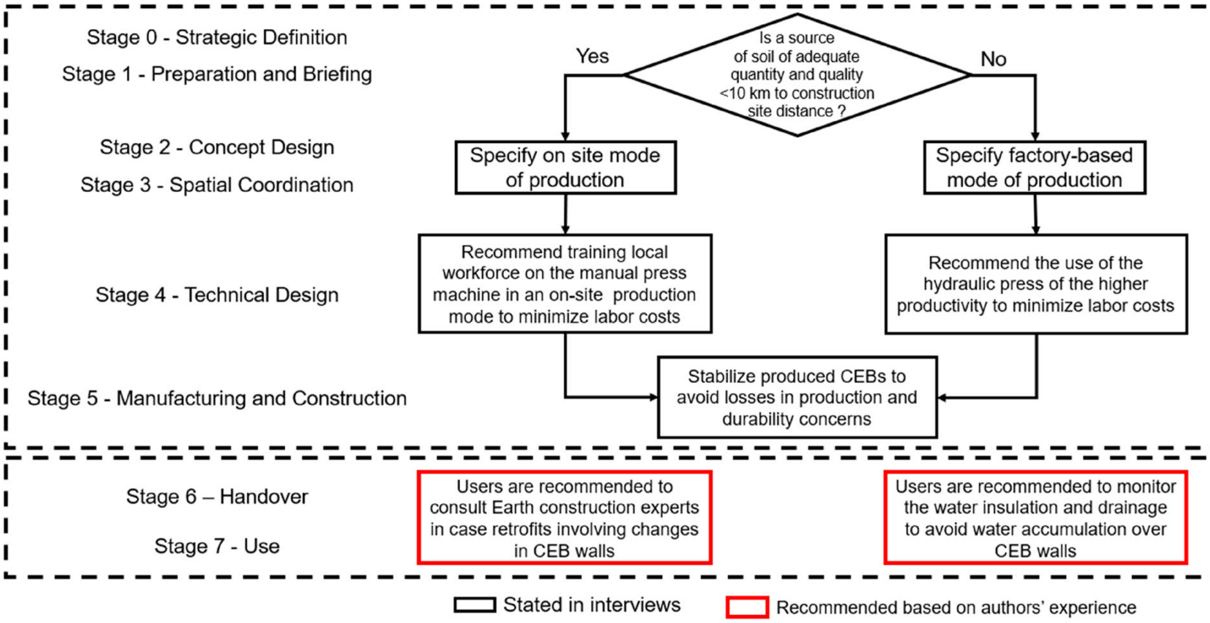

Figure 5. A flow chart summarizing the technical and economic enablers through the typical project stages according to the Royal Institute of British Architects. Decisions are represented with diamond-shaped boxes, and enablers are represented with rectangular boxes.

based in that country – for example, the Rwanda Cricket Stadium (Ramage et al., 2019).

To raise awareness amongst the architectural society, architects with experience in Earth construction are advised to collectively run an online forum with the purpose of answering technical questions about CEB. The online platform, similar to what is presented through the website and social media accounts of the 'House of Egyptian Architecture' (History of the house, no date), would also include a gallery of photos from international and local projects featuring CEB, as well as news and notifications about relevant events such as exhibitions, calls for relevant design competitions and project inaugurations. The network of architects within the Egyptian Earth Construction Association (Cluster, no date), which is inactive at the time of writing – if revived, can play a key role in facilitating these social enablers. For the role of CEB producers, they should attend conventions such as the Big5 (The Big 5, 2023) which are related to contracting and building materials (expert 2). Marketing and advertisement has been recommended as a key enabler for earthen construction in Western Europe (Morel et al., 2021); the experts' recommendations such a similar key role for communication activities in Egypt (summarized in Table 2).

The suggested enablers to address negative perception of CEBs were divided into two groups, based on the targeted user/audience: high-income users, and low- and middle-income users. The housing profile of Egypt is characterized by price-to-income ratios which are relatively high (Abdel Gelil & Abo Eldardaa, 2023). For the high-income users, experts agreed that where negative perceptions arise from doubts over the material's aesthetics, the enablers described above for raising awareness of the CEB use in bespoke projects would be sufficient to overcome these negative preconceptions. It was also recommended to emphasize the environmental savings of using CEB, which appeals to the sustainable consumer profile (Zoungrana et al., 2021). For middle- and lower-income users, negative perceptions of CEBs are believed to stem from their association with mud bricks, which equate to lower social and economic status (Gado et al., 2010; Zoungrana et al., 2021). Accordingly, experts agreed that CEBs should be promoted without referring to its 'earth'

Table 2. A list of the suggestions by the interviewed experts for marketing and communication to overcome the social barriers identified through the surveys.

1	Permanent exhibition of CEB wall elements in Architecture companies offices
2	Promotional videos featuring influential architects for existing CEB building stock including coverage of the existence of CEB codes and standards in Egypt
3	Educational workshops and galleries featuring local and international projects with exemplary use of CEB
4	An online platform specialized in covering news about projects, regulations and industry news about CEB including a Q&A technical forum ran by volunteering CEB experts

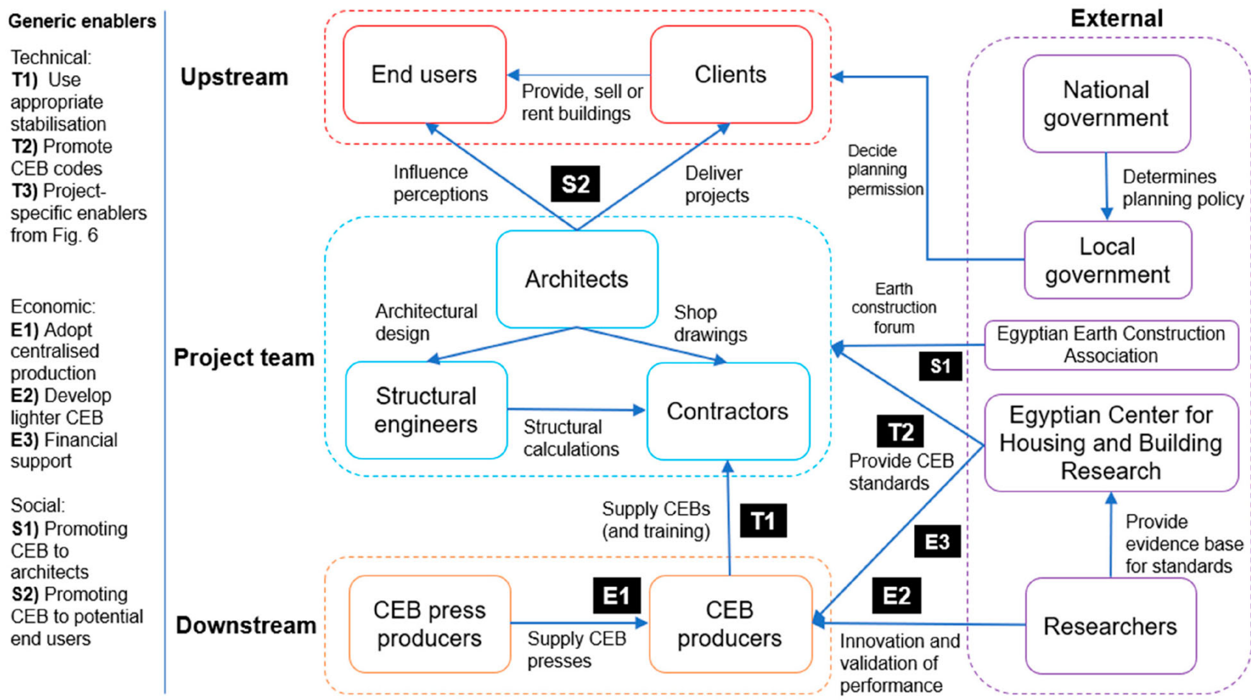

Figure 6. stakeholder map, showing which stakeholders are targeted by the recommended Technical, Economic, and Social interventions.

component, and instead to emphasize its versatility in construction and low cost compared to concrete blocks. Another recommendation was to highlight the use of CEB in expensive, modern designs in other countries, which might have a cultural 'trickle down' effect and increase its social appeal to middle- and lower-income users in Egypt. Within African countries, the majority of CEB projects are believed to be targeted for lower or middle-income users (Bredenoord & Kulshreshtha, 2023). Yet, high-income clients can be more open to use CEB in their housing, if they value its environmental credentials and are not affected by associations of CEB with poverty (Zoungrana et al., 2021). It is therefore reasonable to adopt different promotion strategies for adopting CEB, broadly based on whether the client is middle/lower-income or higher-income, but moreover tailored to their personal priorities and motivations.

Stakeholder mapping

To evaluate how the recommendations for enablers mapped onto the broader socio-technical system of CEB production and use in Egypt, a stakeholder influence diagram was produced. Given the often-fragmented nature of the construction sector, identifying ways to improve communication between key stakeholders is important for earth construction (Morel et al., 2021). The stakeholders were grouped into four categories as described by Walker et al. (2008): upstream stakeholders (the client and end users); downstream stakeholders (i.e. suppliers and sub-contractors); external stakeholders (i.e. those who are affected but lie outside of any individual project); and the project team (i.e. the architect and designers). The primary interactions between different stakeholders were described, as recommended by Bryson (2004). The generic recommendations, which fall outside the scope of individual projects, were then mapped onto the stakeholder map.

This schematic mapping in Figure 6 below shows the majority of recommendations are clustered around a few key stakeholders and interactions. This is not surprising, given that the survey and interview respondents comprised of architects, academics and CEB producers. This tendency to focus on these stakeholders, as well as end users, is generally reflected in previous studies (Samarasinghe & Falk, 2022; Zami, 2022; Zoungrana et al., 2021). In comparison, studies which explicitly seek the views of contractors (Hughes et al., 2017) and government official (Hadjri et al., 2007) are less common. This analysis therefore highlights a need to identify enablers which are recommended by, and for, stakeholders who have been relatively neglected in studies around CEB barriers: government officials, CEB press producers and contractors.

Conclusion

The study of barriers to earth construction has an underlying theme of similarities and differences: between different earth construction techniques; between Global South and Global North, between different countries, and stakeholders. This study's findings show that many barriers to CEB construction in Egypt are shared with many other contexts – for example, client concerns around CEBs' durability. Yet other barriers are specific to CEB, and to the Egyptian context. In particular, architects' lack of awareness about the Egyptian HBRC code for CEB construction, despite being introduced in 2019. This example highlights that some barriers are simply perceived. Overall, respondents considered social and economic barriers to be more critical than technical barriers – this is a reality across earth construction, now known for several years, which researchers need to respond to more proactively.

Identifying enablers to overcome barriers was the second focus of this study. Several of these are similar to proposed enablers from other regions. For example, the need for more effective marketing strategies to communicate the benefits of earth construction. Yet other enablers are specific to CEB, and to the Egyptian context. For example, promoting CEB construction in different ways to lower/middle- and higher-income groups, reflecting trends in different priorities and perceptions between these groups. Wider adoption of CEBs is portrayed by many academic studies as a beneficial outcome, but scale-up of CEB production deserves critical scrutiny. Respondents' predictions of CEBs' potential market share were optimistic – the majority believed that ≥25% market share is possible. Yet the magnitude of scale-up required to meet these projections raises potential issues around quality control and land remediation. Moreover, the supply of CEB presses, and the investment required to procure them, is a potential rate-limiting step if demand for CEB does indeed grow that quickly in the coming years.

This study also shows the value in applying different viewpoints and methodological approaches to the proposed challenges. Regardless of its scale or formality, CEB construction is a complex socio-technical system involving a variety of stakeholders. Mapping the recommended enablers across the different stakeholders in CEB construction revealed an uneven distribution, with government officials and CEB press producers being neglected. Respondents' suggestions should be interpreted with an understanding of bias, in that they are likely to focus on what is within their own experience and knowledge. The proposed enablers are valid and valuable; at the same time, future studies should seek to be more inclusive in understanding the viewpoints of neglected actors. This viewpoint of inclusivity is also relevant to the study of other non-conventional construction materials.

Data availability statement

As per the UKRI open access requirements, the survey and interview data could be accessed using this link https://doi.org/10.5518/1378.

Notes

1. Based on purchase orders presented by CEB press manufacturers to the authors in 2019.
2. Based on the authors' own experiences.

Acknowledgements

The authors thank Eng. Ahmed Abdelgawad (Hand Over Projects), Eng. Farah Faheem (Karm Architectural Lab), Eng. Rasha Emad el-din (Benaa), Eng. Waleed Arafa (Dar Arafa) and Eng. Mohamed Hilal for their effort in the data collection process.

H.H would like to acknowledge the support of the ESPRC fund through the TransFire hub (Grant Reference EP/V054627/1). A.M. would also like to thank the Building Research Establishment Trust for funding, via the Royal Charter International Research Award.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This work was supported by UK Research and Innovation: [Grant Number EP/V054627/1].

CREdiT statement

H.H.: conceptualization, methodology, data collection, investigation, writing – original draft preparation; D.M.: validation, data collection, writing – original draft preparation; A.M.: methodology, formal analysis, writing – review and editing, funding acquisition.

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