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The future of cob and strawbale construction in the UK

Natural building materials and methods

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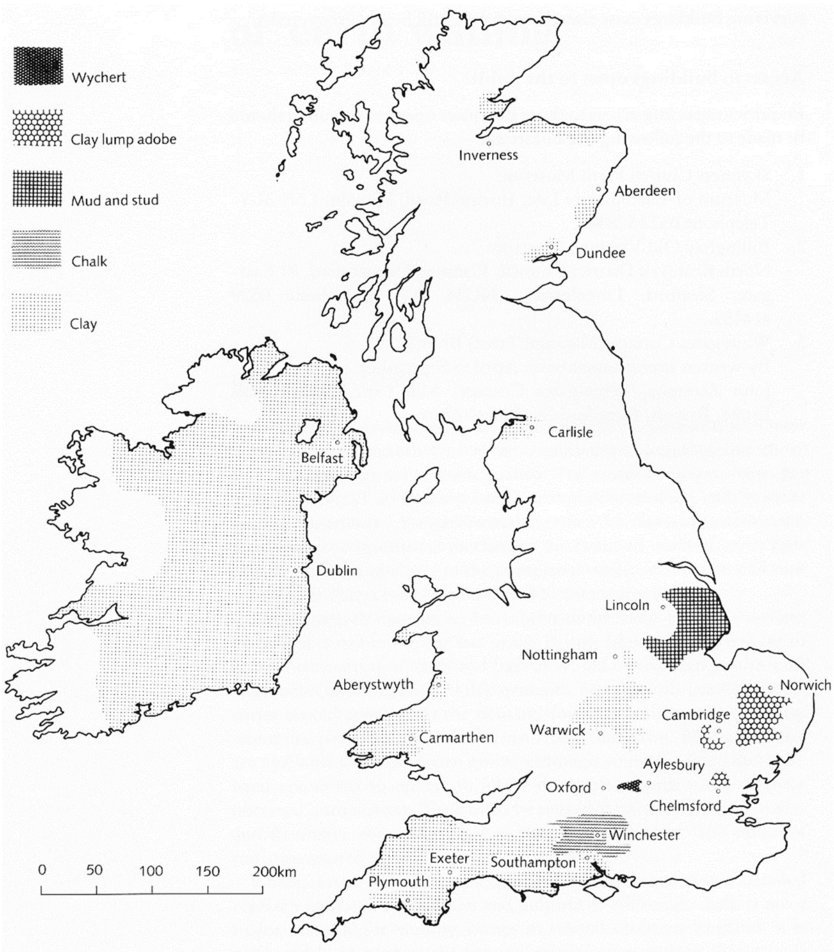

Figure 1. Regional distribution of earth buildings in the United Kingdom; [1].

Figure 2. Great Mosque of Djenne, Mali (rebuilt in 1907); [2].

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The future of cob and strawbale construction in the United Kingdom

Recent building research literature demonstrates a renewed interest in the use of natural building materials for constructing modern buildings. This paper considers earth (inorganic) and strawbale (organic) natural materials and their respective methodologies to identify potential for application in mainstream construction in the United Kingdom. It identifies current barriers for their wider uptake, along with developments necessary to enhance opportunities for greater use in new-build construction.

Natural building

'Natural building' is concerned with more than the surface application of natural materials and assemblies. It describes a philosophy of building that nurtures a profound respect for the contextual natural environments engaged [3]. This is best exemplified by abbé Laugier's (1753) representation of the 'primitive hut' as the original archetype of a construction in harmony with its natural environment [4]. The many traditional vernacular constructions from most cultural contexts could be argued to demonstrate an affinity with this philosophy, with methodologies intuitively developed over centuries of interaction with their respective natural environments (e.g., see Figure 3). The materials and assemblies in such constructions are holistic solutions (including lifecycle processes), developed and sustained to serve their function, while having minimal adverse impact on the ecosystems they occupy.

The modern age of building construction in the western world was marked by the onset of the industrial revolution and the introduction of mechanised production. This ensured uniformity and reproducible quality that consumers could readily identify as a reliable product. The scalability of this production generated its own demand, paving the way for mass-scale consumerism. In response, production demanded mass-scale processing of materials and remote manufacture to diversify the production chain. This increased efficiencies that translated to higher profitability, with continued streamlining enhancing profitability to demand even greater processing. Raw materials were thus refined to remove all imperfections and products were given an engineered finish with the aid of machines to result in the ‘mechanised aesthetic’. This aesthetic came to signify modernity to consumers, and as the result of efficient and standardised production. Natural building materials meanwhile were increasingly associated with inefficiency and imperfection, appropriate only for rural self-build experiments.

The 1960s marked a radical turning point with the awareness of the global impact of resource consumption necessary to sustain such mass-scale production and consumption. This in turn gave rise to the ‘environmentalism’ movement [5], which escalated to political action following the oil crisis of the 1970s. By the 1990s, the ‘sustainability agenda’ was being integrated to all aspects of policy, including built environment design and construction. This reignited interest in natural material systems and renewable resources to address policy demands, as well as the increasing introduction of regulatory compliance requirements.

Although resource management concerns have been the critical policy driver, several other influences also encouraged this reengagement with the natural building movement. Health and wellbeing of building occupants has been cited as significant, as industrially processed materials over the years had acquired a reputation for being harmful and contributing towards various ailments [6]. The rediscovered appreciation of the aesthetic of natural materials was another influence. Minimally processed, raw, and earthy finishes had started to gain acceptance as ‘alternatives’ to the sterile characterless finishes of processed materials. The other main driver was forwarded from a socioeconomic perspective. The community involvement encouraged by building with such materials had been long identified to enhance social cohesion and reinforce local communities. Natural building as a result gained political attention as means to drive the agenda to develop rural regions and economies.

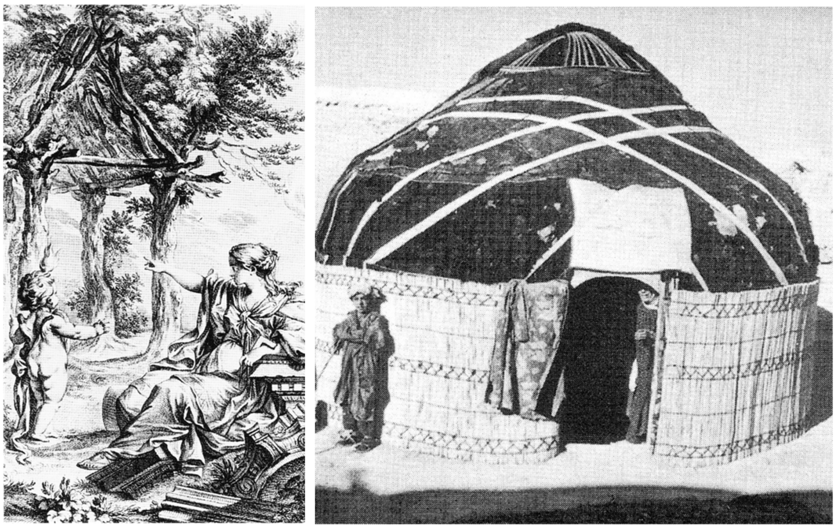


Figure 3. Plate representing Laugier's primitive hut (left), and a Yurt from Central Asia with matt coverings (right); [4].

Figure 4. Adobe brick making with a timber-framed mould in Yemen; [2].

Earth construction

Earth as a material and methodology to construct habitable structures has been utilised for millennia (e.g., Figure 2). It is a material of abundance, and different cultures around the world have developed diverse approaches to construct structures that address their needs by utilising its inherent properties. Such earth construction methodologies include [1–7]:

- Moulded earth blocks (adobe, e.g., Figure 4);
- Stacked earth (cob, used in southern England);
- Direct shaping (balls or coils of clayey soil);
- Extruded earth (blocks);
- Daubed earth (wattle and daub; mud and stud);
- Poured earth;
- Cut earth blocks (sod);
- Compacted earth (blocks or rammed earth);
- Pneumatic earth;
- Straw-clay (blocks or panels);
- In-fill (bagged earth); and
- Excavated dwellings (e.g., *Yaodong,* cave dwellings in the Loess plateau in northern China).

Earth material has high ‘thermal mass’, characterised by high heat capacity and thermal inertia, which is favourable for moderating temperature fluctuations. These thermal properties enable passive solar strategies to be employed in constructions to reduce space-conditioning needs and resultant fuel and energy consumption. Since most assemblies have significant porosity and are thus breathable, humidity of indoor environments is also moderated to facilitate cooler and constant hygrothermal conditions. Another benefit of high mass is low sound transmission and high absorption, making the material favourable for any building use requiring high acoustic comfort. Earth is also nontoxic (provided that uncontaminated soil is used), which has encouraged it to be identified as a healthier construction material, particularly favoured by those who have adverse reactions to processed materials [1–7].

As suitable earth for construction is abundant locally throughout the inhabited world, the impact of material transportation is minimal. Localised and decentralised production also ensures relatively low assembly and building costs, while labour-intensive processes create local employment opportunities, which in turn promotes social and economic sustainability [1–7]. Earth construction systems therefore have been recognised for having high potential to replace the need for scarce, energy intensive, and polluting construction materials like kiln-dried products, lumber, and cement.

Cob construction, as an example

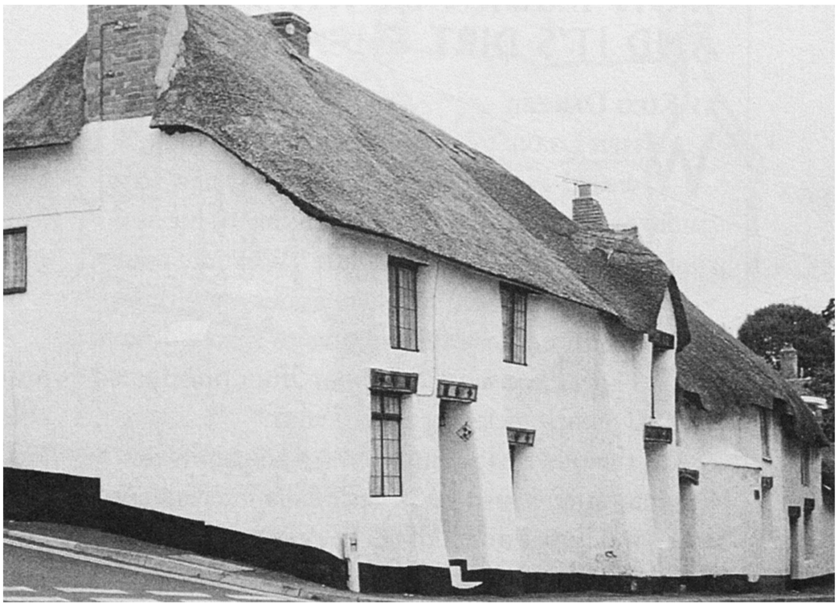


Figure 5. A cob house in Devon, England, built in 1536 [8].

The word 'cob' originates from the old English for 'loaf', and describes an earth construction practice found in southern England, notably in Devonshire [3]. It is one of the oldest and simplest forms of construction in such areas, with historical accounts dating as far back as 1212. A few sixteenth and seventeenth century buildings with original cob still exists in Devonshire (e.g., Figure 5), although most buildings date from the eighteenth and nineteenth centuries. Broadhembury in east Devon for example, is a notable settlement that is almost entirely constructed with cob [9].

Cob buildings require no formwork, ramming, industrial additives, or highly skilled labour to construct. The material typically consists of sand, clay, straw, and water, all combined to present a cohesive mixture that is applied and formed. As the walls are typically moulded by hand, they present a distinct sculptural aesthetic that in turn contributes to the characterisation of the architectural form of the entire building. The material is still in use in Devonshire for constructing new farm buildings and dwellings. The methodology used in these areas is conservative and demonstrates little digression from the cob building methods of the past. The construction method is still regarded by locals to be economical, and as a recyclable material with little environmental burden [3–8].

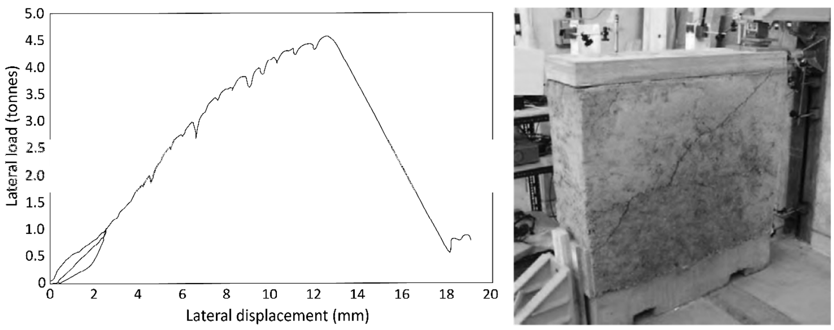


Figure 6. Load-displacement curve for an in-situ cob wall (left); and the test wall at failure (right); test conducted by the University of Bath.

The physical properties of a cob wall are influenced by its depth or thickness. A typical cob wall is around 600 mm in depth, although there are examples that are as slender as ~450 mm. Where such buildings have remained stable for centuries as in Devonshire, the walls are built on firm subsoil with the base rarely extending beyond its average depth. Typically, such a wall with an average density of ~1,900 kg·m^{-3}, would present an average compressive strength of around 1.9 N·mm^{-2} [9]. At the Genesis Centre for example, the 500 mm in-situ cob wall constructed included clayey soil from the site, which was mixed onsite, and samples tested at the University of Plymouth. Where testing was not possible, conservative values of unconfined compressive strength (0.5 N·mm^{-2}), permissible shear stress (0.04 N·mm^{-2}), and flexural capacity (0.01 N·mm^{-2}) had been assumed to complete the design [10].

Depending on moisture content and density, the thermal properties of a cob wall varies. For example, a typical 600 mm thick wall with 3% moisture content and a density of ~1,900 kg·m^{-3}, will have a U-value of 0.94 W/m^2·K, while a lower value of 0.79 may be obtained by reducing the density to 1,750 kg·m^{-3}. If enhanced thermal performance is required, externally applied insulation is recommended to offer the best solution [9].

With the design of cob buildings, control of moisture and erosion are significant considerations [9]. Cob structures should always be sited on higher ground and away from standing water. In climates as in the United Kingdom, they are typically constructed above a stone foundation (raised footing or plinth), which would stand above the damp-proof course, with the damp-proof course linked to the damp-proof membrane in the floor [3]. Since in-situ cob has relatively high water content, design detailing should allow for ~3% shrinkage [10]. When the wall has dried out, this moisture content will reduce to between <3 and 1%. Although some sources suggest the contrary, cob does not require rising moisture to keep its structural strength and will perform according to its hygroscopic moisture content [9]. This however varies marginally, with north Devon cob for example having lower values than south Devon. In any case, the rapid infusion of liquid into the base of a wall must be avoided as it may cause rapid destabilisation and collapse. Once any part of a wall reaches its saturation level, it rapidly moves through the plastic phase and slumps dramatically to result in extensive collapse [9]. As common practice with any earth building method, the need to provide adequate roof overhang applies to protect the walls from driven rain, ensure durability, and control weathering. Most cob buildings in Devonshire are coated with a lime-wash to preserve their integrity, which also gives them their characteristic and traditional white colour [3].

The fire risk of cob construction is relatively low. Although they contain straw that is used as a binder or filler (mainly in south Devon and less in the north), there is usually adequate earth content to provide fire resistance comparable to brickwork [9]. The reported collapse of walls during fires is therefore attributed to water damage rather than fire. The other significant advantage of cob is its good sound insulation attributed to the mass provided (which for an average wall of ~600 mm at 1,900 $kg \cdot m^{-3}$, the density would be around 1,140 $kg \cdot m^{-2}$). A significant disadvantage of this high material mass however is its vulnerability to vermin infestations. Some walls have been found to be riddled with rodent holes that had consumed up to a third of their mass. When such holes are repaired, filling with a lime-based slurry and sealed with cob reinforced with a stainless steel mesh is recommended [9].

In contrast to in-situ cob walls, cob blocks provide an engineered modular approach to construction. At the Genesis Centre for example, a cob block wall of 400 mm depth was designed and built as a conventional masonry wall using BS 5628 [11], and assuming conservative material properties such as 0.75 $N \cdot mm^{-2}$ compressive strength for a block. Onsite testing was deemed unnecessary, provided a large enough random sample had been tested prior [10]. As the cob blocks are mostly dried out (i.e., pre-dried), a lower shrinkage allowance of 1% was used for the detailing of the wall. The 'engineered' qualities of the block therefore controls material properties to make it viable for mass production, and in turn wider applicability as a mainstream construction solution.

Figure 7. Cob wall construction at the Genesis Centre; [10–12].

The Genesis Centre is located at the Somerset College of Arts and Technology in Taunton, Somerset, England. It is a £2.5 million educational resource funded by the South West Regional Development Agency (SWRDA) and the Learning and Skills Council [10–12].

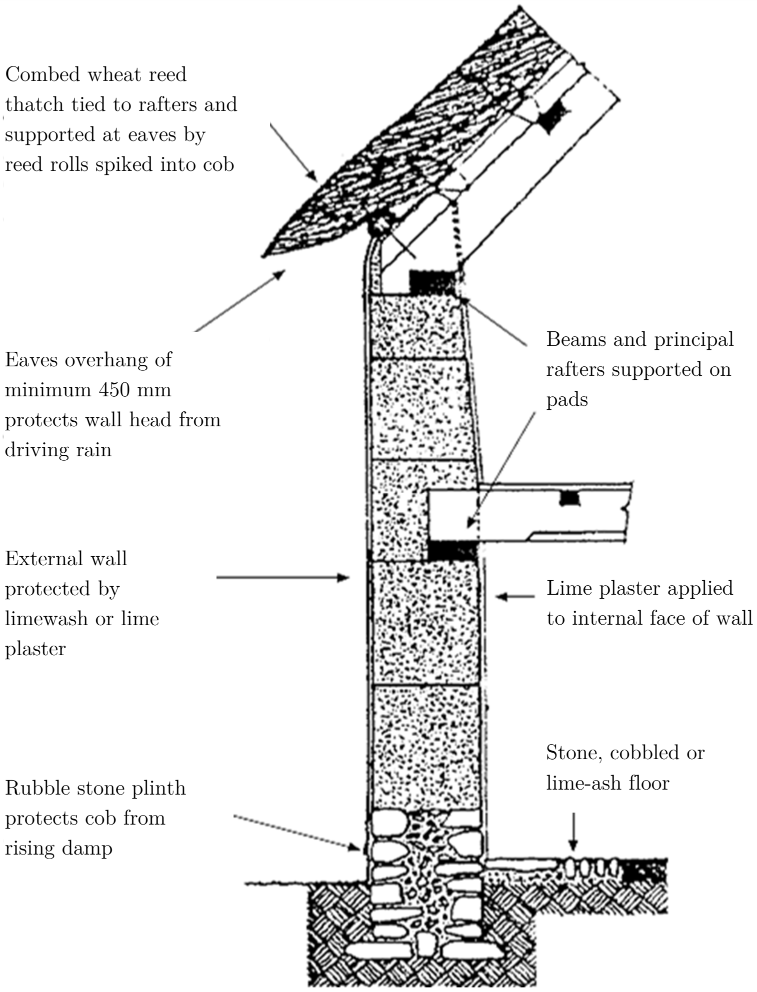


Figure 8. Section through a typical cob wall construction; [9].

Strawbale construction

Straw is an agricultural by-product that represents the dry stalks of cereal plants after the grain has been removed. It is composed of cellulose, hemi-cellulose, lignin, and silica [13–14]. As a building material it has had a significant presence in construction for centuries. Traditional adobe and cob constructions have utilised it for tensile reinforcement, while roofs thatched with straw is traditional across northern European and East Asian cultures. Straw therefore has a rich presence in building construction practices, although has suffered neglect over the generations following industrialisation.

The emergence of straw as a viable principal construction material occurred in nineteenth century America in response to material shortages, particularly lumber shortages in Nebraska [3–13–15]. It gained wider acceptance from the 1850s onward with the development of the mechanised baler. The large modular sizes of the bales produced by the balers translated to speed in building erection. This in turn encouraged many modular straw buildings to be constructed between 1890 and 1945 in America.

The straw of different grains has varying biochemical compositions. Rice straw for example is considered the toughest due to its high silica content [14]. Such micro properties however have been found by laboratory tests to be less significant than the macro properties of moisture content, density, and bale history (storage record from harvest to construction) in determining bale quality [13]. If such macro properties have been controlled, the usually high silica content and long stems of most straws present a durable material. This in turn makes it suitable for construction applications where a typical building lifespan of 50 to 60 years is expected. In America there are strawbale houses older than a century still in service, while in the United Kingdom the available service history remains limited to only a decade or two [10]. Long-term exposure to moisture is the greatest threat to strawbale longevity, although it typically requires relatively high moisture content between 20 to 25% of the total weight for fungal growth and decomposition to occur [14]. To manage the variability of the quality of bales, performance criteria must address the maximum allowable moisture content and minimum density at construction [13]. At the time of installation, it is recommended that the moisture content of bales should not exceed between 10 to 16% of the total weight of the bale and have a minimum dry density between 110 to 130 $kg \cdot m^{-3}$ [10].

A significant advantage of straw is its thermal insulation properties. Although its U-value is similar to most other insulation materials such as cellulose or mineral wool (density between 110 to 130 $kg \cdot m^{-3}$, would have thermal conductivity between 0.055 to 0.065 $W/m \cdot K$), typical assembly depths between 450 to 600 mm enable strawbale walls to achieve a ‘super-insulated’ state (e.g., 450 mm width would have a U-value of ~0.13 W/m^2·K). The indoor environments of strawbale structures are as a result thermally comfortable and energy efficient to sustain. The embodied energy of strawbales is also low and calculated to be ~0.24 MJ/kg. In comparison to insulation materials such as expanded polystyrene (117 MJ/kg), it is acknowledged as a renewable material that is well-suited for low carbon construction [16].

Table 1. Advantages and limitations of strawbale construction.

Advantages	Limitations
▪ Low-cost renewable material, widely available from local sources. ▪ Stores carbon throughout its life. ▪ Lightweight material that reduces loading with simple construction details and processes. ▪ Good insulation properties. ▪ Avoids thermal bridging and provides good airtightness with simple detailing. ▪ Vapour-permeable construction envelope. ▪ Suitable for in-situ and prefabricated approaches. ▪ Simple building skills needed, thus suited to self-build and community projects.	▪ Inconsistent properties (e.g., dimensions, density, and moisture content); can be problematic during construction. ▪ Details restricted by need to protect straw from water ingress. Limited water resilience (concerns over flood damage) and problems for repairing if water damaged (particularly loadbearing walls). ▪ Requires shelter before finishes can be applied. ▪ Use limited to above damp-proof course or equivalent level. ▪ Limited to relatively lightweight fixings. ▪ Suitability of rendered finishes limits application in some locations.

A common concern with the use of straw in buildings is fire risk. Unlike loose straw that readily combust, strawbale assemblies are densely packed to deny adequate oxygen to sustain a fire. Exposure to a fire typically results in the surface of a bale wall being charred (provided the exposed bales remain intact), after which the worst that happens is smouldering. Unprotected loose straw however is extremely vulnerable to fire, and some bale buildings in the past have burned down in the time between erecting and the bales being protected with plastering. Caution must be exercised during construction to avoid this risk by clearing loose straw around the building site and avoiding welding and other spark generating activities near exposed straw [16]. A composite assembly with plaster on both faces, which combines incombustible surfaces and an insulating interior that neither burns well nor melts, provides for a fire-resistive construction. This composite assembly has been verified by laboratory tests to withstand a two-hour fire test, which outperforms most other wall systems [16–17]. Plastering also adds to wall strength, with those plastered flat 36% stronger than those plastered on edge. Plastered bale modulus however has been found to be highly variable and unpredictable [18].

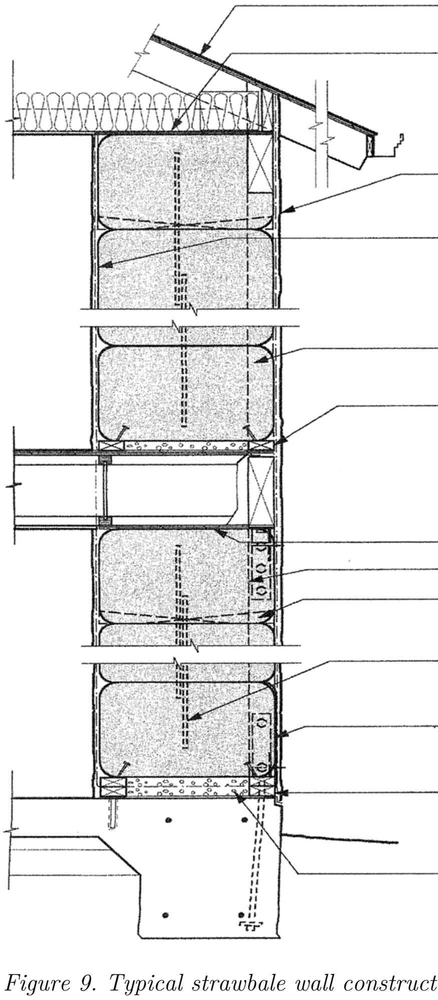


Figure 9. Typical strawbale wall construction section; [3].

As straw represents the empty stem of a grain crop, it does not contain nutrients to attract vermin as with hay. Infestation however is a common threat from vermin that search for warmer conditions to nest, which is typically dealt by either denying access by sealing the walls, or by special chemical treatment. In common with earth, straw is considered a nontoxic benign material, with no known adverse influence on human health and wellbeing [3].

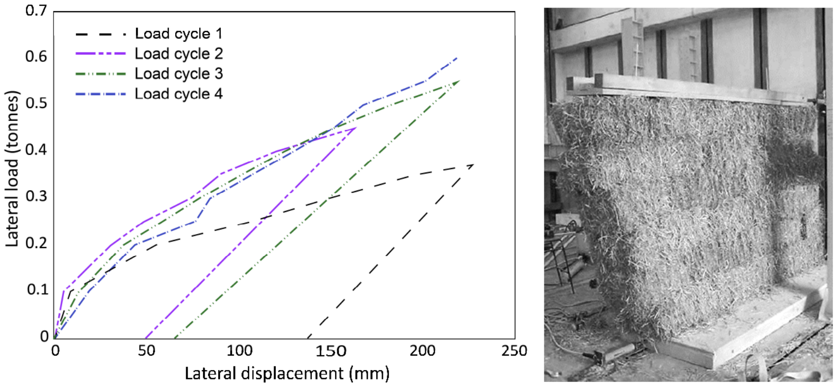


Figure 10. Load-displacement curves for a bale wall; and the test bale wall at failure; test conducted by the University of Bath.

Strawbale constructions are typically classed as either 'loadbearing' or 'post-and-beam' assemblies. Loadbearing structures are mostly single storey, and load requirements are accommodated by pre-compressing the bales. The structural action is aided by the finishing plaster layers on either side, which enables the assembly to function as a stress-skin sandwich panel [18]. Loadbearing strawbale construction is virtually non-existent in the United Kingdom, although is popular in Arizona and Colorado, parts of Canada, and Australia. Post and beam strawbale construction encompasses a large variety of bale arrangements that are non-loadbearing. Typically, 'infill' and 'fabric' strategies are the most common forms. The fabric arrangement uses strawbales internally as a skin and a timber frame takes the load externally, while the infill strategy uses strawbales as infill in-between a loadbearing timber frame. A mixture of framing and loadbearing techniques are also employed as 'hybrid' solutions, particularly in the construction of multistorey structures. Although bales created on farms with baling machines are typically used for construction, higher density mechanically 'pre-compressed' bales can be used to increase the loadbearing capacity. New modular prefabricated wall panels with higher loadbearing capacity are also being developed for potential application in the construction of multistorey buildings.

Figure 11. Loadbearing strawbale construction in Arizona, USA; [1].

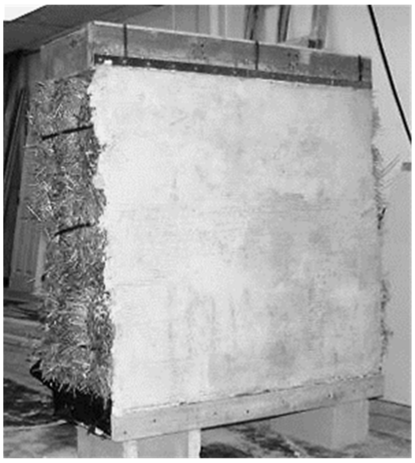
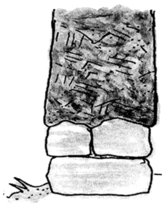
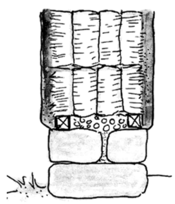


Figure 12. Strawbale test assembly with plastered exterior surface. University of Bath; [1].

The main disadvantages of building with straw relate to modular restrictions and building tolerances. As the dimensions of bales are determined by the baler, the design of the walls should ideally be based on this modulation. This means that bales would have to be sourced first (as bales come in different sizes), after which the design of the building can be determined. However, if a building's height were to be fixed based on other considerations (e.g., planning conditions), the coursing of the bales would have to be calculated so that the wall is the required height with the expected compression included. Any shortfall would require smaller bales to be used. As the compression deflection in strawbale buildings is substantial compared to conventional buildings (typically between 50 to 100 mm per storey), the final dimensions of a wall will be elastic. This is a concern at interfaces that require tighter tolerances (e.g., curtain-walling interfaces, adjacent structures, etc.), where any creep occurring may cause sealing problems. At the Genesis Centre for example, the designers had to install timber studs to the inner face of the walls to act as safeguards by preventing the wall compressing below the height of the studs to avoid plastic deflection and mitigate variable elastic compression [10]. Due to these shortcomings resulting from modular restrictions and tolerances, there is general tendency to consider bale construction for standalone structures with reduced necessity for precision and include sympathetic detailing and finishes.

The limited use of straw construction in the United Kingdom is dominated by conventional post-and-beam infill arrangements. The approach however is still regarded as unconventional by the industry, with little application interest demonstrated and design examples implemented. This is further complicated by material property values quantified tending to vary widely, as well as significant shortfall in available shear capacity and creep data [10]. Unlike earth construction, research interest at present is also lagging in comparison to non-European sources. These available sources (mostly North American) however, relate to applications in in relatively drier conditions. Long-term stability in high humidity conditions is therefore not well-understood [8]. This lack of evidence-based supporting material has thus far led to little guidance and regulatory incentives encouraging the uptake of straw as a mainstream construction material in the United Kingdom [3–10].

Table 2. Cob and strawbale material comparison.

	Cob	**Strawbale**
Typical detail		
Shape and size	Cob is made on-site as required in small to large amounts. Amorphous, it can be formed to almost any shape and applied by handful to	Pre-assembled bales are a modular agricultural by-product that is relatively homogenous. Available in several sizes dependent on the

	Cob	Strawbale
	bucket load. It can be custom mixed to a wide range of densities, strengths, etc.	baler, mostly large and rectilinear. Strings must be very tight, polypropylene baling twine, sisal, or hemp, but not wire [10]. Must be stored in dry conditions.
Thermal properties	High thermal mass, poor insulation. Stores heat or 'coolth' (high inertia).	Excellent insulation, low thermal mass.
Load bearing properties	Needs no additional structure, roof-bearing. Cob settles as it dries, after which is extremely stable. Tolerates water until saturation, after which possible failure, often rapid and without warning.	Bales compress under vertical loading. Long-term stability in high humidity climates not known. Water penetration is potentially disastrous at any time from manufacture onwards. Multistorey buildings need special support and detailing.
Construction conditions	Not in frost or very humid, still conditions. Protect from heavy frost and rain.	Any temperature, but not in rain. Rain protection and dry storage is essential.
Protection needed	Excellent weather resistance. Needs interior plaster and driven rain protection. Fire resistant.	Protection essential from moisture, rodents, and fire.
Durability	Proven by many centuries of service in various weather conditions, including windy, rainy coastlines.	Proven by a century of service in dry conditions.
Rate of building	Faster than assumed. Slow building rate, although little finishing is needed.	Slower than assumed. Fast erection, although needs extensive finishing.
Most appropriate use	Small, complex, sculptural, artistic, curved buildings; on stable ground, multistorey; long-lasting buildings; cabins, greenhouses; buildings that are solar heated and need thermal stability. Used for floors, interior walls, and exterior walls in mild climates.	Large, simple buildings, typically single storey; fast or temporary structures; buildings that need fast heat for occasional use: classrooms, meeting halls, etc. Used for walls, roof insulation, and exterior walls in extreme climates.

Based on Evans *et al.* [8].

Overcoming barriers for future uptake

Earth construction has a long and rich history of application in the United Kingdom. While most of this knowledge is preserved and applied in conservation projects, interest in modernising such approaches to encourage wider uptake has received significant attention in recent years [7]. Exemplar projects such as the Eden Centre in Cornwall and the Genesis Centre in Taunton have demonstrated this interest by successfully integrating rammed-earth and cob constructions. They have shown that such approaches could advance beyond one-off self-build dwellings and be implemented in other building typologies. This modern earth building drive is therefore not advocating a return to the 'mud-hut', but attempting to advance such methods to address mainstream construction application opportunities. With cob construction for example, moving towards engineered modular methods are identified to present greater potential for future mainstream application [10], while traditional methods would continue their relevance in the conservation of historic buildings [9]. Strawbale construction however is relatively novel to the British construction industry and at present remains largely a self-build solution used for one-off standalone buildings. In terms of establishing technical experience and longevity of its application, the material has considerable gaps to bridge. Further research is therefore critical for it to progress as a mainstream construction opportunity, whereby understanding the strengths and weaknesses of the material's micro and macro properties in the context of the climate of the United Kingdom, will lead to the development of detailed guidance and standards.

When proven low-risk construction methodologies are available, the construction industry seldom engages with novel alternatives; which has led to its characterisation as inherently conservative. Alternatives are typically held back as a risk, until certainty of profitability has been identified. The critical driver for proactive engagement is therefore the opportunity to significantly enhance profitability. This risk averse inertia typically leads to a time lag between the introduction and adoption of alternatives; and if profitability is not substantial, mainstream adoption is unlikely.

The main external mechanisms that compel adoption of novel alternatives are market demand, and the introduction of policy and regulation. Both mechanisms include the community as grassroot level influencers, with market demand represented by what the community demands to consume, while regulations are shaped by what the concerned community demands of the government in order to address market failures. The community therefore plays a significant role in encouraging the uptake of alternatives. This community however represents diverse groups of interest that are not necessarily proactive in their demand and influence generation. Industry marketing strategy therefore takes advantage of this reactionary nature to influence communities by disseminating information as means to 'educate' demand generation. This however is laden with the agenda to generate demand that leads to profitability. It is therefore concerned with enhancing consumption of what is on offer, and not necessarily sympathetic to promoting an informed judgment based on a consideration of all available alternatives. Nevertheless, this acknowledges information and education as vital means to influence how communities consume resources.

Informing and educating communities of the benefits of using natural materials is by no means a straightforward task. The construction industry has over the decades engaged in many campaigns to promote processed, standardised, and engineered materials and their assemblies. This has also promoted considerable prejudice that suggests natural materials are 'primitive' and representative of the converse of 'modernity' [3]. The result of such thinking in the United Kingdom has led to these materials and constructions being considered appropriate only for the rural countryside and not urban areas. Challenging this narrative with counter rhetoric alone is unlikely to overturn decades of misguided beliefs. What is likely to yield progress is an evidence-based approach to informing and educating, with constructed exemplar projects demonstrating real-world application potential and delivered value.

The duty to disseminate evidence-based findings to the community is with researchers and impartial professionals. Considering the procurement of buildings, architects as industry professionals play a significant role in the specification of materials and assemblies. In-depth knowledge of all materials available and their potential for appropriate application is vital to their craft, and the profession in recent years has actively directed greater attention to natural building materials as means to achieve low-carbon, climate resilient buildings. An understanding also exists in such professional communities that recognises the necessity to integrate research findings with real-world applications.

Developing built examples of merit has been demonstrated to be a powerful tool, where the realities of alternatives are demonstrated as concrete working examples. Projects such as the Genesis Centre in Taunton exemplify this strategy, and introduce alternatives to the wider community to observe and engage with the reality of what such methodologies deliver [10–12]. Although the ethical environmental argument for the use of natural materials is inherently potent, aesthetic and tactile considerations have gained increasing primacy in recent consumer decision-making. Physical representation of natural materials as built examples therefore enhances community engagement and appreciation (i.e., enhances their appeal), which in turn would lead to market demand generation.

The gradual advancement of community interest and engagement is however unlikely to address the pressing concerns of climate change. The declarations of urgency by the UN Intergovernmental Panel on Climate Change have stressed the need to address climate challenges with urgent legislative force and to compel all industries into compliance. The UK Government response of introducing targets to cut carbon emissions by 60% by 2050[1], revisions to the Building Regulations, and further anticipated environmental legislation, are all expected to oblige the construction industry to consider the greater use of natural building materials. Overarching policy and legislation generated to address such issues however must be detailed and reconciled in secondary regulatory mechanisms. A central barrier to wider uptake of alternative construction solutions at present is the discontinuation and disjunction between

[1] Office of the Deputy Prime Minister, United Kingdom, 2006.

these two regulatory tiers [3]. For example, testing for code compliance is an area that requires reconciliation with the idiosyncrasies of natural building methods. Although localised material extraction is a benefit in terms of minimal transportation and associated lower economic and carbon costs, it is a principal concern when producing and complying with regulatory testing practices. As demonstrated by the testing requirements for earth construction (see Table 3), testing locally sourced material to meet Building Regulations criteria at present requires considerable effort and cost for field and laboratory testing. This is as a result a significant disincentive for proactive industry engagement, given the already approved standardised options available on the market.

Table 3. Tests for earth construction; [1].

Standard field tests	**Standard laboratory tests**
▪ Sensory tests: visual; smell; touch (soil composition)	▪ Sedimentation and sieve analysis (soil composition)
▪ Jar sedimentation test (soil composition)	▪ Plastic limit (plasticity)
▪ Dry strength test (clay content)	▪ Liquid limit (plasticity)
▪ Dilation or water retention test (fines composition)	▪ Linear shrinkage (plasticity)
▪ Thread test (clay content)	▪ Proctor test (optimum moisture content)
▪ Cohesion or ribbon test (clay content)	▪ Mineralogical analysis
▪ Drop test (optimum moisture content)	▪ Chemical analysis (salts; pH; organic matter; carbonates)
▪ Shrinkage test (plasticity)	

Ensuring quality is necessary for assigning accountability for defects. As most natural materials are minimally processed with little quality control, raises concern in relation to guarantees and defects liabilities that can be reasonably honoured. A degree of testing therefore is necessary to address such risk, although must be moderated to ensure that they do not become disincentives to engagement. This balance however is likely to be specific to each natural building material and their assemblies, which in turn highlights the necessity for regulatory frameworks to develop material system specific requirements, informed by evidence-based research.

As a solution for alternative natural building materials overcoming such concerns is to embrace some standardisation practices. As demonstrated earlier with reference to cob construction, moving towards standardised modular forms are more likely to be accepted by building contractors as a degree of quality control can be certified. Even with straw construction, modular composite panels that are engineered and sealed as 'cells' are likely to provide greater opportunity for urban applications. Care however must be taken to ensure that such standardisation processes do not embody vast amounts of energy and carbon in their modularisation and processing. If that were to be the case, a central purpose of utilising natural renewable resources for construction will be invalidated.

Concluding remarks

'Natural building' is increasingly gathering public interest and participation. As modular engineered solutions, they have been demonstrated to advance beyond rural self-build domestic solutions of the past to offer application opportunity in other building typologies and urban settings. Enhancing the adaptability of such materials through technical innovation that complements modern construction processes is likely to aid wider construction industry engagement. Regulatory incentives are however still necessary to address initial inertia and market risk aversion. With the implementation of such combined strategies, the coming decades are predicted to see significant growth in the use of such materials.

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