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Wood needs mass – Improving timber construction with earth building materials

Modern-day timber construction and traditional half-timbering and earth infill are worlds apart. For centuries, the walls of almost all timber constructions were closed off with earth to form enclosed spaces, but today earth plays practically no role in timber construction. Even with the development of new earth building materials and corresponding DIN standards, modern timber construction fails to leverage their potential for remedying its shortfalls. Modern methods of lightweight, super-insulated timber construction have not been as promising in practice as they sounded in theory. Their inability to insulate against heat gain in summer or to retain passive solar energy in winter, their inadequate sound insulation and the need for complex wall constructions to ensure moisture protection and airtightness are just some of the issues. The problem of overheating in summer along with the high cost of high-tech timber construction has led many people to return to conventional forms of solid wall construction.

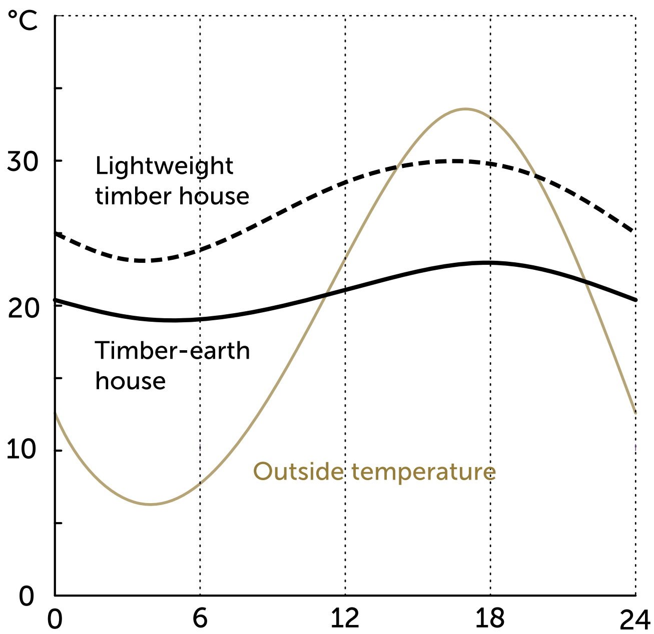
Earth building has likewise evolved significantly over the past few decades, and there are now numerous examples of successful approaches to using earth building materials to add mass to modern timber constructions, improving their thermal and acoustic qualities as well as the indoor room climate. Using simple construction methods, it is possible to achieve good fire protection and robust moisture protection without the need for airtightness, vapour barriers or separate layers for installations.

The reservations people still have about using earth building materials need to be addressed so that the combination of timber construction and environmentally friendly earth building can be jointly developed into an exemplary, sustainable, resource friendly and high-quality construction method.

Climate friendly building

Traditional timber construction was either half-timbered with solid infill, usually straw clay, or solid log construction, clad or shingled. Modern timber construction, by contrast, is usually infilled with insulating material. This is a reflection of new insights into building physics in which air-encapsulating materials were found to insulate better against the cold than solid materials. The era of *thermal insulation* was born and since then, external wall constructions have primarily been viewed in terms of heat loss from the interior to the outside. This one-dimensional perspective is also enshrined in the philosophy of the U-value. The commonly cited metaphor is that of wrapping a house in a thick sweater to keep it warm. But a building is not merely a freezing creature; it is also solid structure that stands in space and is warmed by the sun. This heat source is freely available, even in winter. The question is how can a house benefit from solar irradiation? To begin with the heat of the sun's rays must be able to penetrate into the interior of the building, for example through large south-facing windows. The heat gain then needs to be absorbed by heavy building mass which heats up and cools down slowly so that the room temperature remains stable. Lightweight building materials are of little use here as they absorb heat quickly and pass it on directly to the room air, which warms up rapidly. In both cases, the energy remains within the house but the comfort levels for the inhabitants are very different.

Opaque building envelopes can also absorb considerable thermal radiation, but if the external envelope is heavily insulated, these heat gains are blocked. Earth represents an ideal surface material for external walls as its mass can absorb direct solar and diffuse global solar radiation. As the wall grows warmer, it reduces the temperature difference between inside



01 Summer temperatures in lightweight timber constructions and in timber-earth constructions

02 A timber house in summer

and outside. And every degree less temperature difference translates into 6% energy savings. A prerequisite for this is good internal insulation, which can be easily achieved in combined timber and earth constructions and has other important advantages.

The U-value also tends to neglect a further problem that is becoming ever more apparent with climate change: *heat insulation in summer*. Normal timber constructions respond rapidly to gains in solar radiation and even rigorous shading cannot prevent rooms from heating up quickly during the day. Shading can entail the need for artificial indoor lighting, and heat gain for cooling measures and air conditioning systems.

Instead, one should make use of the principles of *natural air conditioning* wherever natural cooling energy is available – also in summer. Alongside greening and shading, appropriate roof overhangs and sensible window arrangements and sizes, a key natural resource is *cool air at night*. The hotter and clearer the day, the more geothermal energy is radiated back into the clear night sky. On some days the difference in temperature between day and night can be as much as 20 degrees, which is an enormous amount of cooling energy. But even when overcast, diurnal temperature differences can still be utilised. Lightweight timber constructions only begin to cool down when sufficiently cooled ambient air can enter late in the evening. The next morning, however, the house will heat up again quickly. A timber construction with an inner mass, on the other hand, cools down in the night air more extensively and can retain the cool temperature for much of the subsequent day. As the building mass absorbs the heat of the day, even opening the windows for ventilation is not a problem. The rooms are naturally illuminated and if the windows are arranged and sized sensibly, solar shading is often unnecessary.

The characteristic value for building elements that can retain their warmth or coolness is the *thermal retention capacity* value per unit area, $Q = c \cdot \rho \cdot s$ [kJ/m^{2}K], a product of the specific heat capacity, density and layer thickness.

Earth building materials are also particularly suitable for adding mass to internal building elements as they possess a greater heat capacity than wood. They can be used as infill in stud walls, be laid between ceiling joists, in facing wall linings to add mass to timber walls or as thick layers of earth plaster in the interior of a building.

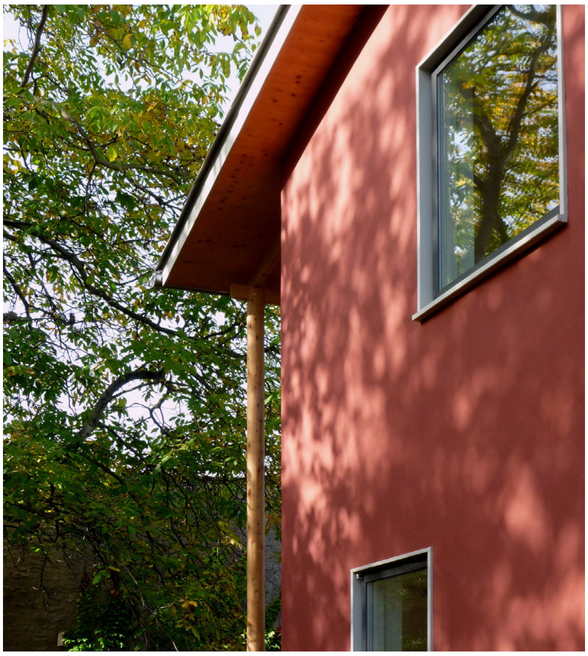
Indoor climate and thermal comfort

Without sufficient thermal mass, additional heating or cooling is needed to maintain a level of thermal stability. Although this is no longer a technical problem due to thermostat controls, it is energy intensive.

With sufficient thermal mass, for example through earth building elements, non-continuous sources of heat and cooling, such as solar radiation and diurnal temperature variation, can be utilised. In simple terms, this means such buildings are *cool in summer and warm in winter* without the need for additional conditioning equipment.

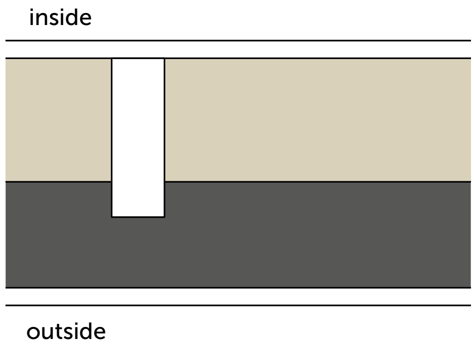
In this respect, the relationship between surface temperature and room air temperature is important. In winter, we want surfaces to be warm, in summer to be cool. In lightweight timber constructions, the interior is usually too warm due to a lack of cooling mass. Very massive external walls (with external insulation) are counterproductive, as they remain cold for a long time after drops in temperature or interruptions in heating patterns. The combination of *internal insulation* and external mass, however, allows a room to reach a comfortable surface temperature within a short space of time, especially when coupled with a form of radiant heating. This form of construction is straightforward to realise in timber and earth constructions, is safe in building physics terms, and also makes it possible to turn off the heating on a room

03 and 03a Timber and earth house as timber panel construction with internal insulation



1 Conventional drywall or earth building board with fine plaster
2 Blow-in insulation cellulose
3 Light earth, 1.0 kg/dm^3
4 Lime plaster, paint

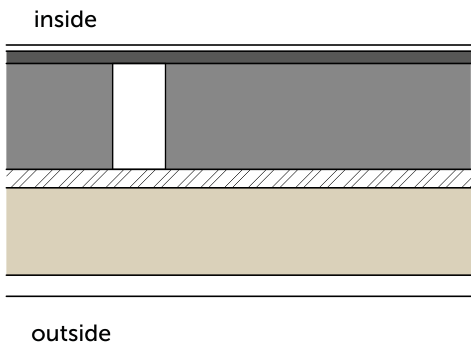
U = 0.24 W/m^{2}K   Q = 190 kJ/m^{2}K   t = 29 cm



04 and 04a Timber and earth house as timber panel construction with external insulation

1 Earth plaster with lime finishing plaster
2 Light earth masonry, 0.7 kg/dm^3
3 Plywood
4 Reed insulation board
5 Lime plaster, paint

U = 0.39 W/m^{2}K   Q = 250 kJ/m^{2}K   t = 29 cm



by room basis. Warm surfaces provide a physiological sense of comfort even at lower air temperatures. If a room is comfortable at air temperatures of 17 or 18°C, the 3-4°C reduction in temperature difference between inside and outside can result in energy savings of up to 20%. The energy consumption of internally insulated projects (Fig. 3 and Fig. 5) has been shown to be 30% less than that calculated according to the EnEV energy saving regulations. However, if no or only a few internal building elements have sufficient thermal mass, this must be placed on the inner face of the external wall, which must then be insulated on the outside (Fig. 4).

Robust moisture protection

According to textbook building physics, conventional timber construction entails a complex series of functional layers: the room enclosure, a vapour barrier, a layer for installations, an airtight layer, a windproof layer, etc. For this an arsenal of building materials with sub-optimal sustainability characteristics is required, including foils, self-adhesive sealing tapes, synthetic resin, artificial fibres and spray foams. A primary concern is the formation of interstitial condensation within the fabric of the wall, which vapour barriers and airtight layers attempt to counteract, as once wet with moisture, artificial insulating materials cannot dry out sufficiently or quickly enough.

The use of earth as a building material opens up new possibilities and greatly simplifies the construction. The microscopically fine laminar structure of the clay minerals enables it to store moisture temporarily within the material and then to dry out again quickly afterwards. In addition, its good capillary conduction and good diffusion properties allow it to absorb and dissipate condensation water in droplet form, and to dry out reliably. If all the materials in the cross-section of the building element have good capillary conductive and diffusion properties, e.g. the insulation, plasters and paints, robust moisture protection is possible even for highly insulated constructions without the need for vapour barriers or special installation layers. With earth materials, particularly when used in combination with plant-based insulating materials, element cross sections with internal insulation are unproblematic in building physics terms, in contrast to traditional solid constructions where these could give rise to thermal bridges (Fig. 3 and Fig. 5).

Diffusion calculations according to DIN 4108 (Glaser) may then be rendered unnecessary as the drying of building components through a combination of capillarity, thermal storage and dynamic temperature and humidity fluctuations are not covered by the calculation – aside from in unrealistic climatic boundary conditions [1].

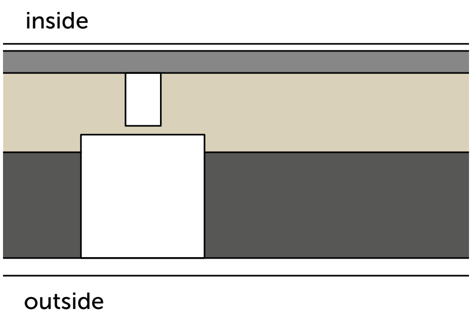
Fire protection and noise insulation

Earth is a non-combustible building material and can therefore provide a degree of fire protection in timber construction. Claddings in the form of panels and plasters have at least fire-retardant properties. Un-

05 and 05a 260 year old half-timbered house with earth infill and internal insulation

1 Earth building board with finishing plaster
2 Blow-in cellulose insulation
3 Existing straw clay wall, 1.2-1.4 kg/dm^3 with light earth masonry additions, 1.2 kg/dm^3
4 Lime plaster

U = 0.39 W/m^{2}K Q = 230 kJ/m^{2}K t = 25 cm



fortunately, the current fire protection standards lack adequate classifications for earth building elements. If required, their fire protection properties may need to be proven.

Lightweight timber constructions can transmit noise easily. Adding weight and mass can improve the situation considerably. Longitudinal sound transmission can be dampened by preventing the timber structure from vibrating and transmitting vibrations through the structure. This is most easily achieved by filling timber elements with earth infill and/or cladding with earth render. The relative softness of earth compared to hard building materials is its particular advantage: vibrations are not transmitted but absorbed by the material. Earth materials added to a building as a thermal mass for retaining warmth or cool temperatures invariably also have good sound insulation properties due to their high weight per unit area [1].

Grey energy

Today's solid, hard building materials almost always require the combustion of fossil fuels for their production. The resulting materials are typically strong and resilient but are then often employed in situations where much lower strength materials would also suffice, essentially wasting the energy input for their production. When it comes to converting or demolishing these solid structures, greater energy is required to break them apart: the sound of pneumatic drills has become omnipresent in modern urban conurbations. Wood and plants, by contrast, regrow silently and the production site is woodland and fields. During photosynthesis, solar energy binds carbon dioxide to create a high-strength, universally usable building material with an optimal energy balance. Wood is used (sparingly) for the load-bearing structure, while earth is used for non-load-bearing infill and cladding – an age old, highly economical principle. Timber constructions can also be easily modified, its material can be reused elsewhere, be disposed of, its residues returned to the production cycle, or ultimately be thermally recycled.

Earth is likewise a building material that requires very little energy to produce – one of the lowest in its class – as the naturally moist or wetted building material only need dry in the air without any additional binders. To reduce the energy required for artificial drying, mass-produced earth building materials are dried under glass in greenhouses using only the energy of the sun. Whether in timber frame, timber panel or solid timber constructions, earth has great potential for adding mass to the room enclosure, whether as a dry lining board, as ceiling infill, as earth masonry or as stacked bricks in a wall lining. Earth can make a major contribution to improving a structure's energy balance. The low strength of earth building materials also proves to be ideal in this context, making it easy to adapt to changing conditions. Dismantling and demolition is, similarly, a comparatively low-noise affair. The energy required for later conversions and alterations is often neglected in the planning of new buildings. Compared with unnecessarily solid, hard building materials, which after removal from the building are typically crushed, shredded and ground – processes neatly glossed over in the term *recycling* – earth is relatively easy to break down mechanically and once soaked in water can be reused in a new form, not just once but multiple times if necessary. Stone walls bedded in earth mortar, as practiced all over the world for thousands of years, is in essence the endless re-use of the same building materials in the same place in ever new configurations.

Absence of pollutants

Most building materials used today are generally free of pollutants – but only once they have been installed or constructed. This considers only the use phase and not the emissions during production, transport, conversion, dismantling and disposal. The manufacture of most industrial building materials is energy-intensive and entails the production of emissions. Earth building materials, by contrast, can be described as *harmless massive building materials*. They are "clean" building materials in that their production, use and disposal is not harmful to nature or to people.

Durability

The fact that clients and architects only rarely consider using earth in timber constructions can predominantly be attributed to deep-seated prejudices and widespread ignorance. The first question one hears is what happens to the earth when it rains. Even the most photogenic images of *earth architecture* around the world with earthen external walls do little to help build confidence in the material. Doubts about its resistance to water and durability cause many to resort to "sound", supposedly more durable means of construction such as brick and concrete. In pre-industrial times, however, earth in combination with half-timbering was the most common construction method in Northern Europe. In its half-timbered old town centres, one sees well-preserved, centuries-old evidence of *earth building*, but few are aware of it because the building material lies concealed beneath plaster in the walls, ceilings and roofs. Investigations have shown that if earth remains dry and is protected against excess moisture ingress (just as with wood) – and here normal weather protection means suffice – it can fulfil its purpose theoretically endlessly [2]. Aside from material life cycle aspects, sustainability also refers to the ability to be able to repair, modify, recycle and re-use building elements. Alongside wood, there are few building materials that are so readily adaptable as earth [3]. Wood and earth in combination complement each other to form an exceptionally environmentally friendly and forward-looking means of construction.

Project examples Figs. 3 to 6: Schauer + Volhard Architects BDA, Darmstadt, *www.schauer-volhard.de*

Reference literature

[1] Franz Volhard: *Light Earth Building. A Handbook for Building with Wood and Earth*. 1st English edition (corresponding to 8th German edition), Birkhäuser Verlag, Basel 2016.
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[2] Franz Volhard: *Lehmausfachungen und Putze. Untersuchungen historischer Strohlehme*. Fraunhofer IRB Verlag, Stuttgart 2010

[3] Franz Volhard: *Erstaunlich unterschätzt und robust. Lehmbaustoffe für die schadenfreie Sanierung älterer Gebäude gezielt nutzen*. In: B+B Bauen im Bestand, issue 1.2019. Verlagsgesellschaft Rudolph Müller, pp. 20-24. *http://www.schauervolhard.de/PDF/Buecher/B_B_Bauen_im_Bestand%201_2019.pdf*

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