Earth - the underestimated super building material

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Part 1 (of 3)

Potentials of earth building materials in sustainable timber construction in combination with insulating materials made of plant fibers. Low manufacturing energy, sufficient strength and stabilization by natural fibers lead to versatile earth building materials.

Figures: Schauer+Volhard Architekten BDA

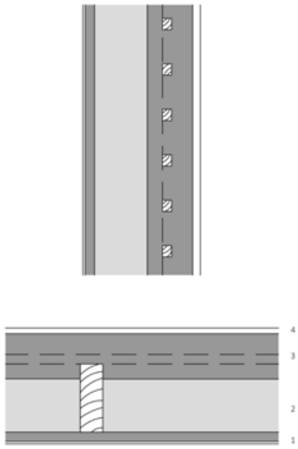
Earth, wood and insulating materials made from plant fibers: Hardly any combination of building materials is likely to be as resource-efficient, proven and durable, and can be used sustainably in the far future. The widespread use of these building materials, which do not harm humans or the environment, has become increasingly popular in recent years - thanks to countless realizations, many publications, earthen building regulations introduced by building authorities, and new DIN standards for industrial earthen products [Lit.]. This is because earthen building materials have special advantages in terms of building physics, which make constructive, even cost-saving simplifications possible in new and old buildings (Fig. 1-3).

Minimum energy for production

The building material combination earth-wood-natural fiber differs significantly from modern industrial building materials in terms of resource conservation and manufacturing energy. Earth building materials prepared with water - or more precisely, the clay minerals they contain - become sufficiently solid exclusively by air drying. Therefore, little fossil energy is required for their production. Essentially, it is used only for artificial drying, for which solar heat from glass houses or air collectors can also be used.
Wood and plant fibers, which grow again through photosynthesis, replace burnt building materials, artificial fibers and foam plastics.

Too hard building materials

Many modern hard building materials are based on burning fossil energy. The result is high-strength building materials that are useful for certain tasks, but are often used where much lower strength would suffice. Apart from the waste of energy, this thoughtlessness ultimately makes itself felt in a noisy way during demolition, dismantling or recycling, and again costs enormous amounts of energy. Firmly bonded composite building materials can often only be disposed of as hazardous waste. With them, only the cheap production is considered and not the end of the product cycle. In contrast to hard building materials such as reinforced concrete and masonry blocks, which have to be crushed, shredded and ground up, nicely dubbed recycling, dry earth



(1) New building, light earth with interior insulation (cf. Fig.2), House J. Darmstadt, Schauer+Volhard Architekten BDA
(2) Exterior wall with interior insulation: 1 Thin-layer interior plaster, light earth board (or light earth application on battens, alternatively gypsum fiber board), 2 Blow-in insulation, 3 Light earth application on battens, 4 Exterior plaster (cf. Fig.1)
(3) Assembly of the frame elements for the wood-loam building, House J. Darmstadt

material is relatively easy to break up mechanically and, processed with water only, can be reused again and again in new forms. This unique selling point of earth has not yet been sufficiently appreciated.

Earth building materials are not particularly strong, but their strength is also sufficient for load-bearing walls. If, however, the earth is „stabilized“ with a few percent of lime or cement - as is usually the case in internationally practiced exposed earth architecture - it acquires greater compressive strength and rain resistance, but has lost its reversibility, i.e. infinite malleability and reusability. According to the definition of the German earthen building rules [Lit. 2], it is thus no longer an actual „earthen building material“. Instead of adding lime to the entire wall mass, a lime plaster is sufficient for weatherproofing unstabilized walls.

If, on the other hand, exposed earth without stabilization is desired, as in the case of the Alnatura Campus in Darmstadt, for example, either the natural composition of the (local) building earth must already be suitable or it must be artificially optimized for a raw earth appearance. However, earth, clay and aggregates are then often transported over long distances, which is questionable from an energy point of view for extremely heavy mass building materials. Historically, rammed earth construction has therefore only been common in regions where in-situ earth is already available in the right composition.

Natural fibers stabilize economically

A common method of stabilization is the addition of natural fibers. The addition of straw fiber to earth blocks is already mentioned in the Old Testament. Straw-clay in half-timbered construction is one of the oldest and most durable building materials. It significantly increases the strength against the effects of water and frost. Elasticity, fracture, bending and impact resistance of earth blocks and panels are achieved without losing reversibility.

Today - and historically throughout northern Europe - earth is used predominantly in a non-load-bearing capacity in (timber) skeleton construction, especially timber frame construction, and in the renovation of half-timbered buildings as a versatile building material for the infill of exterior and interior walls, ceilings and roofs - in lower layer thicknesses and usually invisible, clad or plastered. Also in interior applications, drywall, plaster and thin-layer coatings, natural ones such as clay and earth are used instead of burnt binders, without compromising quality, with adequate strength and good serviceability. These infill principles can be applied to the extension and refurbishment of skeletal buildings in general, e.g. also steel or reinforced concrete.

Even solid wood construction could be supplemented with earth, e.g. to cool better in summer with additional storing mass, or for mineral surface designs. The optimal solution, however, is skeleton construction, in which the load-bearing and filling functions are sensibly divided. Wood is used (sparingly) for the load-bearing structure, and earth is used for non-load-bearing infill and cladding, an old very economical principle (Fig. 3).

The use of high-grade, dimensionally stable wood material is minimized, and the tasks of space creation and area are performed by the adaptable building material earth, along with renewable fiber insulation materials. The benign structural-physical properties of these infill building materials allow for compact building components that save floor space.

Earth building materials are infinitely reusable

Just as earth only becomes solid by drying, it only becomes soft again and reshapable by the addition of water. This process can be repeated infinitely. Historic straw-clay infills and straw-clay plasters have always been reused in remodeling projects, as studies show Lit.4). Such a self-evident reuse, as it was practiced for centuries in half-timbered construction, is unthinkable with other building materials - apart from wood or stone. The special thing about it is that a solid building structure such as an earthen frame or earthen masonry mortar becomes soft and malleable again only with water and is available for a new earthen frame or new masonry mortar. Or an earthen plaster can be repaired with water and a sponge, and chipped plaster can be reconditioned and reapplied without removing or adding material (Fig. 4). Reuse - also a contribution to noise and traffic prevention.

(4) Repair of straw-clay fillings. Intact parts are preserved and the missing parts are completed with reclaimed material
(5) Stone masonry with earth mortar in the Dordogne.

Quite unknown is the historically worldwide widespread and millennia old (natural) stone masonry with earth mortar (Fig. 5). Romanian villages are built of burnt bricks with earth mortar. The Berlin rubble women were still able to knock off the soft lime mortar in order to reuse the valuable burnt bricks. This is unthinkable with cementitious mortars. The same building materials can be reused several times on site, in new shapes and forms. With artificial stones, earthen mortar also opens up a new and sustainable perspective here and now for load-bearing masonry that is re-approved according to Lehmbau Regeln (earthen building regulations).

Earth building materials are versatile

The wide range of density from about 400 to over 2000 kg/m³ allows for light to heavy earth building materials, corresponding to wood to heavy concrete. The framework is formed by suitable aggregates, mineral, vegetable or both. The cavities of this framework are more or less filled by earth, thus controlling the density and thermal properties. Light materials are air-containing and heat-insulating, heavy materials have only a few air pores and act as mass storage.

Thermal insulation is now considered the most important property of exterior building components. This has led to excessive use of synthetic foam and mineral fiber insulating materials. They are highly diffusible, but hardly capillary moisture conductive and compensating. Thus, nonsensically complicated and multilayered constructions are often necessary for their moisture protection.

Heat storage as an energy-saving property, on the other hand, has faded into the background and is largely ignored in current calculation methods. But with too little storage mass, heating must be provided in winter and cooling in summer because of the lack of thermal stability. Thermostatically controlled, this is technically not a problem today, but it is energy-intensive. With a mass storage system such as earth, on the other hand, non-continuous solar radiation in winter and night cooling in summer can be used. In the simplest way, such buildings without technology are cool in summer and warm in winter.

Earth and especially light earth building materials of medium bulk density have a well-balanced ratio of insulation and storage. They are a non-load-bearing room closure and plaster base in one. Exterior building components are usually supplemented with an insulating layer of natural fiber or cellulose on the inside, outside or as core insulation. This provides the required thermal insulation - in simple, slimline constructions in skeleton buildings and without vapor barriers (Fig. 1-2).
In earth solid construction with rammed earth or earth block masonry, on the other hand, load-bearing walls must be much thicker than would be sufficient for heat storage for structural reasons. If the required thermal insulation is added, the wall thickness is unnecessarily oversized from a building physics point of view.

Part 2 (of 3)

Normal structural moisture protection is sufficient to make water-sensitive earth durable in uncomplicated wood structures. Its unique capillarity provides robust protection against moisture. Yet its sorption capacity is often overrated.

And when it rains?

The first question is often what happens to the earth when it rains. The unlimited plastic mouldability only by adding water is seen as a disadvantage of water sensitivity. Photogenic images of worldwide earth architecture with exposed earth facades are also unlikely to help build confidence. One doubts water resistance and durability and then resorts to „reasonable“ solutions, mostly solid construction. It is forgotten that in pre-industrial times, earth building in the form of earthen framework fillings was the most widespread construction method in northern Europe. Thus, the well-preserved centuries-old testimonies in half-timbered inner cities are not perceived as earth construction, because the main building material in walls, ceilings, roofs is hidden under plaster. But this shows that earthen facades can be easily protected by plaster or cladding (Fig. 6).

Normal structural moisture protection is sufficient

Studies show: if earth is protected from moisture, it theoretically serves its purpose indefinitely. Trapped straw and wooden parts show up completely intact and fresh as on the first day, once an old compartment is dissolved (Fig. 7) [Lit. 3]. The prerequisite is, of course, that the earth always remains dry, for which quite normal structural moisture protection is sufficient, as is the case, for example, with timber construction.
It would be wrong to seal the building hermetically out of fear; what is more important is that moisture that occasionally penetrates the building can dry unhindered at any time. Unhindered means that all layers such as plaster or insulation are moisture-conductive and in contact with each other to promote constant drying. The earth, which is highly capillary conductive, dries quickly until its very low normal moisture content is reached.

(6) Plastered wood+earth buildings in the city centre of Troyes

(7) Well-preserved straw of a 700-year-old straw-clay filling from 1298, Limburg [Lit. 3].

Condensation moisture does not pose a hazard in earthen building components

Moisture transport by diffusion is orders of magnitude less than capillary transport of (liquid) water. After all, only the humidity bound in the air diffuses as „vapor", and this in the direction of the vapor pressure gradient, mostly in the opposite direction to capillary drying. Nevertheless, in the calculations according to DIN 4108 (Glaser method), condensation in the building component due to diffusion is still exclusively investigated. Heat and moisture storage, simultaneous drying by capillary moisture transport and the different properties of the building materials are not taken into account. In addition, eight weeks of continuous frost at minus 10 °C is assumed as the climatic boundary condition. It is therefore not surprising that some proven and safe (interior insulation) constructions made of capillary and diffusion-open building materials such as earth and plant fibers appear to be critical from a mathematical point of view. Current hygrothermal simulations tend to approximate reality.

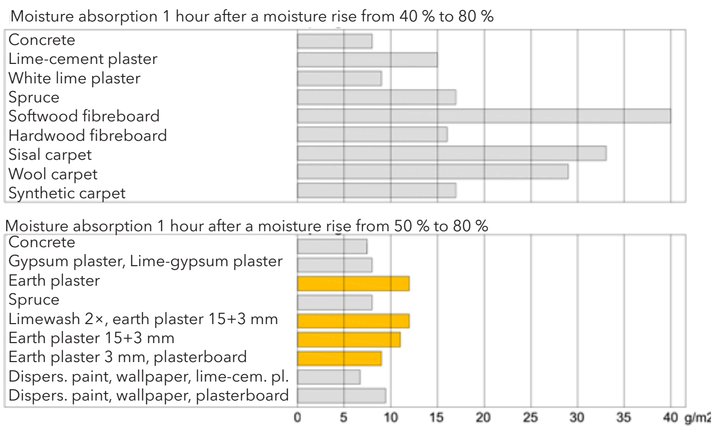
Uncomplicated constructions with robust moisture protection

These findings in the field of building physics explain, on the one hand, the durability of proven constructions with wood and earth. On the other hand, completely new possibilities are opening up for new and old buildings of uncomplicated constructions with robust moisture protection of exterior components, well insulated with capillary cellulose or natural fiber insulating materials, as in the case of House J in Darmstadt (Fig. 8).

Sorption capacity not a unique feature of earthen building materials

In contrast to the moisture-equalizing property of earth and its ability to keep the structure dry, there is also „moisture equalization" in the hygroscopic range, albeit on a completely different scale. There, capillaries transport liquid water; here, earth sorbs vaporous air humidity. However, sorption capacity is not a unique feature of earthen building materials. In most cases, normal interior furnishings with furniture, textiles and books are much more capable of sorption (Fig. 9). The underlying „humidity jump" test with an extremely high

(8) New building, light earth with interior insulation, House J. Darmstadt (cf. Part 1, Fig. 1-2)



(9) Moisture absorption of building materials and building components, 1 hour after increase in room air humidity from 40 or 50 % to 80 % RH at 20°C, according to various sources [Lit. 1+5].

room humidity driven over several hours and days, in which earth shows higher sorption values, hides the fact that in interiors humidity shocks are only very short-term and hardly represent a real problem [Lit. 4].

Part 3

Proven earthen building components such as earth masonry, stacking technology, interior insulation, drywall panels, fire and sound protection, and waterproofing complement sustainable wood construction.

Earth blocks as masonry and storage material

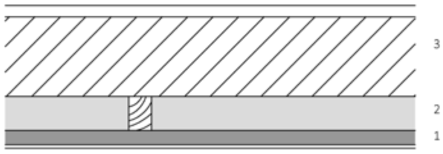
Earth blocks are used in a variety of ways in timber construction, non-load-bearing as room finishes in exterior and interior walls, mostly as masonry in earth mortar (Figs. 10-11). Compared with lightweight insulation infills, they improve heat storage, especially in interior building components. In summer, they store nighttime coolness; in winter, they store the daytime heat from the low sun. The built-in mass also improves sound insulation.

The earth stacking technique allows mass to be added to the building without building moisture. Heavy earth blocks are stacked dry, without mortar, in construction cavities or facing shells (Fig. 12). Earth blocks are easy to work with, and the offcuts can be soaked and reused as mortar or filler. Likewise, dry-laid heavy floor overlays of earth blocks incorporate the horizontal surfaces as a storage mass and improve sound insulation. All these constructions can be dismantled easily and with low noise, and their building materials can be reused intact. Earth masonry is already indispensable in the renovation of half-timbered buildings. The homogeneous earth filling keeps the wood dry. Occasional rain moisture is absorbed and quickly released.
Earth blocks and earth masonry mortar are now DIN standardized [Lit.]. Their application is governed by the Lehmbau Regeln (earthen building rules) [Lit. 2].

Interior insulation with earth and natural fibers

The many possibilities have in common that all component layers are in contact with each other without cavities, so that capillary drying is not interrupted. Various systems are possible with renewable, capillary-active and diffusible insulation materials. Either earth drywall panels (see below) are fastened to an aligned lath construction in an economic insulation thickness of six to eight centimeters, the spaces between which are filled with fiber or cellulose insulation material of the same thickness beforehand or blown out later. In this case, unevenness of the substrate is evened out (Figs. 13-16).
Alternatively, insulation boards - usually made of soft wood fiber - are glued on with earth adhesive and secured with dowels. For surface contact, unevenness is leveled out beforehand with earth plaster. The panel surfaces can then be finished with earth or lime plaster or even a thin-layer earth coating.
A similar procedure is followed for insulating roof slopes (Fig. 17).

(10) In the renovation of half-timbered houses, the homogeneous brick lining with light earth blocks is the state of the art. House Schneiker, Mörfelden, Schauer+Volhard Architekten BDA
(11) Universal use of light earth masonry in exterior (and interior) walls, prepared lath construction for interior insulation with light earth boards. House Schneiker
(12) New wood-earth building: exterior walls 12 cm light earth with interior insulation, interior walls stacked with earth bricks. House J. Darmstadt



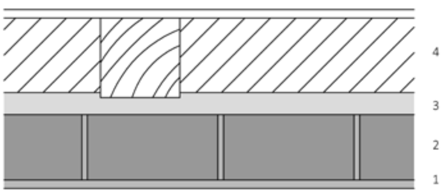
(13) In the case of half-timbering renovation, the interior insulation reain the outer form. Here, cellulose blown-in insulation in a cladding of light earth boards (cf. Fig.14). Sandberghof Darmstadt, Schauer+Volhard Architects BDA
(14) Interior insulation of exterior wall masonry: 1 Thin-layer interior rendering, light earth board (or light earth undercoat-plaster on battens), 2 Wood fibre or blow-in interior insulation between squared timbers, 3 Existing exterior wall: brick/ quarry stone masonry/ half-timbering

In internally insulated new buildings, even greater insulation thicknesses are no problem if capillary re-drying is possible. In most cases, it is possible to dispense with vapor barriers, which are seldom easy to install in practice and are of dubious durability and functionality, and also hinder re-drying. These simple, self-drying constructions have proven their worth.

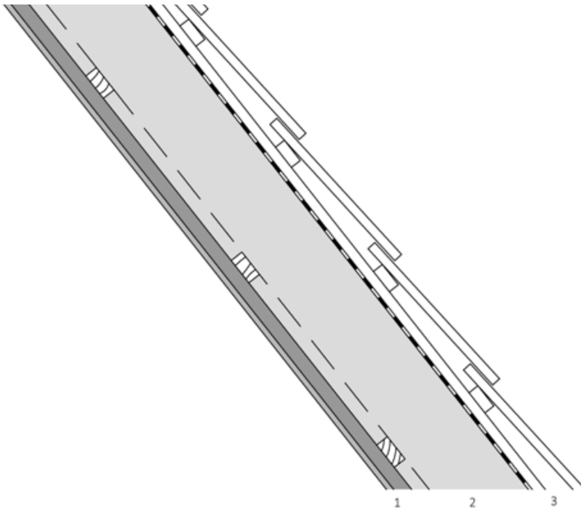
Dry construction with earth

The development of drywall panels made of earth is a great advance. With thicknesses of two to three centimeters and in handy panel formats with little waste, they make it possible to clad walls, roof slopes and ceilings. Construction moisture is thus minimized.
The boards are screwed to a substructure. Joints are reinforced and filled with earth. The surface is so even that a very thin and fast-drying layer of plaster is sufficient. There is no need for time-consuming and noisy grinding of plaster joints. Earth boards are now also DIN standardized. One advantage is the softness of the material, which provides excellent sound insulation.

Lightweight earth boards with a low density of around 700 kg/m³ are characterized by surface warmth. They are also and above all suitable for cladding internally insulated exterior walls or for sound insulation facing shells.
Earth panels can also be applied in smaller formats and thinner (16 mm) as dry plaster on old building surfaces. Earth is also used as an adhesive. The new flat surface is covered with a thin, fast-drying layer of earth or lime plaster. The special feature compared with conventional building adhesives is again the reversibility of earth, i.e. the adhesive can be dissolved and used again. Screwed panels can be easily removed and reused elsewhere.



(15) Interior insulation of half-timbering: 1 (earth) interior render, 2 light earth masonry, 3 fibre insulation or light earth mortar,
4 Existing building: half-timbering with earth block, brick masonry or historical straw-clay infill, exterior rendering
(16) Interior insulation of exterior wall masonry with wood fibre insulation, cladding with light earth rendering on battens (cf. Fig.14)



(17) Roof extension with ligth earth board: 1 Thin-layer earth plaster, light earth board, 2 Blown-in internal insulation between rafters, 3 Sarking membrane, ventilated tile roofing

Fire and sound protection with earth

Earth is non-combustible, which means it can perform fire-protective functions in timber construction. Cladding in the form of boards and plasters have at least fire-retardant properties. Unfortunately, current fire safety standardization leaves something to be desired in terms of the classification of earthen building components. Current research by Liblik, Just and Küppers presented at Lehm2020 started there. If required, fire protection must be verified.
Lightweight wood buildings can be very bright. With weight and mass, sound insulation can be significantly improved. Longitudinal sound conduction is damped by preventing wood components filled or clad with earth from vibrating and propagating through the wood building. The relative softness of earth compared to hard building materials is the particular advantage here. Vibrations cannot be transmitted, but are absorbed into the material. For heat and cold storage desirable heavy interior components also have good sound insulation because of the higher weight per unit area.

Waterproofing with earth

When sufficient moisture is absorbed, earth particles in the earth swell until waterproof. This has always been used for waterproofing ponds, building dams, etc. But horizontal and vertical waterproofing against soil is also common in construction. Basement walls, base masonry and floors are sealed against ground moisture, even water under pressure, by a layer compacted to about twenty centimeters of earth. Old masonry, for example, does not even have to be plastered, and bituminous waterproofing is not required at all. Today, earth waterproofing can be used as a finished product, as the article by Michette, Lorenz and Ziegert for the Lehm2020 shows.

Earth is not waterproof

Earth as a building material is not waterproof, but it is precisely the rapid absorption and release of moisture that are particular strengths of this material. Its ultra-fine structure - the end product of millions of years of rock weathering - means that building components can be reliably kept dry by capillary moisture transport and diffusion openness. And it enables simple, sustainable building structures for new construction and damage-free renovation. However, sustainability also includes the ability to repair, modify and recycle building components, and here there is hardly a more ideal building material - apart from wood. Earth and wood complement each other to form an exemplary, environmentally friendly, future-oriented construction method.

Earth product standards:

DIN 18942-1:2018-12 Lehmbaustoffe – Teil 1: Begriffe *Earth building materials - Part 1: Definitions*.
DIN 18942-100:2018-12 Lehmbaustoffe – Teil 100: Konformitätsnachweis *Earth building materials - Part 100: Proof of conformity*
DIN 18945:2018-12 Lehmsteine - Anforderungen und Prüfverfahren *Earth blocks - Requirements and test methods*
DIN 18946:2018-12 Lehmmauermörtel – Anforderungen und Prüfverfahren *Earth masonry mortars - Requirements and test methods*
DIN 18947:2018-12 Lehmputzmörtel – Anforderungen und Prüfverfahren *Earth plaster mortars - Requirements and test methods*
DIN 18948:2018-12 Lehmplatten – Anforderungen und Prüfverfahren *Earth panels - Requirements and test methods*

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