Guide 0 -

General guide: Building sustainably with Léém

Introduction

For millennia humankind has built with what was close, at hand, healthy, easy and abundant : earth. By shaping earth into floors, walls and roofs, people were capable of making a shelter, create a warm haven for family and loved ones. Over time, and by the end of the 19th century, we discovered the advantages of fossil fuels for transforming unbaked clay into baked bricks on an industrial scale, and for firing certain minerals to acquire cement. But now the intensive use of fossil fuels is creating many dangers as it is heating up our climate, polluting our air and depleting our resources.

We believe that by going back to unbaked earth and upgrading it with state-of-the-art production infrastructure, we can reduce the enormous carbon footprint of the building materials sector, valorize locally abundant materials that are perceived as 'waste', and improve the living environment of so many people.

Contents

1. Léém's general guide

1.1 Who are we and what is Léém?

BC materials is a Brussels cooperative company which transforms excavated earth into circular building materials, like plasters, masonry blocks & rammed earth. It has founded the earth building material range “Léém” in collaboration with a number of Belgian industrial partners, both suppliers & waste managers such as ABR/De Meuter, Nonet, AC materials, and industrial producers such as Beton Claesen and Vande Moortel/Brickz. By scaling & industrializing the approach of re-using ‘waste’, we can both reduce the enormous amounts of waste (37 millions tons of excavated earth in Belgium every year) and at the same time reduce the heavy footprint of the construction sector and the CO2 intensive materials it produces (10% of all CO2 emissions worldwide).

By teaming up with different partners with complementary qualities, Léém offers a set of building solutions, which turns a niche into a standard for the building sector, taking earth building into the 21st century.

1.2 A general guide ...

This Léém General Guide aims to provide trustable information to the building professional (architect, engineer, contractor) on the topic of Léém earth building materials and their sustainable principles. As such, we – the authors of the cooperative BC materials – have chosen to heavily « stand on the shoulders of giants »: the knowledge and guidelines which are asserted come from reference works from two of the most experienced earth building communities: the French and the German community. The French network is built around the university research institution CRAterre, and spreading out towards organisations such as Cycle-terre, Amaco, ENTPE, CSTB. The German network is built around the Dachverband Lehmbau, with experts such as Dr.-Ing Horst Schröder, Dr.-Ing Christof Ziegert, and nation-wide regulation such as DIN norms and the EPD framework.

This Léém General Guide is hence a compilation of the most recent research publications, technical approvals and norms in Germany and France, updated with specific extra research and experience by BC materials related to a Benelux context. We have tried to show as much as possible from which reference we have compiled certain specific information, by mentioning the reference in the side column in the text, and by adding the full bibliography in section 4. We are more specific in who to thank for what kind of contribution in our acknowledgement section at the end of this guide.

We hope to have made clear how this guide exists from a European spirit of sharing earth building expertise. We hope this Léém General Guide will help you, and hence continue to grow the earth building sector in Benelux.


© Hé architectuur

1.3 … to be used with Léém Technical Guides and Léém Technical Sheets

Aside from this general guide, we also offer specific Technical Guides on the application of Léém Clay Plasters & Paints, Léém Earth Blocks and Léém Rammed Earth, as well as Technical Sheets per product, all downloadable on leem.works . The General Guide, the Technical Guides and the Technical Sheets could be read in parallel:

— This general guide links sustainable principles with certain parameters for physical properties. When listing the physical properties on Technical Sheets, it might not always be clear what a parameter for a given physical property means. For example, on the Technical Sheet of Léém Clay Plaster, one might find the Water Vapour Diffusion Resistance Number μ : What does this actually signify? This General Guide explains the parameter in section 2.2.3.

— These parameters linked to specific physical properties of Léém building materials, are highlighted in a text box throughout this General Guide. This way, they are easy to find.

— For each sustainable principle in Section 2 and 3, we highlight in a one-liner pitch the respective benefit of Léém building materials. This makes it rapidly understandable what Léém building materials bring as an advantage. This advantage is subsequently scientifically explained for everyone's comprehension, and in the end, conviction.

2. Sustainability and circularity

In the Brundtland report to the United Nations World Commission on Environment and Development entitled “Our Common Future” (1987), the term “sustainability” was first used to describe a lasting development of humankind. Sustainable development ensures that it “meets the needs of the present without compromising the ability of future generations to meet their own needs” The term “sustainable development” has three aspects which must be considered as equals over an appropriated period of time:

— Ecology
— Economy
— User demands (sociocultural concerns/functional quality)

The Sustainable Development Goals (SDG) framework established by the United Nations in 2015 builds on the concept of sustainable development by providing a set of specific and measurable goals that countries and other stakeholders want to achieve to create a sustainable future. All 191 countries have committed to these goals. The SDG’s are a set of 17 goals established as a universal call to action to end poverty, protect the planet and ensure that all people enjoy peace and prosperity by 2030. The World Green Building Council applied these SDG’s to the construction sector. Today, Léém building materials actively contribute to 9 SDG’s as shown in the image below.

[30] Principes et aspects importants pour le choix de matériaux de construction durables

Let us take a look at what exactly are the sustainable principles of earth construction.

Section 2.1 focuses on sustainable principles of Léém building materials regarding the general environment. These are explained as topics from sections 2.1.1 to 2.1.6. For each of these topics, a quantifiable parameter is presented, relevant within a Life Cycle Analysis framework.

The Life Cycle Assessment or Analysis (LCA) is a method to calculate the environmental impact of a product throughout its life cycle based on an inventory of inputs (raw materials, energy resources, etc.) and outputs (air, water and soil emissions). The LCA results are expressed in terms of various indicators reflecting the potential contribution to various environmental problems, such as global warming, natural resource depletion or ozone depletion. Optionally, these indicators (current number in Europe: 13) are weighted and combined into 1 parameter with the unit «millipoints». The broad principles of an LCA are described in the international standards ISO 14040 and 14044. In addition, the European construction industry also has specific standards: EN 15804 at product level and EN 15978 at building level. [30] In this General Guide to Léém building materials, we focus only on the product level (which is the basis for the calculations at building level). This life cycle analysis for building materials considers the following life cycle stages: production, construction, use and end-of-life. These stages are divided into modules.

Production			Construction		Use stage					End of life stage				B / L *
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	C1	C2	C3	C4	D
Raw materials supply	Transport	Manufacturing	Transport	Construction/Installation	Use	Maintenance	Repair	Replacement	Refurbishment	Deconstruction/Demolition	Transport	Waste processing	Disposal	Reuse, recovery, recycling, potencial
					B6 Operational energy use									
					B7 Operational water use									

*Benefits / Loads

Modules qualified as part of the LCA of the DVL project [1] where earth building materials have special characteristics. (shaded: A1, A2, A3, C3, D)

Balance scheme for the UPD life cycle phases according to DIN EN 15804

— Product Stage (module A1-A3): This stage involves the extraction, transportation, and processing of raw materials to be manufactured into building products

— Construction Process Stage (module A4-A5): This stage involves the transport and delivery of building products from the manufacturer to the construction site, and the subsequent installation.

— Use Stage (module B1-B7): This stage includes the use and maintenance of the building product during its expected lifespan, including refurbishments and replacements.

— End-of-life Stage (module C1-C4): This stage involves the end-of-life stage of the building product, including demolition or deconstruction of the building product, and the disposal of the building materials.

— Benefits and Loads Outside of the Boundaries (module D): environmental or social benefits or loads that are generated outside of the system boundary of the building product being assessed, but that can be attributed to the building product, such as reuse, ...

An LCA-value in millipoints can thus be considered as the quantified summary of the environmental impact, or in other words, of the sustainable principles of a building material. In order for the European Commission to fulfil its Green Deal (2019 -2050: full net decarbonization of the European Union), Life Cycle Analysis is recommended as a valuable scientific tool.

Section 2.2 focuses on sustainable principles of Léém building materials regarding the building use and interior climate. These are explained as topics from sections 2.2.1 until 2.2.9. For each of these topics, a quantifiable parameter is presented. These parameters say something about the specific physical properties of a building material related to sustainability. For Léém building materials, its values might be findable in the physical properties as listed in the Technical Sheets downloadable on the website leem.works .

2.1 Environmental sustainability

2.1.1 A CO2-neutral production process

Earth building material production does not use fossil fuels for production: all processes - drying, sieving, crushing, premixing, mixing, compacting, moulding, palletising - are electrified, and do not use direct fossil fuels for firing material or driving on machinery.

Léém building materials are practically carbon neutral: they don't need to be fired and no fossil fuels are needed in the production process.

BC materials' infrastructure uses electricity from solar panels, backed up by an electricity contract offering the most renewable energy in Brussels. However, some additives such as cement in Léém Compressed Blocks or cellulose in Léém Earth Adhesive Mortar or Léém Finish have been produced by third parties using fossil fuels. BC materials carefully controls the proportion of these additives in Léém building materials.

Parameter: Carbon emissions and other greenhouse gas emissions are calculated as the "Global Warming Potential - Fossil" indicator in a Life Cycle Analysis (LCA) according to EN15804 (see also Section 2.1.6) in the measure of equivalent tons of CO2 emitted per unit of measurement of the respective building material.

2.1.2 Circular in origin and in destination

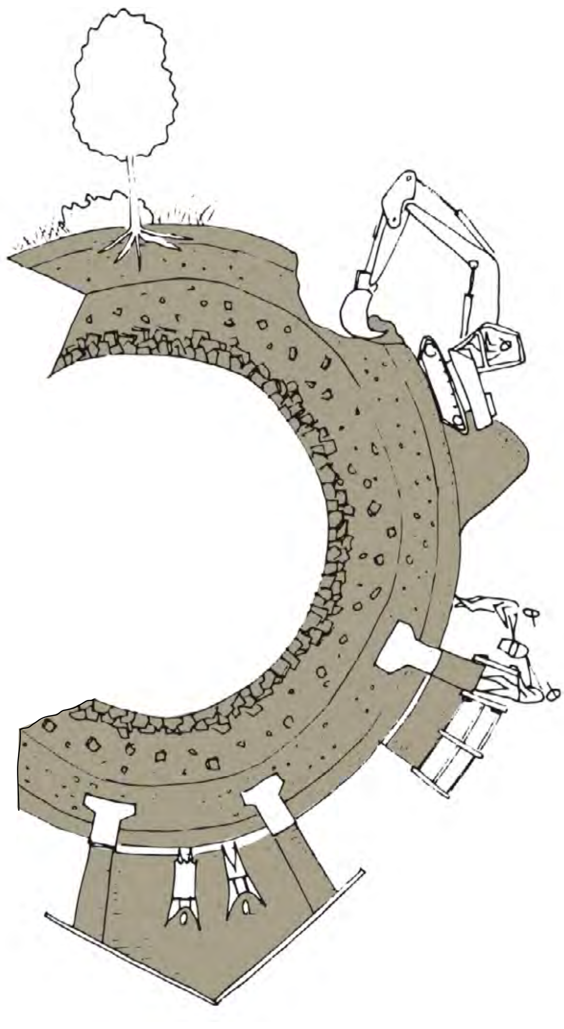
Léém building materials are both circular in its origin and in its destination:

Circular in its origin:

BC materials works with secondary resources: unpolluted, undisturbed geological resources excavated or mined from urban construction sites. These excavated earths and urban mined resources are legally considered as a waste once they leave the construction site.

Léém building materials are circular in origin: we source secondary resources from construction sites, considered as waste from a legal perspective.

In Belgium, 37 million tons of earth per year are excavated from construction sites, of which 16 million tonnes is unused and thrown away in landfills or quarry fills, with all its problems of land use, transport, and so on. Next to these excavated earths, Belgium produces yearly around 22 million tons of mineral building waste, of which today 90-95% is mainly downcycled to low-grade aggregates for below-ground infrastructure works.



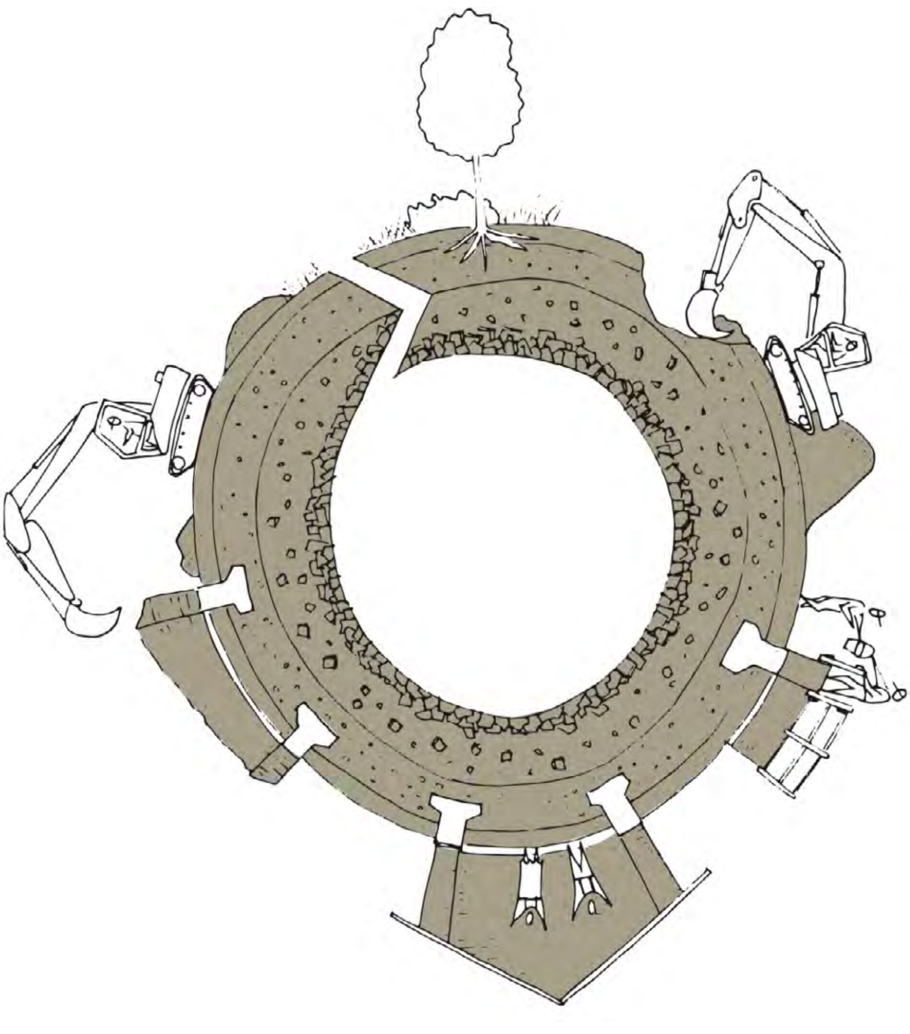
Circular in its destination:

Léém building materials use clay as a binder. Clay binding forces do not require chemical alteration of the material and are hence reversible. By adding water, the building material becomes earth again. This makes for the excellent repairable qualities and reusability of Léém building materials. (See section 3)

Léém building materials are also circular in destination: they are infinitely reusable or recyclable without loss of quality.

In essence, earth construction uses the soft layer of the earth (called “horizon B”, “soil”, or “loose rock”) to make structures for human use. After the end of the life cycle of the building use, Léém building materials can return to the soft layer of the earth (zero waste), or they can be reshaped into Léém building materials (Reuse).

Parameter: Circular in origin means avoiding the use of primary resources, which lowers the Environmental Impact score because of less impact in the product stage A1 and others (see also Section 2.1.6).
Circular in the destination means avoiding disposal in the End-of-life stage and generating benefits in module D, which lowers Environmental Impact score.




DE MEUTER
DE MEUTER

2.1.3 Local sourcing and minimum transport

[25] The hidden cost of transportation of construction materials: An overview, Journal of Engineering Design and Technology

Instead of transporting mineral waste from construction sites far away and at the same time bringing in primary resources from faraway quarries, BC materials keeps the supply chain short and transports close. We source from local construction sites, avoiding waste transports as well as primary resource transports.

Léém building materials are local: we source from close-by construction sites and deliver in short supply chains.

Since earth building products don't have a firing process in their production, the only place where fossil fuels are used are in the transport of resources and products. Keeping these transports minimal and short is built into the core of our circular sourcing and production model. Of course this also offers economic benefits, as transportation costs represent approximately 39%-58% of the total logistics costs of a construction site and between 4%-10% of the selling price of the building [25]. We deliver with an action radius of 250 kilometers, as exceeding this radius makes the impact of the materials less ecological.

Parameter: Local processes means avoiding the transport of heavy resources and building materials, which lowers the Environmental Impact score because of less impact in the product stage A2, the construction stage A4 and the End-of-life stage C2.

[26] Diagnosis of the State of the Territory in Flanders
[27] Beleidsplan Ruimte Vlaanderen
[28] Schéma de développement du territoire (SDT),

2.1.4 Space scarcity

Belgium has the highest score for urban-sprawl indicators, and within the European context, almost the entire area is considered urban [26]. As a consequence, space is scarce and the Flemish government aims to legislate net zero new space uptake by 2040, starting today with progressive limits on new space uptake [27], and the Walloon government by 2050 [28]. In this perspective, BC materials thinks it is better to make maximum use of existing infrastructure, existing waste streams centres and existing logistical possibilities instead of occupying new space or having to tap into raw materials from new (or extendable) quarries. This approach has a substitution effect on many building materials and their processes, and Léém's philosophy here is that Léém building materials does not need any new infrastructure, but uses the infrastructure of standard building materials.

Léém building materials are made within already existing infrastructure: no need to take up valuable space for new factories or quarries.

This avoids new space take-up, and obviously has a positive impact on the resilience of existing ecosystems, habitat and species conservation because our approach and materials do not require landfills, new resources, new quarries or new open space to be carved up.

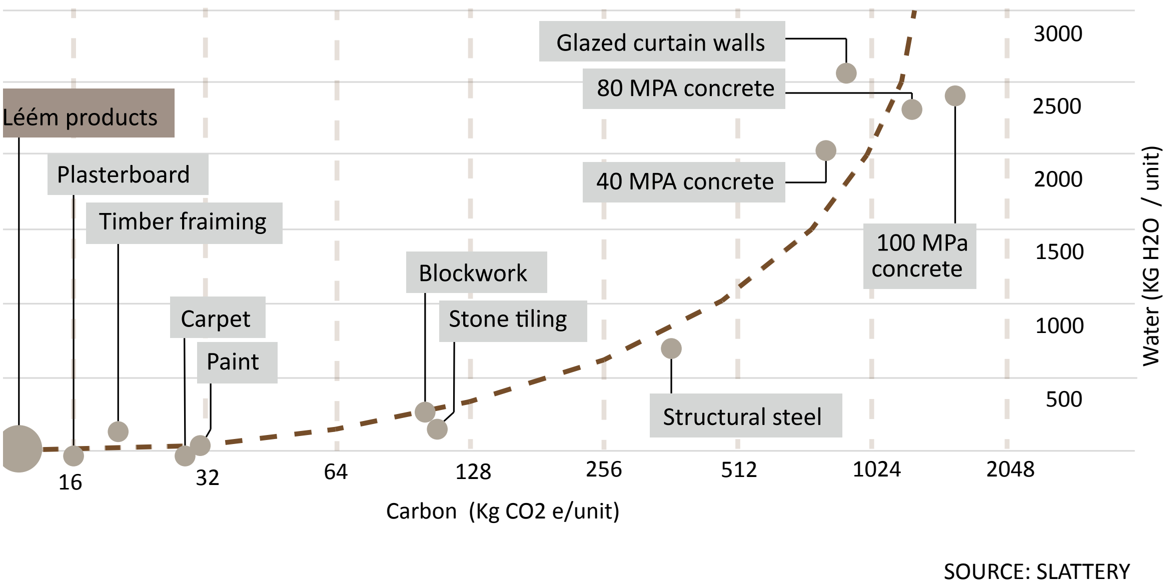
2.1.5 Embodied water

[29] Embodied water' is the latest challenge for the building industry

Aside from the use of minerals, the construction sector also has a heavy footprint in water use. Today, 38% of a building's lifecycle water consumption occurs before anyone ever turns on a tap in a completed building [29]. High amounts of fresh water are used for the production of concrete, steel and glass, as shown in the graphic below.

Léém building materials do not need large quantities of freshwater, in contrast to classic building materials. All of the freshwater is given back to our planet's water cycle in the drying process.

Léém materials, however, are partly produced with recuperated rainwater and most of them can be produced with a very limited amount of it. On top of that, most of the production water evaporates again through an air drying process into the atmospheric water cycle.



Water and carbon of commonbuilding materials.

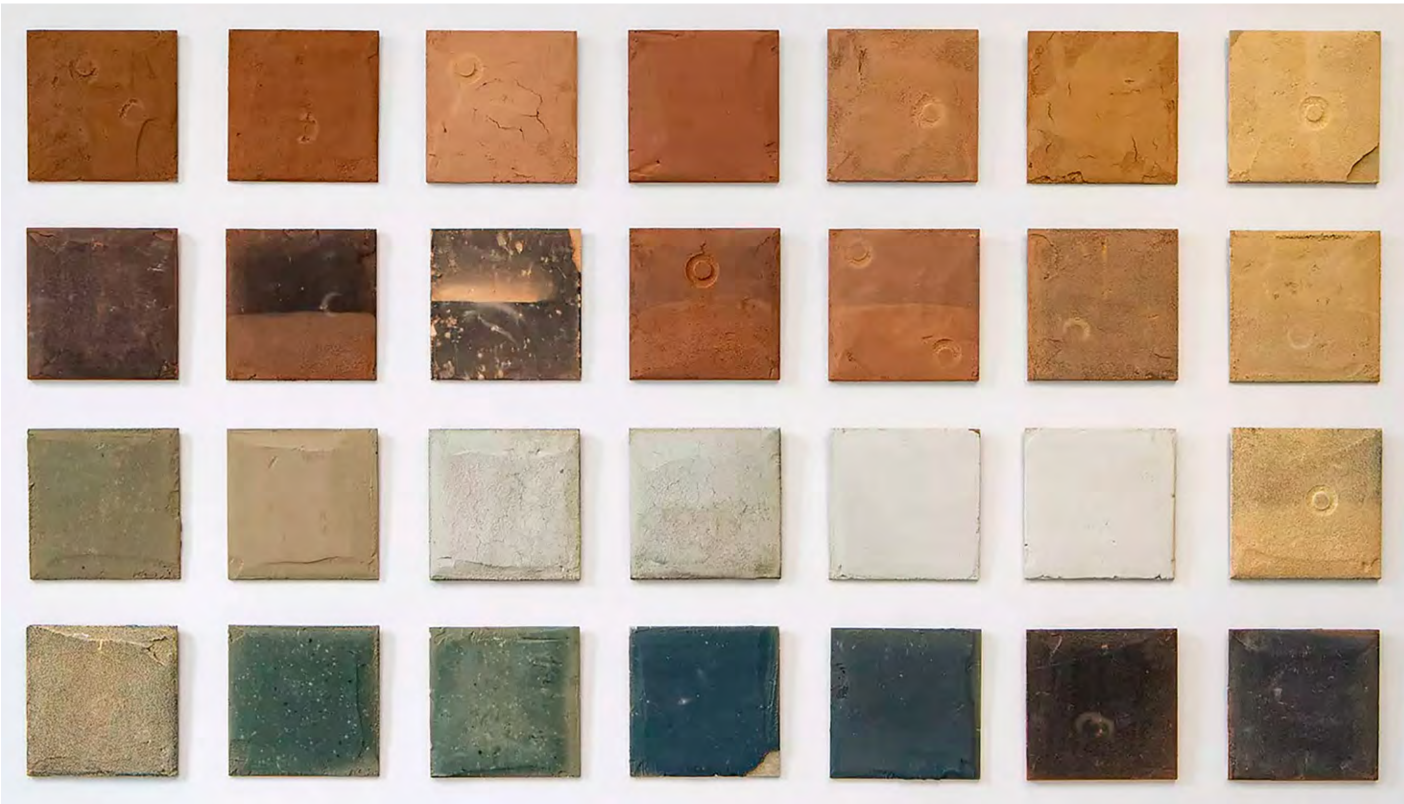
2.1.6 Environmental impact score and EPD

Once a Life Cycle Analysis or LCA – see section 2 for an introduction – for a building material is complete, it can be declared by a company in the form of an Environmental Product Declaration (EPD) so it can be used in software to calculate the LCA of a building. In Belgium, this software is called "TOTEM" (totem-building.be). On the website of TOTEM, one can read more in detail about the calculation guidelines of LCA of building materials and buildings.

Léém building materials have excellent environmental impact scores: 10 to 20 times better than current standard building materials.

BC materials has done specific LCA screenings of its Léém building materials. Because of carbon neutrality, circularity and locality of Léém building materials, they perform at an environmental impact several multitudes lower than fired materials, concrete, or other fossil fuel intensive materials. The specific values for different Léém building materials are declared in the respective Technical Sheets downloadable on leem.works .

Parameter: 2 environmental impact scores are generally provided: Global Warming Potential - Fossil and general Environmental Impact Score.



2.2 Sustainable building and indoor climate

2.2.1 A healthy indoor climate

[10] Sustainable Building with Earth.

Indoor air quality is on average 2.5 to 5 times worse than outdoor air (Flemish government & VITO, 2010) while we actually spend 90% of our time indoors (European Environment Agency, 2022). Unhealthy indoor air can be caused by building materials that emit harmful substances. These include materials for flooring and their coatings, room dividers and furniture, walls and wall coverings, insulation materials, paints, varnishes, putties and adhesives, vapour barriers, wood preservatives, technical installations, and materials containing aggregates and additives. [10] (p.415)

Léém building materials are made of natural, mineral, clean resources whcih contribute to a healthy indoor climate.

However, all of our excavated earth resources do not emit any harmful substances (see also section 2.2.2). On top of that, they are found to be free of pollution, following continuously implemented testing according to OVAM Vlarebo (Flanders Region) and Normes d'intervention (Brussels Region), with extra testing for PCB and asbestos. In total, 51 pollution parameters are tested, such as heavy metals, hydrocarbons, mineral oils, inorganic components, volatile organic components, PCB and asbestos. These parameters are tested twice, once upon excavation, and once upon transformation into building materials. This way BC materials is absolutely sure that undisturbed, unpolluted, virgin geological soils are used for the Léém building materials. These naturally formed construction soils are free of harmful substances and are «recommended on the basis of the principles of construction biology». [10] (p.415)

One step further is even to point out the cation-binding properties of clay particles in earth building materials: earth building element surfaces with open pores have high adsorption capacity for external toxic and non-toxic particles, with or without smell effects. Earth building materials integrate compounds into their clay mineral structure, thereby neutralizing them and/or making the odours imperceptible. However, there are limits to the absorbing capacity. [10] (p.518)

2.2.2 VOC-emissions

Besides confirming non-pollution of resources, pollution can also be checked on the product as a measure of Volatile Organic Compounds (VOCs), which are emitted as gases from certain solids (or liquids). VOCs include a variety of chemicals, some of which may have short- and long-term adverse health effects. Concentrations of many VOCs are generally consistently higher indoors (up to 5 times higher, see section 2.2.1) than outdoors. However, Léém building materials are zero VOC and hence contribute to a healthy interior living climate.

Léém building materials lead to healthy indoor climates : they improve the air quality and are completely VOC-free.

Parameter: Total VOC emissions are measured at micrograms per cubic meter of product. Zero-VOC emissions are declared if the measurement is lower than 1000μgr/m3 as is the case for Léém building materials.

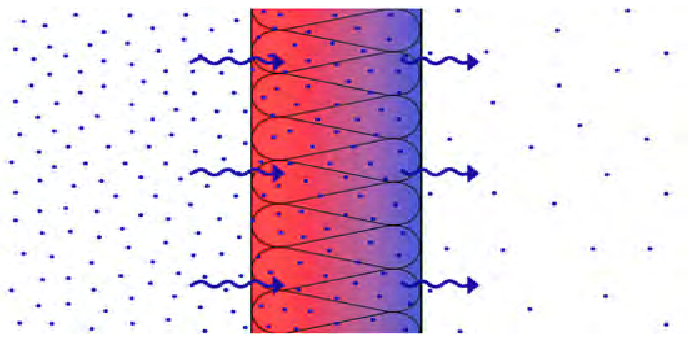
2.2.3 Hydric comfort

When cooking, showering, and cleaning, an average family adds 10 liters of moisture to the interior climate each day. Approximately 10-50% of all buildings today suffer from excessive moisture. People living in damp homes are 40% more likely to develop asthma and other respiratory diseases. Also, viruses, such as COVID-19, do well in too humid or too dry environments (MIT, 2022).

Optimal indoor humidity levels are balanced, not too high, not too low, between 40-60% relative humidity. Below we describe several ways in which Léém building materials can help improve indoor hydric comfort.

a. Indoor humidity regulation

Moisture can enter an earth building element as a liquid or a gas due to the material's hygroscopic properties and its open pore structure. Depending on the differences in moisture, temperature, and vapour pressure between the earth building element and the adjacent medium, moisture can be transported through the earth building element, stored in it, and released again. The earth building element and its immediate surroundings are constantly moving towards a hygroscopic balance. This is also called the principle of the "breathing" wall.



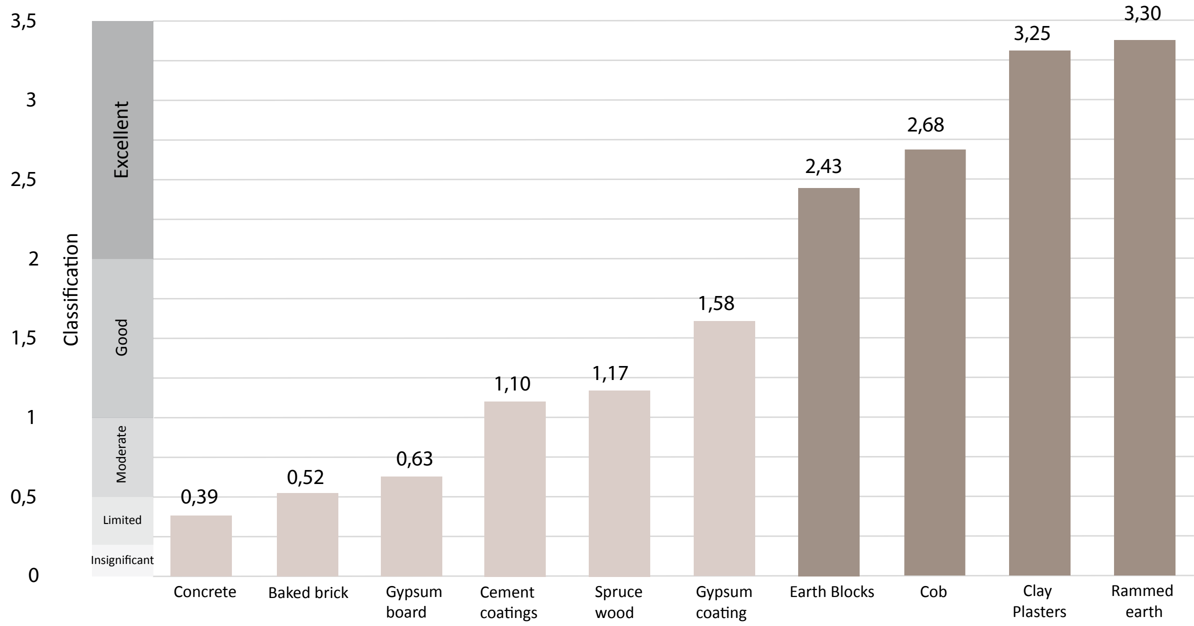
Wall assembly showing outward vapour drive for a cold climate

"Breathing" means that the water vapour ("air humidity") diffuses through the porous building material. This property is indicated by the water vapour diffusion resistance factor μ. The value μ is a dimensionless ratio which compares the diffusion density of the water vapour flow in a building material with that found in an air layer of an equivalent thickness sd. Still air has a μ value of 1. The sd value indicates the required thickness of the air layer in order to possess the same diffusion resistance as the specified building material with a layer thickness d. This makes it possible to compare building element layers of different thicknesses:

$sd = \mu \times d$

A low μ indicates an easy moisture transport for the building material.

Moisture Buffer Values are another measure that can define the capacity of a building material to regulate humidity. In general, the moisture buffer value will be reversely proportional to the water vapour resistance number: a high MBV is linked to a low μ .



Comparison of moisture regulation capacity of earthen materials

[7] Guide de conception et de construction.
[9] Earth Masonry: Design and Construction Guidelines.
[10] Sustainable Building with Earth.

Léém building materials have low water vapour resistance factors between 5 and 10 and high Moisture Buffer values between 2,2 and 3. This has 2 beneficial effects:

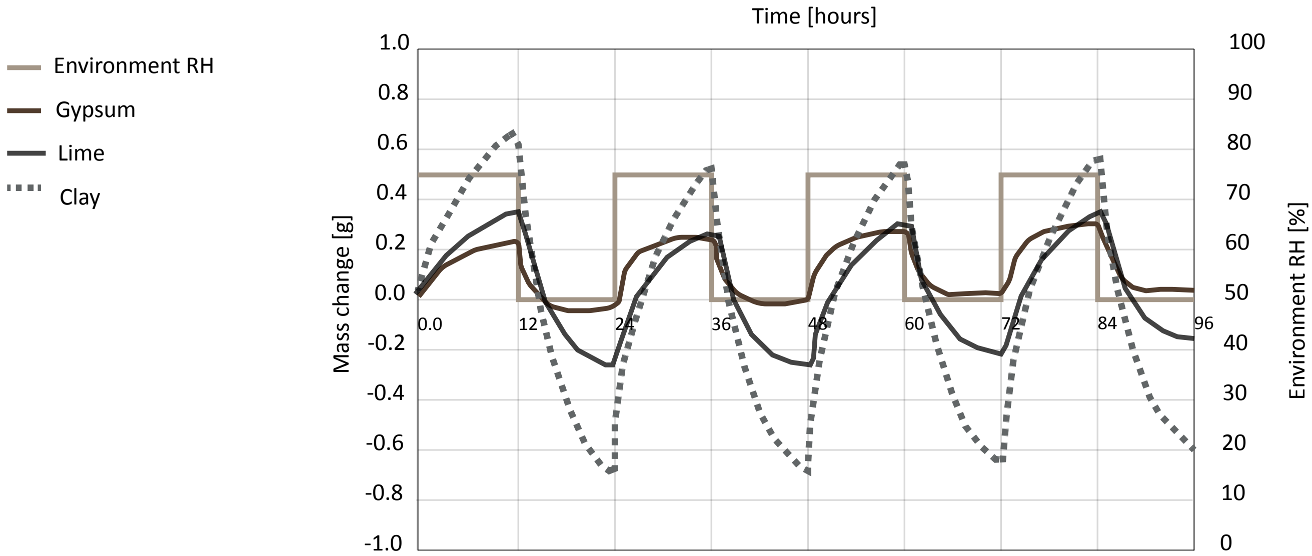
— Short-term moisture regulation: Raw earth material can quickly absorb excess moisture through its surface (the first 10-15 millimetres), thus mitigating immediate fluctuations in relative humidity, for example in bathrooms. [9] (p.74-75)

— Long-term moisture regulation: Raw earth material is capable of regulating moisture between the spaces on either side of the wall through its thickness. The thicker the wall, the more moisture it can absorb and regulate over a longer period of time.[9] (p.74-75) Therefore the need for air renewal can be limited to other needs, such as the evacuation of carbon dioxide. This property thus limits the risks of condensation and mold. [7] (p.78-79)

Studies conducted by Minke and Holl/Ziegert [10] (p.408) show that earth construction materials have a considerable better performance than conventional construction materials that use lime, gypsum, or cement as a base material.

Furthermore, the first 15mm of an earth building material can absorb 300g of water in 48h when the relative humidity increases from 50 to 80%. (For comparison: wood absorbs 100g and a baked brick absorbs 30g under the same conditions) [9] (p.74-75)

Parameters: The water vapour diffusion resistance number compares the diffusion density of the water vapour flow in a building material with that found in an air layer of an equivalent thickness sd. (Still air has a μ value of 1.)
The moisture buffer value indicates the amount of water that is transported (adsorption or desorption) in or out of a material per open surface area, during a certain period of time, when it is subjected to variations in relative humidity of the surrounding air.



Mass change of plasters when exposed to changing relative humidity

[12] Relevance of Earthen Plasters for Eco Innovative, Cost-Efficient and Healthy Construction

"Results (Fig. 32.1) demonstrate that earth plasters in combination with wood fibre boards are characterised through an outstanding water vapour adsorption capacity, which is up to three times higher in comparison with gypsum plasterboards, as evidenced also in (Minke 2012; Eckerman and Ziegert 2006)." [12] (p.375)

b. Equilibrium Moisture and effect on other building materials

[9] Earth Masonry: Design and Construction Guidelines.
[10] Sustainable Building with Earth.

Equilibrium moisture refers to the average moisture content of the building element in its specific use context. This level is rarely exceeded or undercut under standard conditions in indoor spaces (40–70 % RH, +20 °C) [10] (p.407) Léém building materials have values between 0,5 and 2 % of equilibrium moisture. This is low compared to other building materials, and as such, earth building materials can help dry out and keep dry other materials in a building, e.g. in wood construction systems. "If the earth material of the building element is always kept dry and the two building materials are permanently bonded, allowing effective diffusion, a diffusion of the equilibrium moisture content from the wood to the earth material develops: the earth material keeps the wood dry and has a preservative effect. This property is particularly interesting for reducing the risk of mold or insect attack in wood" [10] (p.408) et [9] (p.75).

Parameters: Equilibrium moisture refers to the moisture content of the building element which gradually sets in as the average value for the building's useful life.

Léém building materials regulate indoor humidity and are beneficial to all living & working in these spaces.

Léém building materials keep other building materials dry.

2.2.4 Thermal comfort

A climate is considered physiologically ideal and comfortable when the human body is in thermal equilibrium with its surroundings. The way a person perceives climate conditions differs depending on age, constitution, gender, diet, as well as the ability to adapt to the climate. The indoor climate is especially influenced by the following factors:

— Air temperature
— Radiation from surrounding surfaces
— Relative humidity of the air
— Air movement

Below it can be observed how Léém building materials have a positive impact on thermal comfort through three out of these four principles.

a. Thermal inertia, temperature amplitude attenuation and phase displacement

In periods with rapid fluctuations in outside temperatures such as day maxima and night minima, building elements which can store heat prevent the building's interior from cooling down or heating up too quickly. The higher a building element's heat storage capacity C and the lower its heat transfer coefficient Λ, the better its effectiveness in terms of heat storage and cooling. The quotient of both values is referred to as the thermal inertia or cooling behaviour of a building element: the property of a material that expresses the degree of slowness with which its temperature reaches that of the environment.

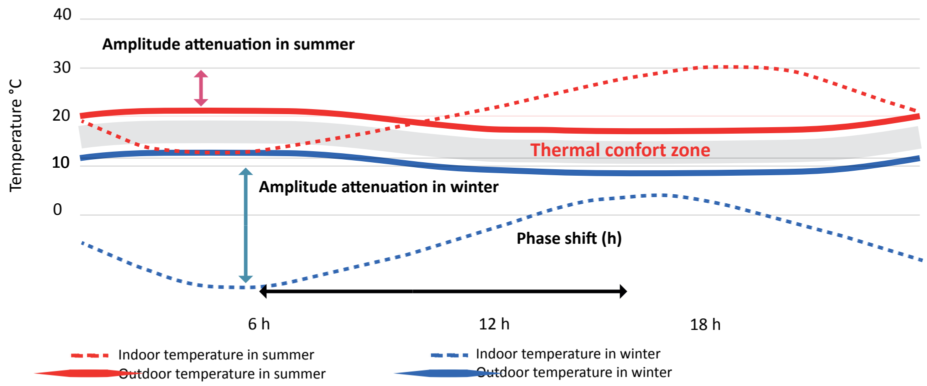
Léém building materials brings thermal inertia to your project, balancing day and night temperature extremes.

If we look at the outside and inside surface of a building element, we see that outside temperature amplitudes passing through the building element become weakened (attenuated) on the inside: this is called temperature amplitude attenuation. The time difference between outside and inside peaks of temperature amplitudes is called phase displacement.

In a moderate climate such as Western Europe, composed walls need to provide a good insulation, as well as a good heat storage capacity through high mass of the wall. Léém building materials offer a good heat storage capacity because of their high density, which helps light buildings such as wooden structures store heat in winter and cold in summer.

Parameters: The quotient of Heat storage capacity C and Thermal conductivity Λ define the degree of slowness with which the temperature of a building material reaches that of the environment, also called thermal inertia. Temperature amplitude attenuation and phase displacement can be calculated from these values.

[11] Wienerberger. Rouge. La Force.



Thermal comfort zone scheme [11] (p.101)

[1] Guide des bonnes pratiques de. la construction en terre crue - Brique de terre.
[10] Sustainable Building with Earth.

b. Thermal effusivity and thermal diffusivity

The thermal effusivity coefficient b of a material describes how much heat is removed from the human body when a person physically touches the material. The higher the thermal effusivity coefficient b, the more heat is removed from the body and the cooler the material feels. In rooms with high air temperatures, building elements with surface layers made of materials with a high thermal effusivity coefficient stay "cool" for a longer period of time. Heavy building materials such as natural stone, concrete, and steel have high b values, whereas the values for light building materials such as wood, cork, or foamed materials are correspondingly lower.

Léém building materials have medium thermal effusivity and therefore seem "warmer to the touch" when left apparent. [1] (p.19) and [10] (p.402)

Léém building materials are warm to the touch, and mitigate fast temperature changes.

The thermal diffusivity coefficient a of a material describes the speed at which a material is capable of transmitting heat from one side of a wall to the other, under varying temperatures.

Léém building materials have medium to high thermal diffusivity and therefore transfer captured solar heat in winter towards inside, and reversely promotes good cool comfort in summer.

Parameters: thermal effusivity coefficient b and thermal diffusivity coefficient a .

c. Thermal comfort through humidity regulation

Relative indoor humidity is an important factor for thermal comfort for people: for the same warm or cold temperature, an indoor climate with higher relative humidity will feel respectively hotter or colder.

Léém building materials help in achieving a good thermal comfort by balancing indoor humidity.

Since, Léém building materials regulate humidity (see Section 2.2.2), they contribute to higher thermal comfort.

— By lowering the indoor humidity in summer, Léém building materials make the indoor spaces feel cooler.
— By heightening the indoor humidity in winter, Léém building materials make the indoor spaces feel warmer.

Parameter: The water vapour diffusion resistance number compares the diffusion density of the water vapour flow in a building material with that found in an air layer of an equivalent thickness sd. (Still air has a μ value of 1.) See also section 2.2.2

2.2.5 Airtightness

A general requirement in order to reduce heating energy is the airtightness of the outer building envelope. According to the Lehmbau Regeln, earth building materials with a density of 900 kg/m3 or more are considered airtight. [15] (p.100) For materials with lower densities, the building element must be covered with a plaster. [4] (p.17) A minimum of 10 mm clay plaster is advised by Buildwise in order to be airtight. [22] (p.53)

[4] . ATEx A 2990_V1. Maçonnerie de remplissage
[15] Rapport d'essai Nr. PB 128 001 2022 (Blocs).
[22] NIT 284: Les enduits intérieurs.

Léém building materials bring airtightness to your building.

Parameter: The airtightness at air pressure 50Pa shows the air flow rate which escapes a space per hour and per square meter of surface.


© Ringo Gomez-Jorge

2.2.6 Fire safety

Fire security of building materials consists generally of two characteristics: fire reaction and fire resistance.

a. Fire reaction

[8] Maçonnerie porteuse en terre crue.
[9] Earth Masonry: Design and Construction Guidelines.
[13] NATURALLY VENTILATED EARTH TIMBER CONSTRUCTIONS
[24] DIN 18947: Mortier de terre pour enduit

Fire reaction or fire performance is how a material reacts in contact with fire, more specifically with regards to its combustibility.

Léém building materials are incombustible.

It is influenced not only by the actual type of material but also by its shape, specific surface area and mass. In general, the incombustibility (Fire Reaction class A1 = M0) of raw earth materials is assured if one of the following conditions is met [9] (p.87):

— Less than 1% organic components [18] (p.19), [19] (p.13),[9] (p.87), [8] (p.19) et [24] (p.15)

— Density of at least 1700 kg/m² [9] (p.87)

— Specific fire test data [9] (p.87)

Parameter: The Fire reaction Class exists of classes A1-F with increasing combustibility as defined in EN13501. Generally Léém building materials are incombustible (A1).

[1] Guide des bonnes pratiques de la construction en terre crue - Brique de terre.
[9] Earth Masonry: Design and Construction Guidelines.
[11] Rouge. La Force.

b. Fire resistance

“The fire resistance REI of a wall is expressed in hours and indicates how long the wall will resist in case of fire. This means that the wall will maintain its stability (R) and resistance to flames (E), and that the temperature on the other side of the wall will remain below a threshold determined by insulation (I), which will prevent objects in an area unaffected by fire from igniting due to radiant heat.” [11] (p.49)

Léém building materials offer high resistance to fire.

In general, it can be said that clay-based mineral materials provide excellent fire-resistant properties for earth building materials through following general principles:

— Fire stability (R): Chemically, the stability of Léém building materials is not destroyed by firing, since the clay building materials become fired clay building materials [1] (p.20)

— Flame and smoke resistance (E): A protective crust is formed due to the firing of the surface layer.» [1] (p.20)

— Thermal insulation (I): A porous network develops and contributes to promoting thermal insulation. This phenomenon also partly explains the good thermomechanical properties related to fire stability. [1] (p.20)

However, attention must be paid to the protection of fire resistant walls against extinguishing jets, either with a protective finish, or with a sufficient thickness to withstand surface erosion caused by pressurized water. [9] (p.87)

Parameter: Fire Resistance, designated as the minutes of resistance to fire in relation to stability R, flametightness E and thermal insulation I.

sist
e [

[7] Cycle Terre. Guide de conception et de construction
[10] Sustainable Building with Earth. Springer International Publishing

2.2.7 Acoustic comfort

In order to evaluate acoustic comfort, we will first present how sounds can be distinguished according to their mode of transmission:

a. Airborne sound:

Sound that travels through the air, for example, caused by human speech. Building elements can be relevant for airborne sound attenuation in 2 ways:

— Airborne Sound Transmission Acoustic tests for airborne sound transmission examine the surface density of a building element (the mass of the materials in g based on 1 m2 of the building element), as well as its bending stiffness and tightness. The sound reduction index R describes the airborne sound insulation of the building elements. It is calculated using the difference in sound level between two rooms, usually the source room and the receiving room. The most important reference value for the assessment of airborne sound insulation is the weighted sound reduction index Rw [dB] as an individual and simplified value for building elements [10] (p.419-420)

— Airborne sound absorption: The acoustic properties of earth materials are still poorly understood. As earth is an open-porosity material, its acoustic absorption capacity is a priori considered to be good. This is because part of the acoustic energy is transformed into frictional heat when the sound waves set the air in the pores in motion. The material's absorption capacity will therefore be all the greater if its finish leaves the pores open, without smoothing the surface. The addition of fibres to the soil increases the open porosity of the material, which is also a favourable factor. Furthermore, absorption at low frequencies increases as the thickness of the material increases. [7] (p.67)

b. Structure-borne sound:

sound that propagates through solid materials, for example impact sound. If Léém building materials have high density, they will perform better in attenuating structure-born sound.

Due to the balanced combination of high surface density and porosity, Léém building materials achieve outstanding results in sound insulation. However, joints between building materials which are not completely filled, and cracks are weak points for sound insulation.

Léém building materials have excellent acoustic properties.

Parameter: Airborne Sound Insulation is measured by the weighted sound reduction Index Rw with the addition of a low frequency sound correction factor Ctr.


evr

2.2.8 Long life span

The life span of a building material can be estimated by the amount of years it sustains, without a specific external intervention (demolition,..). In the Rhine-Meuse-Scheldt delta which contains North of France, Belgium, Luxemburg, Netherlands and parts of Germany, earthen buildings have proven their durability over centuries of time. These were made mainly of earth construction techniques such as wattle-and-daub, cob, adobe masonry and plasters. Still today these vernacular buildings make up a big part of the current building stock mostly in the North of France and in Germany. In Weilburg, Germany, one can find the example of a seven-storey high building in loadbearing Rammed Earth walls, built in 1830. In Hasselt, Belgium, the 16th century Tackoen house was built in half-timbering with Wattle-and-daub infill. Moreover, many European Unesco Heritage buildings are made in earth construction techniques, such as the Alhambra in Spain, built between de 13th and 15th century. Also, in Belgium and Netherlands wattle-and-daub vernacular earth buildings from the 15th to 18th century are still used by families today.

This building use throughout centuries demonstrates both the potential and the reality of a long life span of earth building techniques, outlasting the limited 50 years of lifecycle currently attributed in Life Cycle Analysis calculations.

The Léém building materials inscribe themselves in this vernacular tradition of long life spans. However, Léém building materials are as well tested and certified in all modern ways. The results of these tests can be found in the Technical Data Sheets of the various Léém building materials, downloadable from the leem.works website . It is the totality of all these tests that shows the lifespan. However, certain specific tests give a detailed idea of the lifespan of exposed Léém building materials:

Léém building materials are resistant against impact and abrasion, and are long-lasting.

Abrasion is the process of scraping or wearing off of the surface of the building material. Impact is the process of sudden localized breaking of the material. Both are due to forces of grinding, shocks, ... Resistance to abrasion and impact is influenced by the degree of the grinding and impact force, the strength and smoothness of the surface and the properties of the used earth (cohesive strength, grain distribution, grain shape, and angularity) and its aggregates.

Parameter: Mechanical strength parameters including abrasion resistance and impact resistance
Life Cycle Analysis which includes the life cycle of 50 years for Léém building materials, this is the same for other standard materials.

1. Vernacular rammed earth building,
Weilburg, Germany

2. Vernacular wattle and daub building
Hasselt, Belgium.

[10] Sustainable Building with Earth. Springer International Publishing
[20] MOVEMENT COEFFICIENTS OF COMPRESSED EARTH MASONRY UNITS

2.2.9 No exposure to (Radon) radiation

All living beings on earth, including humans, are exposed to natural high-energy (ionizing) rays. Unmodified natural exposure consists of cosmic and terrestrial radiation as well as the incorporation of radioactive material (ingested with food). There is also modified natural exposure for people in the form of building materials and through inhalation of radon within buildings, as well as man-made exposure such as artificial radiation in the field of medical diagnostics and therapy or as results of disaster (Chernobyl, Fukushima,..). [10] (p.421-424)

Léém materials have no radioactivity

Soils and clays can generally be considered “free” of natural exposure to radiation. (With the exemption of sourcing on rocks containing Radon radiation.) [10] (p.421-424) In this sense, Léém building materials are harmless in terms of radiation, and hence are considered to be radiation free. (This is not always the case for other building materials, such as gypsum, which has radiation levels above the reference value considered to be harmless)

Parameter: Activity concentration index I

[10] Sustainable Building with Earth. Springer International Publishing

2.2.10 Shielding from High-Frequency Electromagnetic Radiation

Wireless data transfer and cellular technology use high-frequency waves in the range of 10–100 kHz over the entire MHz range up to 150–300 GHz. Transfer is facilitated by an extensive system of transmitters. This generates high-frequency electromagnetic radiation which, for the most common functions of cellular communication and GPS, is in the frequency range of 890–2170 MHz. The characteristics of HF waves are similar to those of light waves: upon impact with an object, such as a building, they are reflected or they pass through the object, depending on the nature of the material.

Léém building materials shield from radiation.

Léém building materials (ρ_d = 1600 kg/m3) have a significantly high attenuation effect compared to vertically perforated fired bricks (ρ_d = 1200 kg/m3) and sand-lime blocks (ρ_d = 1800 kg/m3) of the same thickness. [10] (p.425)

3. End-of-life guidelines

[10] Sustainable Building with Earth. Springer International Publishing

Waste management is well established in Europe, and more specifically in Belgium. Waste directives and regulations have been installed in order to control how to dispose of, recycle or reuse standard (building) materials at their end-of-life: PUR, concrete, aluminium, steel, ...

The Léém building material range wants to put forward the benefits of earth construction in terms of waste management. Building with Léém materials implies building locally with the soft crust of the earth without altering these earth mixes chemically: it essentially stays earth, shaped into a specific form. This fact means that there is minimal to no energy added for recycling or reusing. Also, the concept of disposal is turned upside down: Léém building materials are reversible, this means that Léém building materials could be « given back » to the soft crust of the earth at their end-of-life stage. This vernacular, low-tech and common sense end-of-life scenario is not possible for other standard building materials currently on the market : how to "give back" PUR, concrete, aluminium and steel to our planet?

In this section 3, we look at how reversible earth building materials such as those of Léém fit in our current waste directives and regulatory frameworks. We also propose different end-of-life scenario's which are specific to Léém building materials: a Take-Back program for Closed Loop Recycling, as well as the unique Reuse possibilities of Léém building materials.

Follow-up of these demolished Léém building materials streams is necessary before these end-of-life scenarios are possible. To lay out the end-of-life possibilities of Léém building materials in the sections below, we use the work of Dr. Horst Schröder as put forward in his work "Sustainable building with earth [10].


© Alexander D'Hiet

3.1 Legal framework

In this section, we limit ourselves here by mentioning the legal frameworks applicable when wanting to dispose, recycle or reuse building materials.

Legal framework in Europe

The general principles relating to waste are currently laid down in Directive 2008/98 of the European Parliament and of the Council of 19 November 2008 on Waste Directives. This includes construction and demolition waste, which are «wastes generated [by] construction and demolition activities» (Art. 3, 2c Waste Framework Directive).

Legal framework in Belgium

In Belgium, waste policy falls under the competence of the regions, which have transposed the Waste Framework Directive, with their own nuances or particularities.

In Flanders:

The Flemish decree of 23 December 2011 on sustainable management of material cycles and wastes («Materials Decree») adopts the Waste Framework Directive, from which it uses the definition of «waste». The Flemish waste catalogue can be found in annex 2.1 of the Flemish government's decree establishing the Flemish regulation on sustainable management of material cycles and waste materials («Vlarema»). The relevant Flemish regional administration is the «OVAM». A 'Demolition Succession Plan' is required when applying for an environmental permit for certain demolition, dismantling and renovation works. The demolition follow-up plan is a tool for selective demolition and selective collection on site.

In Wallonia:

The Walloon decree of 27 June 1996 on waste («the Walloon Waste Decree») adopts the Waste Framework Directive rather faithfully, and from it takes the definition of «waste» verbatim. A decree of the Walloon government of 10 July 1997 («AGW catalogue «) established the «Walloon waste catalogue» with waste codes based on the European waste list.

In Brussels:

The Brudalex (Bruxelles/Brussels-Déchets-Afvalstoffen-LEX) provides the Brussels-Capital Region with a legal framework to switch to a circular economy, by reducing administrative procedures and encouraging the selective collection and reuse of waste. Adopted on 23 June 2022, Brudalex 2.0 amends the previous 2016 decree and reinforces the Region's transition to a more circular economy.

3.2 Demolition

[10] Sustainable Building with Earth. Springer International Publishing

The first action in an End-of-Life scenario of Léém building materials is the demolition of its building elements. This needs to happen in a certain way, to allow for Closed Loop Recycling and Reuse scenarios.

“Structures made from earth building materials are demolished using mechanical methods. The methods should allow for a targeted recovery of correctly sorted demolition materials for recycling, in this case raw earth blocks, raw earth mortar, stabilised earth blocks, stabilised earth mortar, raw earth plaster, … […] Demolition work on earthen structures typically generates a high amount of dust which poses a threat to the health of the workers. In order to bind the dust, the building elements scheduled for demolition can be sprayed down with water. This needs to be done carefully due to the water solubility of the earth building materials and the possible risk of mixing the earthen materials with other demolition materials.” [10] (p.507)

If done correctly, dust can be avoided, which significantly lowers the environmental impact of the respective Léém building material (in the “Particulate Matter” indicator of an LCA analysis).

If specifically envisioning the Reuse of Léém building materials, general principles of demolition for reuse apply: manageable logistics, ease of deconstruction in terms of reachability, disassembly possibilities with regards to adjacent material layers, load conditions, …

3.3 Pre-requisites to recycling Léém building materials

[10] Sustainable Building with Earth. Springer International Publishing

Landfill space is becoming increasingly scarce and more expensive. Construction waste represents the largest share of the total waste volume by far. Reducing the yearly volume of construction waste could contribute considerably to a decrease in demand for landfill space. [10] (p.510) Closed Loop Recycling and Reuse strategies can contribute significantly to the lowering of construction waste quantities. However, there are prerequisites to make this possible.

The general prerequisites [10] (p.511-512) for the reuse or recycling of building materials are:

Technical suitability:

The technical suitability of recycled earth building materials depends largely on the purity of the material obtained during demolition. [...]. In terms of usability, no technical requirements with quantified criteria for recycled earthen materials have been formulated thus far. [10] (p.512)

Environmental safety:

During the lifetime of the building or structure, the earth building elements might be exposed to a number of different substances. This can limit or rule out the reuse of these earth building materials. In some cases, this exposure can even lead to problems with the disposal of the materials in an environmentally safe manner. This includes:

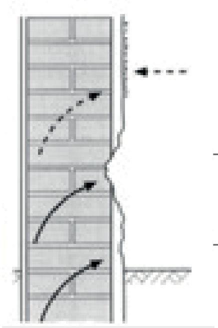
— Salts
— Air pollutants
— Dry rot and mold
— Hygiene-related concerns, such as the binding of odors and germs in dismantled livestock barns

[10] (p.512-513)

Specifically, “The crystallization of salts, frequently connected to an accumulation of water molecules (hydration), leads to an increase in volume. The volume increase and repeated freeze–thaw cycles destroy the structural strength of the earth building materials in the affected zone. The lower strength of earth building materials compared to block and cement results in a faster decay of the material. Shell-like flaking of the loosened areas leads to a weakening in the structurally effective cross section of the loadbearing exterior walls (Fig. 5.13). As a result, the salt-loaded material becomes virtually pulverized on the outside. Through the chemically altered clay minerals, the plastic properties (but also the strength of the soil) are largely lost. This limits or prevents the material’s reuse as recycled earth.” [10] (p.429)

BC materials has an in-house quality control procedure in place to establish the technical suitability and environmental safety of recycled Léém building materials.

[10] Sustainable Building with Earth. Springer International Publishing

Height cm	Diagram	Name	Chemical formula	Solubility per 100 ml of water
		Calcium nitrate	$Ca(NO_3)_2$	226
		Sodiumnitrate	$NaNO_3$	92
		Calcium chloride	$CaCL_2$	75
50		Halite	$NaCL$	39
		Potassium chloride	KCL	24
		Glauber’s salt	$Na\ 2SO_4*10H2O$	92
20		Magnesium sulfate	$MgSO_4*7H_2O$	71
0		Potassiumnitrate	KNO_3	13
		Gypsum	$CaSO4*2H_2O$	0.3

Types and distribution of harmful salts arround the foundation and stem wall [10] (p.429)

3.4 End-of-Life scenario's for Léém building materials

[10] Sustainable Building with Earth. Springer International Publishing

If the prerequisites for recycling or reusing are followed, different end-of-life scenario's for a Léém building material are possible:

Reuse:
Reusing earth blocks for earth block masonry, which means using them for the same purpose, constitutes the highest possible value retention strategy and is thus most desirable. This is due to the fact that the incorporated work (entropy) which was applied to the earth building material is preserved in the "shaped" building material itself." [10] (p.520) The earth block is already ready to be masoned again on the same (or another) construction site The same principle goes for other Léém building materials such as Léém Clay Plaster, which can be scraped off the wall and remixed on site with water and reapplied without quality loss: no need for a recycling intervention by a material producer such as BC materials.

Closed Loop Recycling:
Closed Loop Recycling is a recycling process through which a manufactured good is recycled back into itself or a similar product without significant degradation or waste. Recycling earth building materials in a closed loop can be done by milling or crushing them and reshaping them into form, whether or not they have been mixed in together with new earth building resources. In Closed Loop Recycling, new Léém building materials are (partly) made from demolished Léém building materials with minimal energy addition: it's a low energy Closed Loop Recycling.

Open Loop Recycling:
Open Loop Recycling is a recycling process that postpones disposal through converting manufactured goods into both new raw materials (which can be used as production inputs) and waste products. For Léém building materials, one could envision similar processes to for example the washing the excess quantity of fresh concrete in order to recuperate certain fractions of sands and gravel while disposing of finer clay and silt material. So Open Loop Recycling for Léém building materials is a technical possibility, however it needs to be seen if there is environmental and/or economic added value in setting up such a process.

Downcycling:
Downcycling is a recycling process in such a way that the resulting product is of a lower value than the original item. Recycled earth building materials (including salt-damaged materials) can also be used as fill material in subgrade construction in a process of downcycling. The same applies to earth building materials contaminated with dry rot spores or salvaged from agricultural buildings. [10] (p.520-522) The demolished materials must conform to the limits of environmentally harmful substances according to the guidelines and regulations of the 3 Belgian regions.

Disposal of earth building materials:
"Even if all recycling measures are intensified, it is not always possible to return residual earth building materials to the material cycle. In this case, their disposal as

"inert waste" cannot be avoided." [10] (p.522) In terms of disposal scenario's, it is informative to distinguish 4 categories of Léém building materials:

— Soil-containing: only natural clays, silts, sands and gravel: Léém Clay Plasters, Léém Moulded Blocks, Léém Earth Mortar
— Cellulose-containing: cellulose on top of natural clays, silts, sands and gravek: Léém Finish, Léém Paint, Léém Adhesive Mortar
— Recycled-Concrete-containing: recycled concrete on top of natural clays, silts, sands: Léém Rammed Earth Mixes
— Cement-containing: cement on top of natural clays, silts, sands and recycled concrete: Léém Compressed Block

Now, one can ask the question of earth building materials which have been tested to be only earth (soil-containing, and maybe also cellulose-containing Léém building materials) should be treated rather as "soil" than as "inert waste", which has different and less impactful disposal strategies available: landscaping, agricultural use, … or a return to the soft crust of the earth. However, current legal frameworks in Belgium do not allow for this disposal strategy. We feel this topic should be up for discussion on the societal table when the earth building sector gains in importance and market share.

For now we encourage as much as possible to Reuse Léém building materials, or use the Léém Take-Back program for Closed Loop Recycling (see section 3.5).

The table below shows some possible applications of Recycled Earthen Materials:

No.	Earth building material	Reuse through de/reconstruction	Reuse through preparation + shaping	Closed Loop Recycling at BC materials	Downcycling	Comment
1	**Rammed earth**		✓	✓	✓	
2	**Cob**		✓		✓	
3	**Straw clay**		✓		✓	
4	**Light clay**				✓	
5	**loose fill**	✓				
6	**Moulded Earth blocks**	✓	✓	✓	✓	
7	**Compressed Stabilised Earth Blocks**	✓		✓	✓	
8	**Clay boards**	✓			✓	Take surface coating into acount
9	**Earth mortar**		✓	✓	✓	Take surface coating into acount
10	**Clay Plaster**		✓	✓	✓	Take surface coating into acount

Possible application of recycled earthen materials [10] (p.520)

3.5 Take-Back program of Léém

For Léém Clay Plasters, Léém Earth Mortars, Léém Earth Blocks, Léém Rammed Earth and Léém Earth Screed, BC Materials has installed a Take-Back program, only if they are free from non-earth building materials, free from harmful substances (NI and NA of Brussels Region and Vlarebo Flemish Region), asbestos, PCB, PFAS and salts (DIN18945). Here are the conditions for "taking back" in separate streams for following Léém building materials:

Léém Moulded Blocks:
Reclaimed, undamaged earth blocks must be manually cleaned of adhering mortar residues. They must be stacked and stored on Europalet protected from the weather. BC Materials will make an evaluation of which blocks can be accepted for Reuse, and which blocks for Closed Loop Recycling.

Léém Compressed Blocks:
identical to Léém Moulded Blocks

Léém Clay Plaster, Léém Mortar:
Reclaimed earth mortar must be clean of other building materials and brought in bigbags or upon approval in bulk.

Léém Masonry:
Recovered demolished earth block masonry with adhering earth mortar residues must be clean of other building materials and brought in bigbags or upon approval in bulk.

Léém Rammed Earth:
Reclaimed rammed earth must be clean of other building materials and brought in bigbags or upon approval in bulk.

Léém Screed:
Reclaimed earth screed must be clean of other building materials and brought in bigbags or upon approval in bulk.

3.6 LCA benefit of Closed Loop Recycling and Reuse

A Life Cycle Analysis of a building material is a quantifiable evaluation of its environmental impact in the unit of millipoints (see section 2). In a life cycle assessment according to EN 15804, the End-of-Life scenario's which are explained above – Closed Loop Recycling and Reuse – have beneficial effects in modules A1-A3, C1-C4 and D:

Module A1 benefits:
No or less primary resources needed when using taken-back materials as secondary resources.

Module A2 and A3 benefits:
No transport nor Manufacturing impact when reusing Lééṁ Building Materials.

Module C1-C4 benefits:
The resources required for the recovery of an earthen building material as a secondary raw material are determined as input factors in modules C1-C3. These resources are less than if these materials would be disposed of and new materials would have to be produced from 100% primary resources. And of course stage C4 Disposal is eliminated. Also, when properly wetting the materials, in Module C1, Particulate matter indicator is lowered significantly because of avoided dust production.

Module D benefits:
The net output factors of on the one hand Closed Loop Recycling or Reuse of the recovered secondary raw materials, and on the other hand the substitutable primary raw materials for the production of an earthen building material are evaluated.

A lower environmental impact is the main driver to undertake the Reuse or Closed Loop Recycling of Lééṁ building materials.


© Hé architectuur

4. References

1. Confédération de la construction en terre crue. Guide des bonnes pratiques de la construction en terre crue - Brique de terre. Edited by Ministère de la cohésion des territoires et des relations avec les collectivités territoriales. Ministère de la transition écologique et solidaire, 15 octobre 2020.

2. CSTB, and Briques Technic Concept. ATEx A BTC 2957_V1. Murs porteurs BTCS. 5 octobre 2021.

3. CSTB, and SCIC Cycle Terre. ATEx 2991_V1. Parement intérieur. 1 février 2022.

4. CSTB, and SCIC Cycle Terre. ATEx A 2990_V1. Maçonnerie de remplissage. 1 février 2022.

5. CSTB, and SCIC Cycle Terre. Cloisons BTC. 10 Mai 2021.

6. CSTC. NIT 271. Exécution des maçonneries.

7. Cycle Terre. Guide de conception et de construction. Mai 2021.

8. Institut allemand de normalisation. DIN 18940. Maçonnerie porteuse en terre crue. octobre 2022.

9. Morton, Tom. Earth Masonry: Design and Construction Guidelines. IHS BRE Press, 2008.

10. Schroeder, Horst. Sustainable Building with Earth. Springer International Publishing, 2015.

11. Wienerberger. Rouge. La Force.

12. Klinge, Andrea, and al. "Chapitre 32:The Relevance of Earthen Plasters for Eco Innovative, Cost-Efficient and Healthy Construction—Results from the EU-Funded Research Project [H]house." The Extracellular Matrix: Methods and Protocols, edited by Davide Vigetti and Achilleas D. Theocharis, Springer New York, 2019, pp. 371-382.

13. Klinge, Andrea, and al. NATURALLY VENTILATED EARTH TIMBER CONSTRUCTIONS (Conference Expanding Boundaries: Systems Thinking for the Built Environment). Conference paper. Zurich, 15-17 June 2016.

14. SIPIZ Laboratoire d'incendie, and Terrabloc. Rapport d'essai Nr. PB 128 001 2022 (Blocs). 24 octobre 2022.

15. SIPIZ Laboratoire d'incendie, and Terrabloc. Rapport de test Nr. PB 128 001 2021 (Plaques). 5 juillet 2021.

16. Empa, and Terrabloc. Rapport d'essai n° 5214027285 (Terraplac). 1 juillet 2021.

17. Dachverband Lehm e. V. Lehmbauregeln. 3. Auflage, Vieweg + Teubner ed., 2009.

18. Institut allemand de normalisation. DIN 18945: Blocs de terre – Exigences, essai et étiquetage. Décembre 2018.

19. Institut allemand de normalisation. DIN 18946: Mortier de terre pour maçonner – Exigences, essai et étiquetage. December 2018.

20. Graham, C.W., et al. MOVEMENT COEFFICIENTS OF COMPRESSED EARTH MASONRY UNITS. 10th Canadian Masonry Symposium, Banff, Alberta, June 8 – 12, 2005, June 2005.

21. Sutton, Andy, et al. "Unfired clay masonry." Edited by University of Bath. Information paper, vol. 16/11.

22. CSTC. NIT 284: Les enduits intérieurs. Novembre 2022.

23. GUILLAUD, H. (2006) TRAITE DE CONSTRUCTION EN TERRE. Place of publication not identified: PARENTHESES EDITIONS.

24. Institut allemand de normalisation. DIN 18947: Mortier de terre pour enduit – Exigences, essai et étiquetage. Décembre 2018.

25. Shakantu, Winston, et al., The hidden cost of transportation of construction materials: An overview, Journal of Engineering Design and Technology 1(1):103-118, December 2003

26. Pisman, A., Vanacker, S. (2021). Diagnosis of the State of the Territory in Flanders. Reporting About New Maps and Indicators Differentiating Between Urban and Rural Areas Within Flanders. In: Smart and Sustainable Planning for Cities and Regions. SSPCR 2019. Green Energy and Technology. Springer, Cham.

27. Beleidsplan Ruimte Vlaanderen, https://omgeving.vlaanderen.be/nl/beleidsplan-ruimte-vlaanderen

28. Schéma de développement du territoire (SDT), https://lampspw.wallonie.be/dgo4/site_amenagement/amenagement/sdt

29. Bleby, Michael, Embodied water' is the latest challenge for the building industry, https://www.afr.com/property/commercial/construction-s-next-cost-challenge-embodied-water-20230328-p5cvvm

30. A. Janssen, L. Delem, L. Wastiels, and J. Van Dessel, Rapport n° 17 : Principes et aspects importants pour le choix de matériaux de construction durables, 2016

5. Acknowledgements and credits

This General Guide is a compilation by BC materials of the most recent research publications, technical approvals and experience in Germany and France, updated with specific extra research and experience by BC materials and BC Architects & Studies related to the Benelux context. It would not have been possible without the specific input of the following people. Thank you to

Deze Algemene Gids van Leem is een compilatie door BC Materials van de meest recente publicaties, technische goedkeuringen en ervaringen in Duitsland en Frankrijk, aangevuld met specifiek extra onderzoek en ervaring door BC Materials en BC Bouwkunde in betrekking tot de Benelux context. Het zou niet mogelijk geweest zijn zonder de inbreng van volgende mensen. Met dank aan

Dr.-Ing. Horst Schröder for his book "Sustainable building with earth" and his groundbreaking work on the EPD-framework for earthen building materials, and Ing. Stephan Jörchel of the Dachverband Lehm e.V. for his facilitation.

Dr.-Ing. Horst Schröder voor zijn boek "Sustainable building with earth" en zijn baanbrekende werk in het EPD-framework voor leembouwmaterialen, en Ing. Stephan Jörchel van Dachverband Lehm e.V. voor zijn facilitering.

This guide is funded by the EU – NextGenerationEU fund.

Deze Gids is gefinancierd door het EU – NextGenerationEU fonds.

Funded by the European Union NextGenerationEU

Gefinancierd door de Europese Unie NextGenerationEU

We have done our best to make all references of text and images in this guide. Please contact us at info@bcmaterials.org if you discover any text or images wrongly referenced or without references.

We hebben ons best gedaan om alle verwijzingen naar tekst en afbeeldingen in deze gids duidelijk te maken. Als een verwijzing wordt gevonden, kan BC materials worden bestraft door de auteur. Neem contact met ons op via info@bcmaterials.org als u tekst of afbeeldingen ontdekt waarnaar niet of verkeerd wordt verwezen.