Design Guide for Rammed Earth

Building with 100% earth

LEHM
TON
ERDE

Without question, building with earth can be complex. But it can also be quite simple. Because with every project we've had the privilege of implementing over the past decades, our understanding of the material and its properties has grown. What we've learned, we want to pass on in this design guide. To you. And to everyone who is ready to indulge in what is perhaps the most beautiful form of building. So have fun with it!

The principles in this guide apply to in situ and prefabricated building methods. Most importantly, they address building with unstabilised rammed earth. Mixing cement with rammed earth produces “dirty concrete.” It looks like rammed earth and is a little stronger, but the benefits end there. Adding cement to the mix removes all of earth’s natural advantages. CO_2 emissions increase enormously, the material can’t be recycled, and the walls no longer breathe. At Lehm Ton Erde we exclusively use 100% earth. No cement stabilisation is needed with good design!

Quick numbers

These rough figures are based on our experience and testing throughout many realised projects. They're good rule-of-thumb values. The real numbers will vary, though, depending on the excavated material. So when implementing a project, material testing needs to take place each time.

Thermal conductivity

λ = 0.9 W/mK

Average compressive strength

2.4 N/mm²

Minimum exterior wall thickness

350 mm

Minimum interior wall thickness

70 mm

Drying time

4–6 Weeks

CO_2 emissions from production*

46 Kg/m³

Fire classification

RE(I)90 for 25 cm wall thickness

Rated sound reduction index

53 dB for 20 cm wall thickness

Mass

2250 Kg/m³

Production energy*

930 MJ/m³

*Source: KBOB: Ökobilanzdaten im Baubereich 2009/1:2016.
URL: https://www.kbob.admin.ch/kbob/de/home/themen-leistungen/nachhaltiges-bauen/oekobilanzdaten_baubereich.html, accessed 02.02.2021.

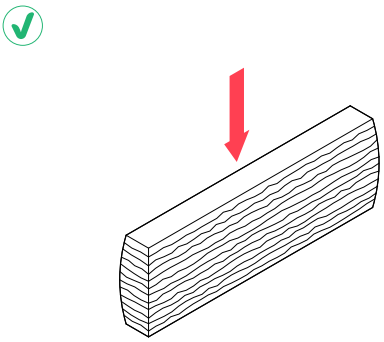
Contents

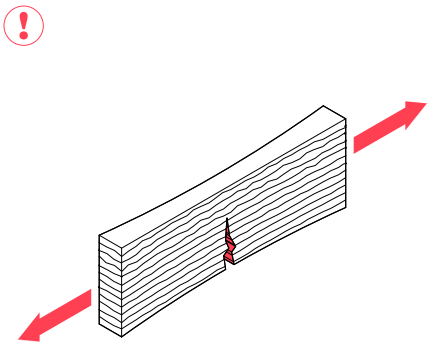
Statics

Rammed earth walls can be used like giant bricks. They are good to load in compression, you stack them to form walls, and openings need lintels.

Good under pressure

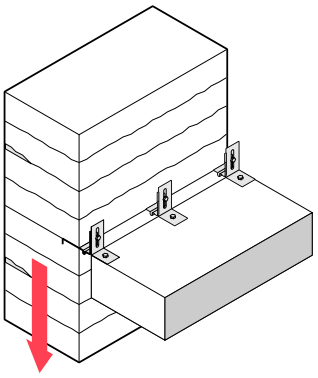
Rammed earth walls can absorb compressive forces very well. Statically, they function like unreinforced brick walls. Forces should be transferred as perpendicularly as possible to the compaction layers. Rammed earth's capacity to absorb tensile forces is negligible.

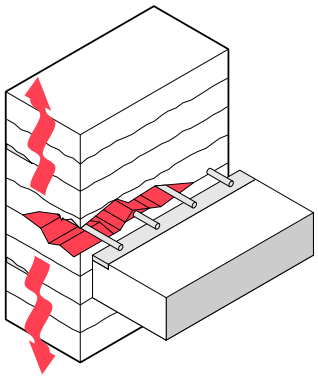




Creep at connections

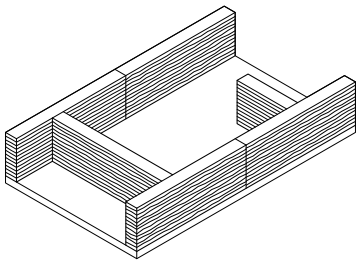
When connecting rammed earth walls to a different material, say a wooden floor structure, the different deformation behaviour of the materials must be taken into account. The earth will 'settle' which means movement. This will require a slip tie connection. This behaviour does not only occur in rammed earth, so a wide variety of solutions have already been established that can also be used.

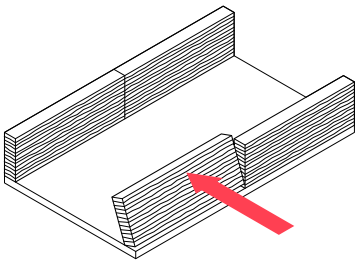




Shear walls, not columns

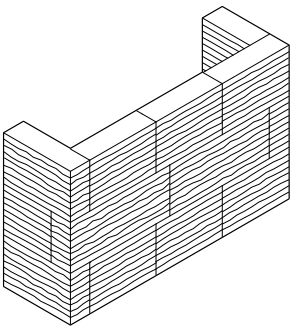
Rammed earth can achieve good lateral stability with suitable design. Columns of rammed earth don't work, but shear walls do. Combine them with ceiling slabs and buttress walls against each other – not necessarily parallel to each other – to achieve a solid construction.

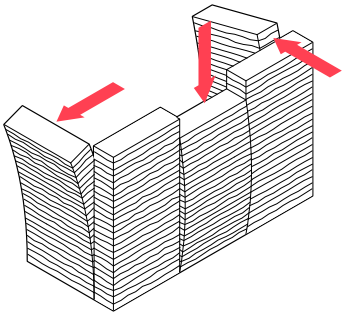




Masonry bond

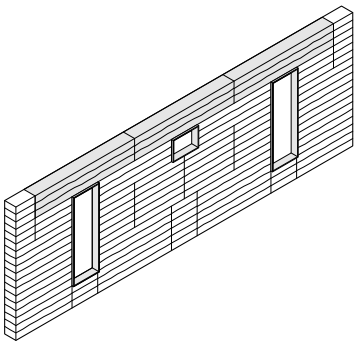
Similar to brick masonry, individual blocks of rammed earth should be laid in a bond. In order to achieve load distribution where point loads act, the blocks should be tied together with a ring beam or other detail.

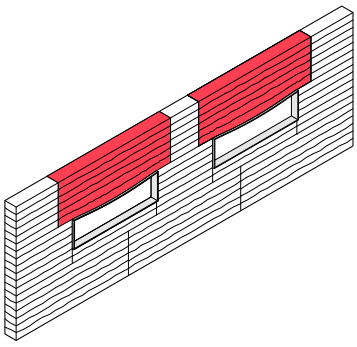




Openings

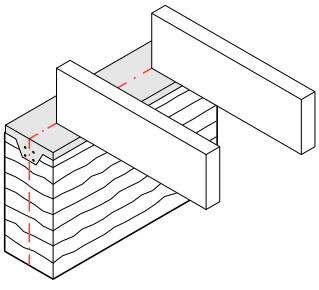
Because of the low tensile strength of rammed earth, lintel elements above openings must be reinforced. The load-bearing function of a lintel can also be performed by a concrete ring beam, for example. Larger opening spans means larger lintels, of course, which means more expense. However, lintels can be concealed within and behind the earth surface.

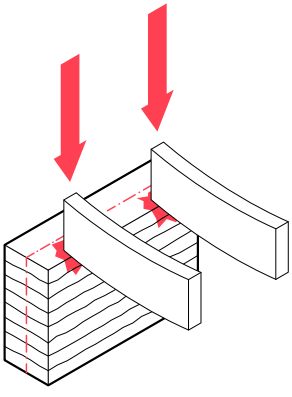




Direct forces through the centre

Point loads acting directly on rammed earth should be avoided since they can cause local stress peaks. Also, the load-bearing capacity of a rammed earth wall can be significantly reduced by off-centre loading. One tested solution is a ring beam, usually made of concrete poured into a channel at the top of a wall. This distributes loads and increases stability.



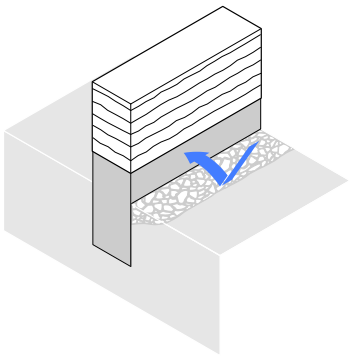


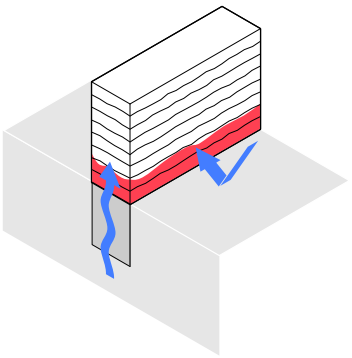
Weatherproofing

Rammed earth is essentially water soluble, so it is also easy to recycle. But it also means that walls need good boots and a good hat for protection.

Good boots

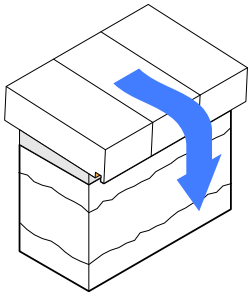
Waterlogging destroys the structure of rammed earth and the strength of the walls. Therefore, earth walls should be set on an plinth above ground to prevent water ingress. The upstand should act as a splash back and rise 20-40 cm above ground level. Ideally, a substrate capable of drainage should be placed along the base to reduce splashing.

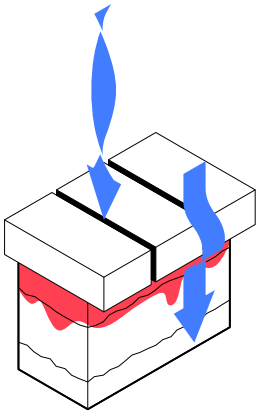




A good hat (with brim)

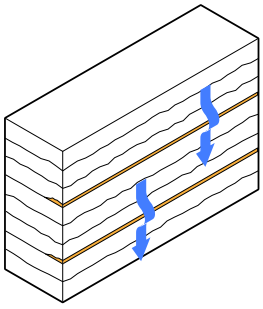
To prevent moister penetrating the core of the wall, a DPC, bituminous coating or flashing needs to introduced under a roof connection or coping. An overhang with a dip gap provides additional protection from water running down the face of the wall. The wall surface can be allowed to moisten as it will dry, however, no water can be allowed enter deep into the rammed earth.

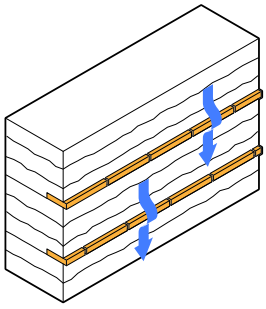




Erosion breaks. Water brakes.

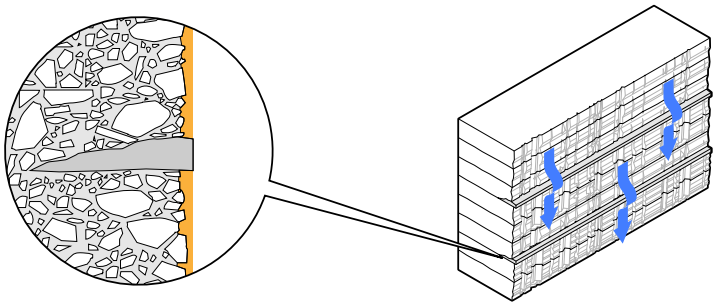
Water flowing down the wall surface washes out clay particles over time. The higher the velocity of the water, the greater the erosion. To reduce this, *erosion checks* are introduced that form a hard lip to channel water away from the surface, dripping away onto the ground. These checks can be a layer of trass-lime concrete or embedded tiles and should be placed every 40-50 cm.





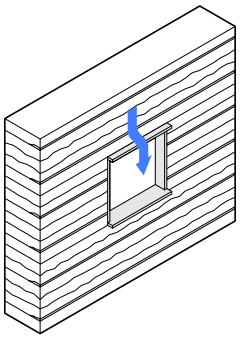
Calculated erosion

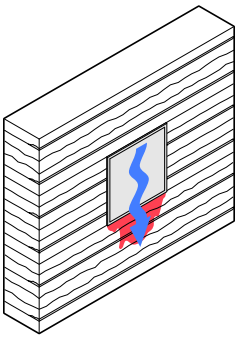
As an exterior rammed earth erodes, the fine particles wash out and larger aggregate becomes exposed. This increasingly uneven wall surface causes water to lose speed and the erosion rate decreases sharply. Eventually, after several years, the erosion rate will cease altogether as the larger embedded aggregate protects the finer material within. Erosion is controlled by design.



Protection by design

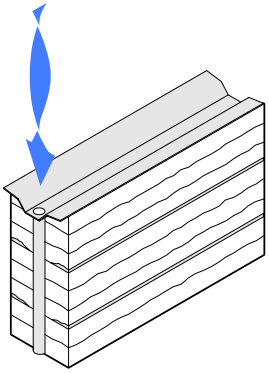
Water running off surfaces such as windows needs to be slowed down. Inset glazing, eaves or overhangs at openings, and sills with dips gaps are good detailing practices. These elements to be well protected from waterlogging too. In any place where water can accumulate, waterproofing elements should be planned.

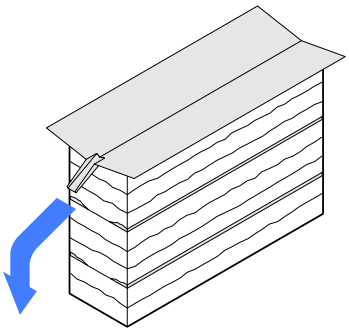




Rain and gutter

Rainwater must always be drained away, ideally via gutters or water spouts. Drained water must not splash back onto the rammed earth wall. Downpipes can be integrated into the wall. Any capping or coping should feature an overhang and a DPC or bituminous coating at the interface with the earth.



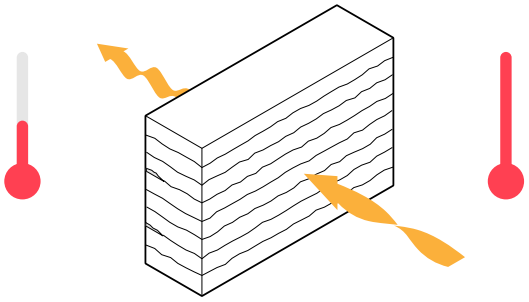


Building physics

Rammed earth walls have a lot of thermal mass allowing them to passively regulate the extremes of indoor temperatures. They also absorb and diffuse humidity to a comfortable 55%.

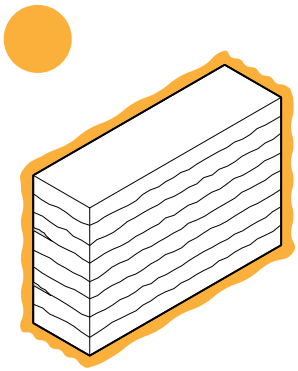
λ-value

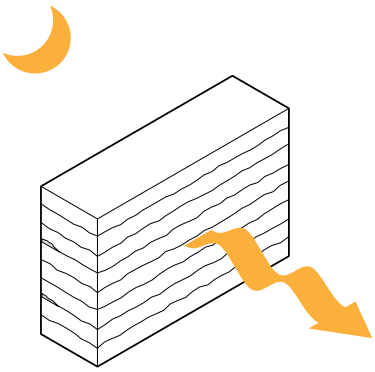
The thermal conductivity coefficient of rammed earth walls is comparable to concrete, roughly 1 W/mK. Walls must be additionally insulated if they are used as exterior walls to fulfil guidelines.



A solar energy battery

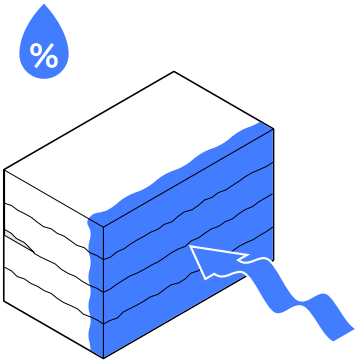
Having high thermal mass, rammed earth can store a lot of heat. This helps reduce overall energy consumption from indoor climate control. Rammed earth walls act as a "heat buffer", flattening the peaks in daily temperature extremes. Indoor temperature is cooler during the day and that stored heat is slowly released as warmth during the night.

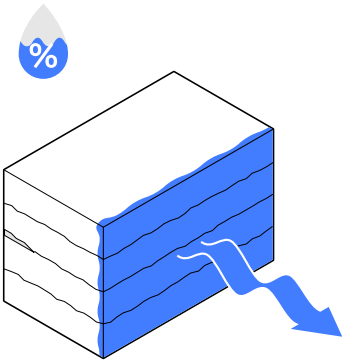




Passive humidity control

In addition to heat, rammed earth can also store moisture. The first few centimetres of the earthen surface act like a sponge. When humidity is high indoors, the wall soaks up excess moisture to roughly 55% humidity and likewise releases this moisture back into the room air when the humidity is low. This is optimal for thermal comfort and respiratory health.

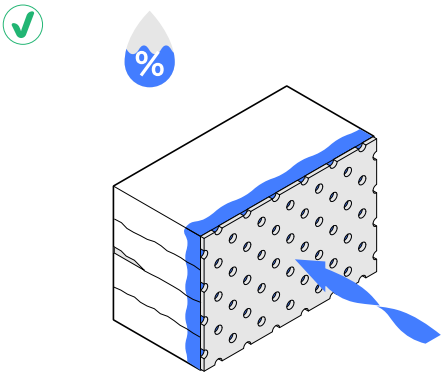


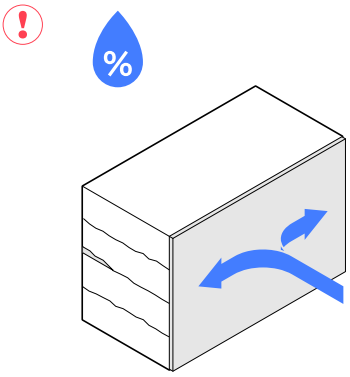


Building physics

Water vapour permeability

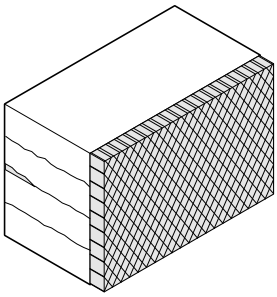
Since rammed earth walls can absorb moisture, additional wall membranes such as a vapour control layer must be open to diffusion to retain earth's moisture-regulating properties. Layers such as vapour barriers can lead to condensation and even structural damage and should therefore be discussed with a building physicist.

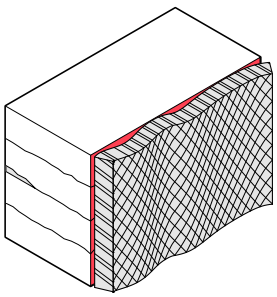




Good bond with other materials

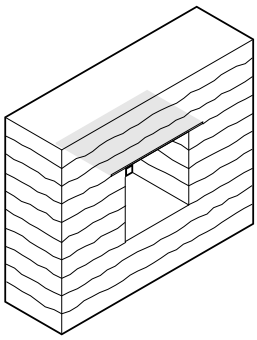
When insulating, make sure that an insulating material is used that can permeable to moisture. It should also be installed in such a way that there are no air gaps between the insulation and the rammed earth wall.

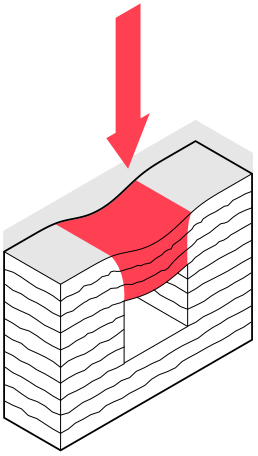




Creep & Shrinkage

Like other building materials, rammed earth is subject to creep deformation or cold flow under persistant loads. Shrinkage occurs immediately after production while the earth is drying. Creep occurs slowly after when the heavy load of the wall compresses the material below it over time. Deformation due to shrinkage and creep must be taken into account during planning.



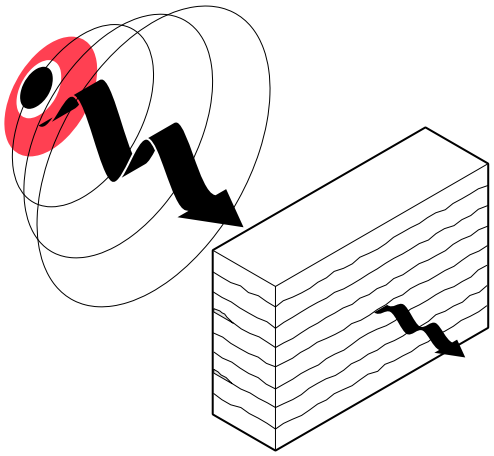


Acoustics

Rammed earth has very good acoustic properties. It provides excellent sound insulation between rooms and reduces echo indoors.

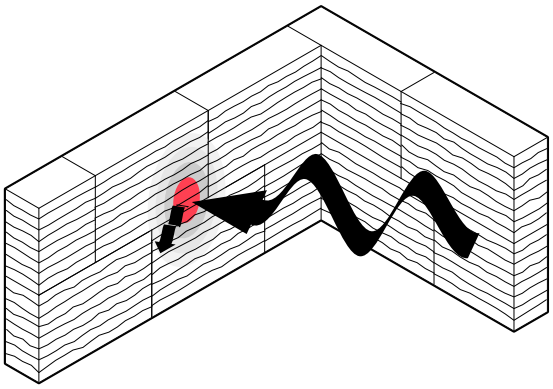
Sound absorbing

Rammed earth has very high sound insulation values due to its high mass and density. Similar to concrete, acoustic requirements can easily be met when detailed in established ways.



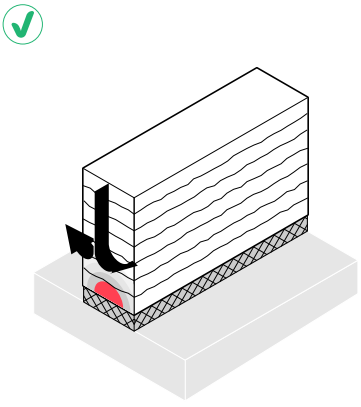
Space and reverberation

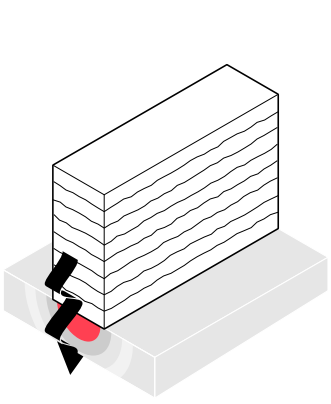
Due to the properties of the material mix and clay binding, rammed earth has a high surface area and constituents of varying hardness. This makeup offers great advantages for room acoustics. A rammed earth wall can significantly reduce reverberation and echoes within a space.



Sound transmission

The high density of rammed earth means that transmission of structure-borne sound is high. Therefore, as with concrete or brick, juntions may need to be acoustically decoupled from each other.



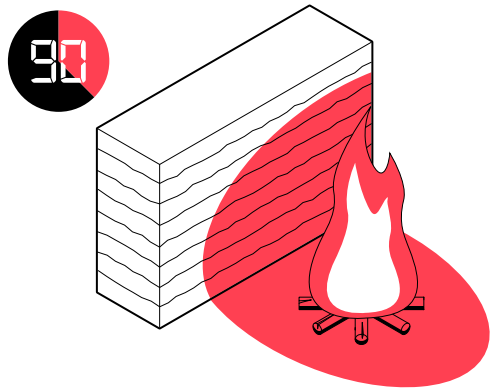


Fire safety

Earth is a non-combustible material. Various rammed earth designs have met all the required fire resistance regulations.

Combustibility

Rammed earth building elements are able to meet the highest fire protection requirements according to OIB guidelines. A 25 cm thick rammed earth wall has a fire resistance class of RE90. We've tested our rammed earth walls are they're very well suited for building standards. Tests have achieved a European classification of EN 13501 for fire resistance.

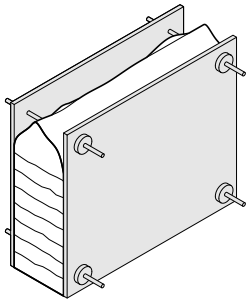


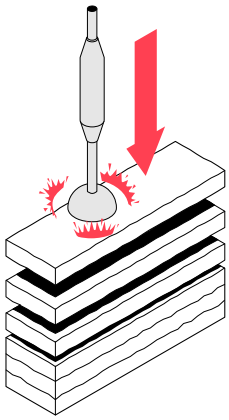
Production process

Rammed earth walls are produced in formwork, similar to concrete walls. They can be made in situ or prefabricated, transported, and craned into position.

Layered production

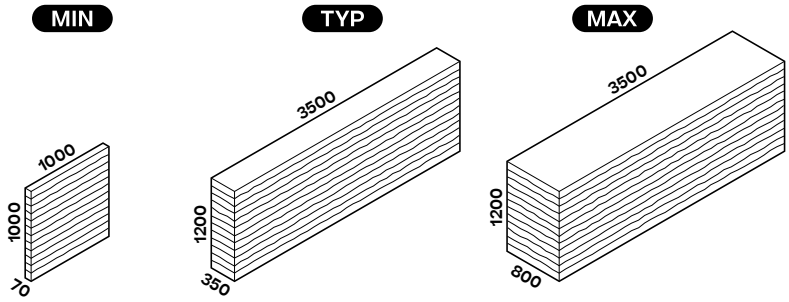
Rammed earth is produced in layers. During the process, loose, earth-moist material is poured into the formwork and compacted to about 10 cm layers. This is then repeated to the full element height. While formwork requirements are similar to that of concrete, planning for production must account for high ramming forces and accessibility within formwork.





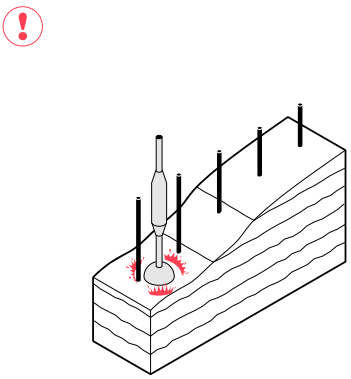
Typical element size

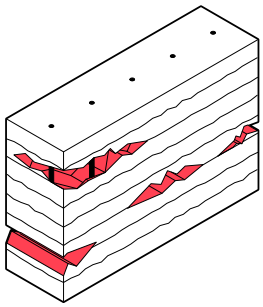
Wall element sizing depends heavily on the application and transport. A panel height of up to 1300 mm and a total weight of less than 4 tonnes per element is the ideal to facilitate transport and installation.



Don't use steel reinforcement

Rammed earth walls do not require internal steel reinforcement. Any vertical elements within walls disrupt the ramming process and must be avoided. Steel can also lead to cracking in the wall during the drying process and through thermal expansion.

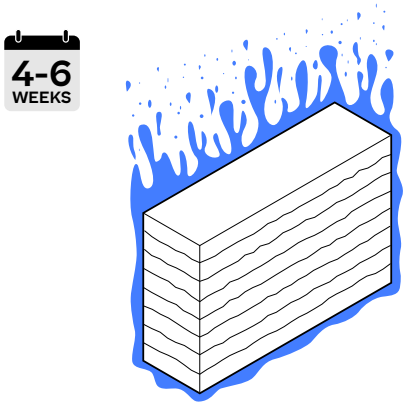




Production process

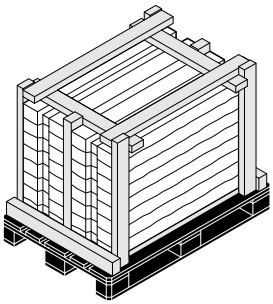
Drying time

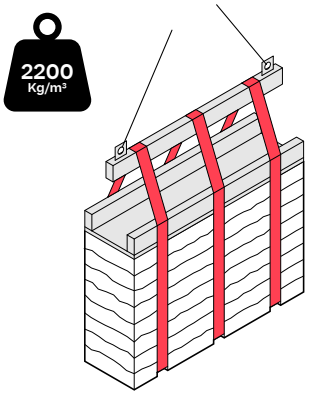
Rammed earth is produced in a moist state. This means prefabricated elements need to be stored and in situ walls need to be built in stages to allow them to dry and reach full strength. Depending the thickness, walls usually need 4-6 weeks of drying time, after which they can be moved, in the case of prefabrication, and loaded.



Weight and transport

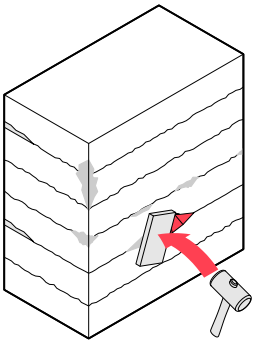
Rammed earth has a high density, similar to concrete. Individual elements are, therefore, massive and heavy. Element size must be taken into account and coordinated during design phases so that no complications with transport and assembly occur further down the track during the construction process.

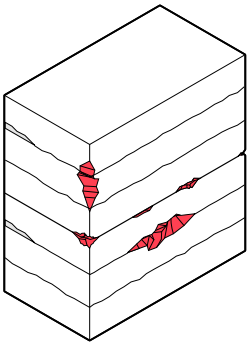




Retouching

Where elements join or imperfections appear, retouching is done to close the surface and give it a seamless finish. Gaps can be filled in and corners can be made sharp by hammering in loose earth-moist material. This gives rammed earth its characteristic continuous appearance. Since our rammed earth is not stabilised with cement, it can be retouched at will, even years later.



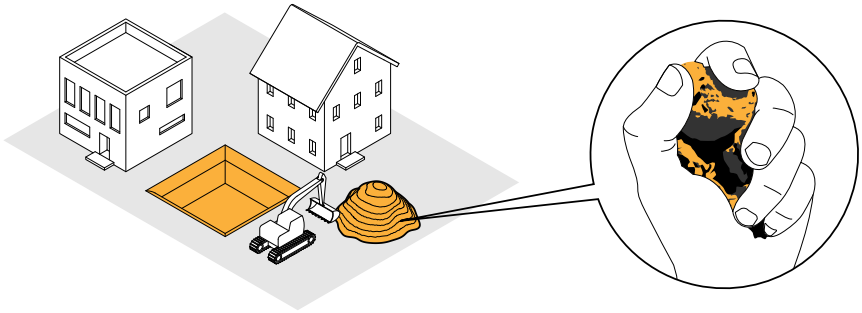


Material

Excavated material varies greatly in makeup which is why we carry out extensive quality management and testing. We have the material characteristics determined by laboratories on an ongoing basis. The material properties we offer here can be used as a guide, but are subject to a certain degree of variation.

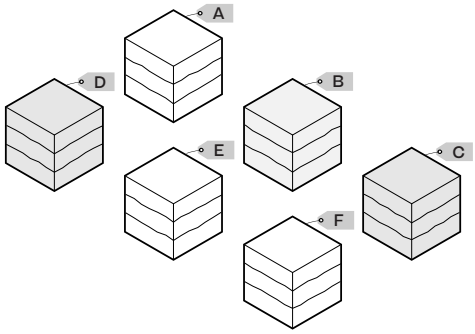
Material procurement

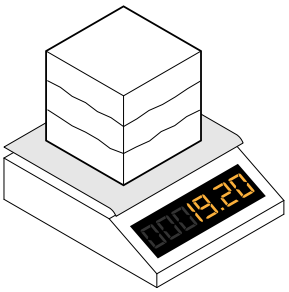
Material can come from site-won excavation or sourced from local suppliers such as quarries. The material is initially examined for composition, building suitability, the grading of aggregates, and the binding capacity of the clay, amongst other factors. If suitable, the material is then processed – sieved, mixed, rested, etc. – according to the needs of the project.



Optimising the material mixture

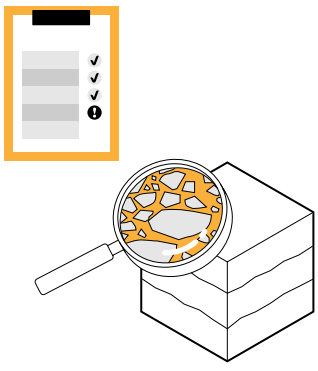
With suitable excavated material, the optimal mixture is then determined through testing. We verify moisture content, compressive strength, and erosion resistance. The excavated material is tweaked with clay, fines and different aggregates to meet requirements. The test blocks created also serve as samples surface finish and colour.

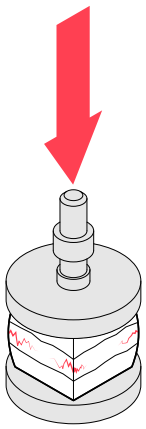




Testing and verifying the mixture

Optimising and testing of the mixture is repeated diligently until the ideal material recipe is found. The recipe is tested again by a certified laboratory in compliance with the current testing standards to verify the material properties we have specified. Engineers can begin calculations using the values offered in this guide and then confirm them against lab results.





Thermal conductivity

λ = 0.9 W/mK

Average compressive strength

2.4 N/mm²

Maximum permissible compressive stress

0.34 N/mm²

Shrinkage

0.25 % to 1 %

Creep dimension

0.2 %

Thermal expansion

0.005 mm/mK

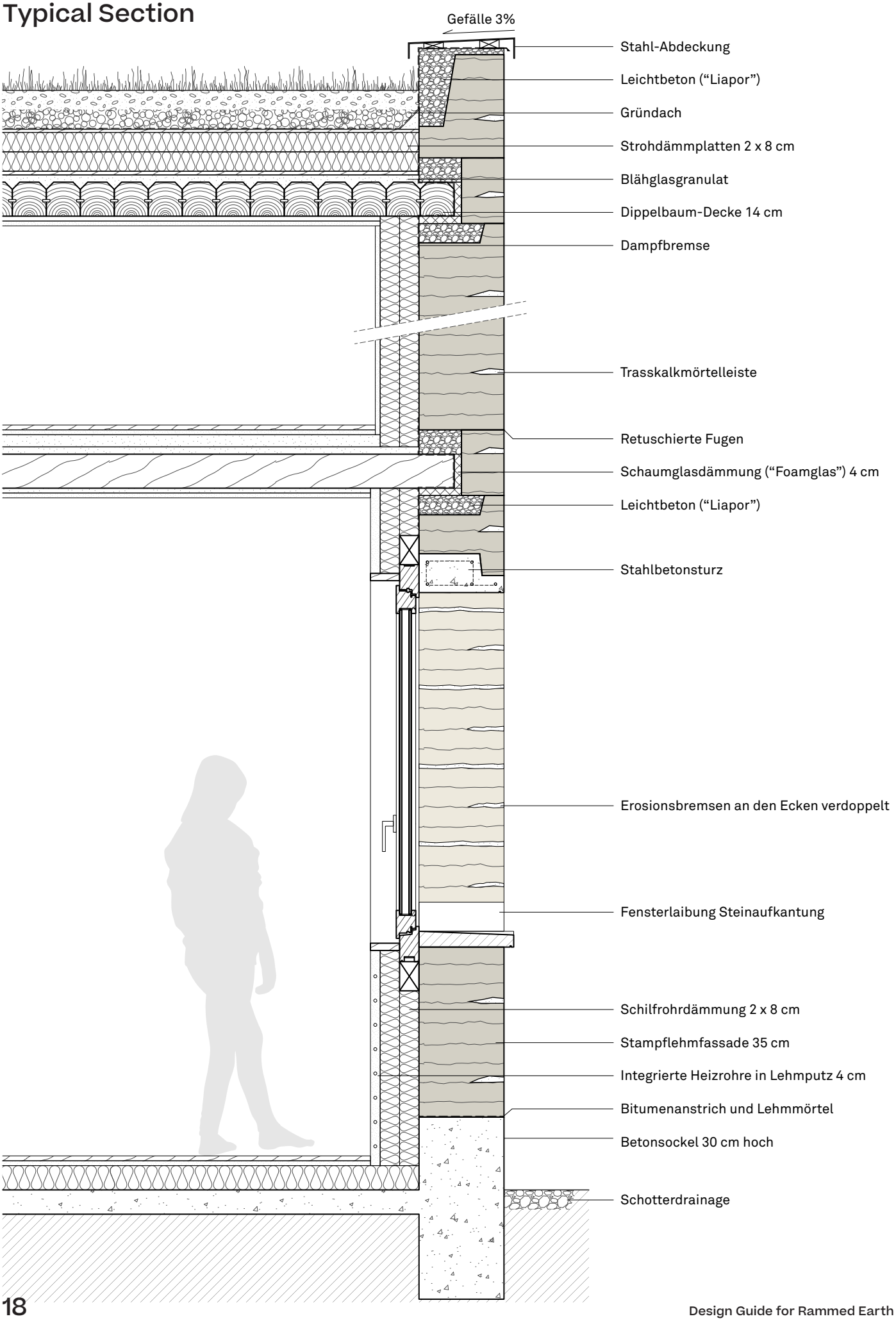
Rated sound reduction index

53 dB for 20 cm wall thickness

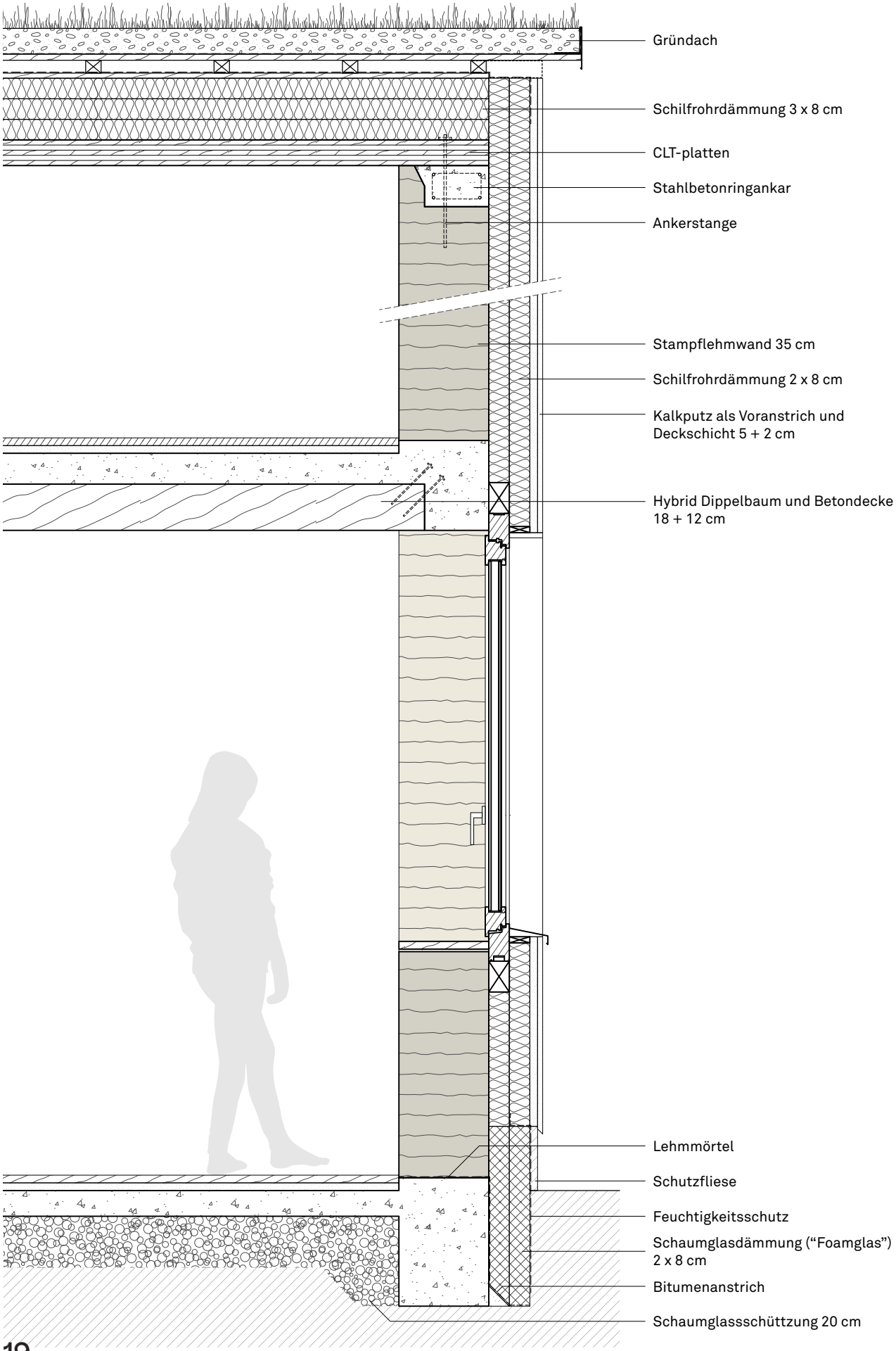
Fire classification

RE(I)90 for 25 cm wall thickness

Typical Section



Typical Section



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