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QuAD

Quaderni di Architettura e Design

Dipartimento di Scienze dell'Ingegneria Civile e dell'Architettura – Politecnico di Bari

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Terra cruda e scarti agricoli
Materiali edili efficienti made in Puglia

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Edizioni Quasar di Severino Tognon s.r.l., via Ajaccio 41-43, 00198 Roma (Italia)
http://www.edizioniquasar.it/

ISSN 2611-4437 · eISBN (online) 978-88-5491-096-6

Tutti i diritti riservati

Come citare l'articolo:

Stefania Liuzzi, Francesco Martellotta, Pietro Stefanizzi, *Terra cruda e scarti agricoli. Materiali edili efficienti made in Puglia,* QuAD, 3, 2020, pp. 229-241.

Gli articoli pubblicati nella Rivista sono sottoposti a referee nel sistema a doppio cieco.

3|2020 Sommario

Recensioni

Design

Terra cruda e scarti agricoli

Materiali edili efficienti made in Puglia

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Loam is one of the most common material worldwide available for the building constructions. Nowadays one third of the global population lives in earthen houses. From Scandinavia to Equator the earthen buildings are located in different climatic contexts. In the developing countries, where the self-building constructions are a necessity, the unbaked earth is a low cost consolidated tradition, easily to access. However, in the industrial contexts, mortars, plasters, covering panels, earthen bricks represents a revival for the building construction of efficient and sustainable buildings. Clay is now reconsidered for the hygrothermal performances of the final building materials. Microstructure, type of clay and the additives strictly influences the final performances of the earthen materials. Ongoing studies at Building Physics Laboratory (ICAR Department of Polytechnic University of Bari) demonstrated that in Mediterranean climate can be realized high efficiency building materials using clay as binder and vegetable fibers as lightweight additives (i.e. straw, olive waste). The comparison with the materials currently available on the market highlights that the unbaked earth as indoor covering material can significantly enhance the comfort in the residential environments.

L'argilla è uno dei minerali più comuni presenti nel terreno e la più antica materia prima usata nella costruzione di abitazioni. Nei contesti in via di sviluppo la terra cruda resta una tradizione consolidata a basso costo e facilmente accessibile. Nei contesti più industrializzati, invece, intonaci, pannelli da rivestimento, blocchi in argilla rappresentano un revival di nicchia per la realizzazione di edifici sostenibili ed efficienti al tempo stesso. L'argilla è stata rivalutata oggi per le sue proprietà termoigrometriche. La microstruttura e il tipo di argilla oltre agli additivi presenti influenzano enormemente le prestazioni finali dei composti in terra cruda. Studi in corso presso il laboratorio di Fisica Tecnica del dICAR (Politecnico di Bari) hanno dimostrato che in clima mediterraneo si possono realizzare materiali edili ad elevate prestazioni termoigrometriche adoperando la terra cruda come legante di base e gli scarti agricoli locali (es. paglia, scarti di potatura degli ulivi) come componenti alleggerenti. Il confronto con i materiali attualmente presenti sul mercato, consente di affermare che l'impiego dell'argilla "cruda" nei rivestimenti interni degli edifici può contribuire a migliorare significativamente il comfort indoor degli ambienti domestici.

Keywords: *earthen materials, sustainable buildings, Mediterranean area, lightweight earth*
Parole chiave: *materiali in terra cruda, edifici sostenibili, area mediterranea, terra alleggerita*

▪ *Earthen architecture: a tradition from the past to the present*

Earth, recognized as one of the most important building materials, is rediscovered nowadays for its sustainability, on one hand, and for its hygrothermal properties, on the other hand. Clay is one of the most common mineral present in loam and the main ancient raw material used in dwellings. Even today one third of the human population lives in earthen houses.

Earth, used as building material, is an ancient tradition, known for over 9000 years. Pumpelly[1] has reported that mud brick (adobe) houses dating from 8000 to 6000 B.C. have been discovered in Russian Turkestan; Minke[2] stated that rammed earth foundations dating from ca. 5000 BC have been discovered in Assyria. Several earthen building techniques exist:

- rammed earth;
- lightweight earth;
- earthen blocks;
- plasters.

In all hot-arid and temperate climates, earth has always been the most prevalent building material, thus one third of the human population resides in earthen houses.

Newly developed, advanced earth building techniques demonstrate the value of earth not only in do-it-yourself constructions, but also for constructions in industrialized countries. Building with earth in Italy is a consolidate tradition, known since 500-400 B.C. In Sardinia were found the first examples of nuragic age. Vitruvio reporting the term "lateres" referred to unfired clayey bricks. He described the mechanical strengths and the improvement of the indoor comfort.

In 40ies earthen constructions were left due to the economic boom. At that time most dwellings were agricultural; however several buildings were placed in urban area of Sardinia. Bertagnin[3] has stated that:

> The different researches for different geographical areas (...) highlighted absence or limited presence of proof about unfired clay use (...). It seems possible to suppose the absence of building tradition of unfired clay in some regional areas, as a consequence of an undoubtedly different and diffuse material availability but also of a lack or lost cultural influence of unfired clay[4].

Several rural buildings can be found in Abruzzo (Chieti, Pescara, Teramo) and in Molise were cob is the main technique. Other significant examples are placed in Veneto and Friuli Venezia Giulia where single-storey buildings were built in adobe with wooden roofs, covered by straw. Also in Piedmont and in Sardinia, where *ladiri* are used, can be found some dwellings built with earth. One of the main common technique used in the Mediterranean area is the lightweight earth adopted as indoor plaster in order to dump the relative humidity fluctuations. In South Italy, Calabria is one of the region with the largest number of these traditional constructions.

Fig. 1. Earthen building at Valle D'Itria (Apulia Region, Italy). (photo M. Ferrarelli for TerraBuildingdesign).

Depending on the site where the loam is extracted, it will be composed of different amounts and types of clay, silt, sand and aggregates. Thus, the final performances of the building products may differ from site to site, and also the preparation of the blend for a specific application may differ (*fig. 1*).

▪ *Earth-based building materials performances*

Microstructure, type of clay phases, additives strictly influence the final performances of earthen materials.

Different researchers described clay[5]. A universal interpretation of the term *clay* leads up to assert that it is a natural, earthy, fine-grained material that develops plasticity when mixed with a limited amount of water. Shaw & Weaver[6] reported the modal mineralogical composition considering the following components: 60% clay minerals, 30% quartz and chert, 5% feldspar, 4% carbonates, 1% organic matter, 1% iron oxides.

Generally, soils are classified by particle size distribution "grading"[7]. The physical and chemical properties of a particular clay mineral depend on its structure and composition. Referring "earth" by a scientific term, it means a basic mixture of clay, silt (very fine sand), sand, and occasionally larger aggregates such as gravel or stones. Clay, containing microscopic attractive particles, acts as a binding agent holding together the larger particles of sand and gravel within the earth mixture. The raw material is commonly obtained directly from the building site when executing excavations for foundations or basements at 1-1.5 m deepness. It can be also produced by mixing the raw components together with a specific amount of water. Currently, the scientific research is directed towards building techniques and materials that have less impact on the environment than modern building materials like concrete and fired clay; thus earth has once again emerged as a sound and practical alternative.

Fig. 2. Life cycle of earthen materials (Liuzzi, Rubino, Martellotta 2020).

Nowadays, earth is rediscovered worldwide for its sustainability and the capacity to assure high comfort level in indoor environment. The life cycle of earthen materials is shown in *figure 2*.

Earth can't be considered a standardized building material. Minke[8] has argued about advantages and disadvantages by using earth for the constructions (*tab. 1*).

▪ *Experimental analysis at Polytechnic University of Bari. Lightweight clay and earth blocks*

One of the most common technique adopted since ancient time is lightweight earth. When preparing lightweight earth, the basic mixture (loam) is mixed with additives (straw, sawdust, woodchips, pumice, expanded clay) forming aggregates to create light insulating walls/bricks. One of the main fiber added to achieve the lightweight loam is the straw. This is a revision of the traditional technique, *torchis,* used to fill the walls of the houses with a wooden load-bearing structure (*colombage* or *Fachwerkhaus*). There is a worldwide debate over which type of straw is most suitable and it should be tested in each case.

Disadvantages of earth	
It is not a standardised building material	It is composed of differing amounts and types of clay, silt, sand and aggregates, influenced by the place in which it is extracted. This can influence the final performances of the product.
It shrinks when drying	Due to evaporation of the water used to prepare the mixture (moisture is required to activate its binding strength and to achieve workability), shrinkage cracks can occur.
It is not water-resistant	It must be sheltered against rain and frost, especially in its wet state.

Advantages of earth	
It balances air humidity	It is able to absorb and desorb humidity faster and to a greater extent than any other building material.
It stores heat	Like all heavy materials, loam stores heat.
It saves energy and reduces environmental pollution	Preparation, transport and handling of loam on site requires only ca. 1% of the energy needed for the production, transport and handling of baked bricks or reinforced concrete.
It is always reusable	Old dry loam can be reused after soaking in water, so it never becomes a waste material that harms the environment.
It saves material and transportation costs	Clayey soil is often found on site, so that the soil excavated for foundations can then be used for the earth construction.
It preserves timber and other organic materials	Loam conserves the timber elements that remain in contact with it by keeping them dry.
It is ideal for do-it yourself construction	Earth construction techniques can usually be executed by non-professionals people.
It absorbs pollutants	It is a fact that earth walls can absorb pollutants dissolved in water.

Tab. 1. Advantages and disadvantages of earth as building material. (Adapted from Minke *2006).*

Fig. 3. Lightweight earth house at Valle D'Itria (Apulia Region, Italy). (photo M. Ferrarelli for TerraBuildingdesign, 2020).

This technique was gradually developed over the last two decades in Europe (primarily in Germany) as response to a better insulation. When creating walls, a structural wooden frame is used. In general, the addition of stabilizers (like cement, lime, bitumen) is used to improve compressive strength of the materials and the water resistance of the building elements. The increase of mechanical strength is mainly influenced by the stabilizer content (*fig. 3*).

For earthen plasters vegetable fibers have proved to be the most suitable, having a softer consistency than the other type of straws.

The main function of the fiber is to create an internal grid inside the mixture reducing the density (ρ_{dry}) of the final products. This allows to achieve better thermal insulation (lower λ_{dry}) and higher hygric performances in terms of water vapour resistance (μ).

The more fiber percentage added to the mix, the higher hygrothermal performances and lower compressive strengths are achieved.

Earth blocks can be extruded in a brick factory or produced manually. Blocks of earth produced manually, by throwing wet earth into a steel/wooden mould, are called *adobe* or *mud bricks* or *sun dried earth blocks*. When compacting them by ramming they are called *rammed earth blocks*. The production process can be manual or mechanical with or without compression. Commonly the size of these blocks are the same of the fired bricks. Some countries adopted different standard measurements. There are three ways of producing earth bricks: *moulding*, *extruding* and *pressing*. When *moulding,* the formworks are placed on the ground, filled with wet earth mix and leveled off, before the moulds are lifted. The earth must be sufficiently wet to allow it to be easily worked into the mould,

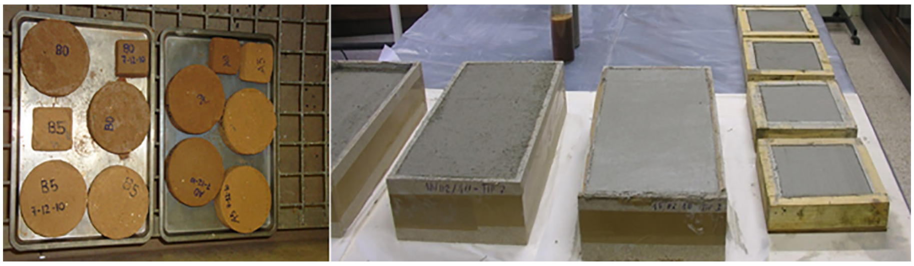

*Fig. 4. Earth bricks with different clays realized at ICAR Department of Polytechnic University of Bari (*Liuzzi *2012).*

Fig. 5. Raw materials used for mixtures.

but not so wet that the brick will slump when the mould is lifted. The moisture content of hand-moulded bricks at manufacture is commonly around 15–20%.

One of the most common moulded brick is known as adobe. The term adobe comes from *thobe* (brick in Egyptian) and it has become adobe in Spanish. They were used especially in the Americas of Spanish origin. In Italy some buildings, made with adobe, can be found in Sardinia, Abruzzo and Piedmont. *Extrusion* is the most common term used for fired brick production. The earth is forced into a die, usually followed by wire cutting on a conveyor belt process. The bricks are produced in mass. *Pressing* earth bricks means producing by small transportable manual and hydraulic mechanical press machines the building blocks. Sizes are usually similar to the concrete blocks. By compaction, a denser and drier product than by hand moulding or extrusion is produced. The final building products have greater compressive strength and durability. Significant quantities of fibers can rarely be included in pressed mixes. Moisture content at the time of manufacture is commonly 6–10% (*fig. 4*).

Different experimental studies were carried out at Building Physics Laboratory (ICAR Department of Polytechnic University of Bari) on clay-based plasters with different kind of local vegetable fibers and on earth blocks. Straw, leaves and the small branches derived from the pruning of olive trees were incorporated, after drying, into a clay-sand mixture to obtain a bio-based plaster[9]. Also lime was used (stabilized plaster). The overall goal of the study was to increase the knowledge of clay plasters looking into the hygrothermal behaviour and the mechanical performances of different unfired clays. Thermal and hygric parameters were experimentally measured: thermal conductivity, specific heat capacity, sorption capacity, water vapour permeability. Furthermore, in order to test the suitability of the unfired clay as mortar, an analysis on the mechanical strengths was carried out, measuring the compressive and the bending strength.

Tab. 2. Hygrothermal parameters of lightweight earth and earth bricks (LIUZZI 2012).

Parameters	Value
ρ_{dry} (kg/m^3)	
(lightweight earth with straw)	500-1000
(lightweight earth with olive waste)	1009-1700
(earth bricks)	1200-1400
λ_{dry} (W/mK)	
(lightweight earth with straw)	0.190-0.093
(lightweight earth with olive waste)	0.428-0.593
(earth bricks)	0.280-0.550
μ (-)	
(lightweight earth with straw)	4.2-5.0
(lightweight earth with olive waste)	6.5-8.3
(earth bricks)	7.2-9.4

The results achieved (*tab. 2*) show that when vegetable fibers are added to the basic mixture a significant improvement of the sorption capacity occurs, while, the addition of lime enhances the thermal properties. On the other hand, any significant improvement of mechanical strengths can be noted when using additives (*fig. 5*).

▪ *Hygrothermal building simulations*

Several studies[10] have argued the improvement of the indoor comfort when using an unfired earthen building material. Padfield[11] has demonstrated a good buffering capacity of the unbaked clay tiles in comparison with other traditional materials. Unbaked earth shows a great capacity to absorb and release the moisture in an internal environment when relative humidity changes.

Allinson and Hall[12], analysing the hygrothermal behaviour of the rammed earth walls of a single storey building, have found that by using earth as building material high hygric performances can be achieved. Minke[13] carrying out several experiments on earthen building materials, has found that earthen materials are able to achieve equilibrium moisture content faster than other traditional materials.

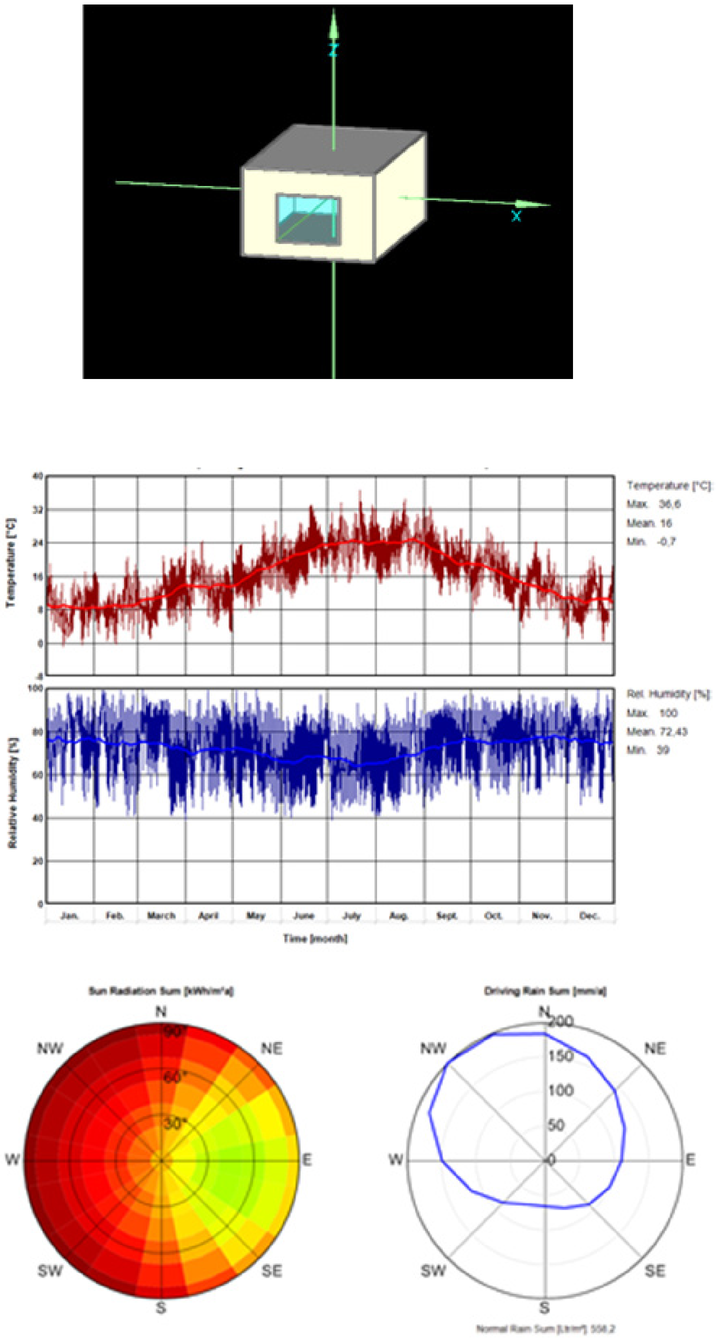

Fig. 6. TESTROOM in Mediterranean Area (Bari).

Earthen materials can absorb a great water content. Furthermore, a great difference can be seen when different-clay based mixtures are taken into account. Bentonite which has 70% montmorillonite, at 50% RH, has an equilibrium moisture content (13%) ca. twenty times greater than kaolinite at same

Tab. 3. Yearly energy demand for conditioned scenario [kWh].

	Humidification	*Dehumidification*
Earth Bentonite	58.88	31.39
Straw Clay	61.69	34.68
Gypsum	68.26	37.89
Acrylic Stucco	78.59	52.68

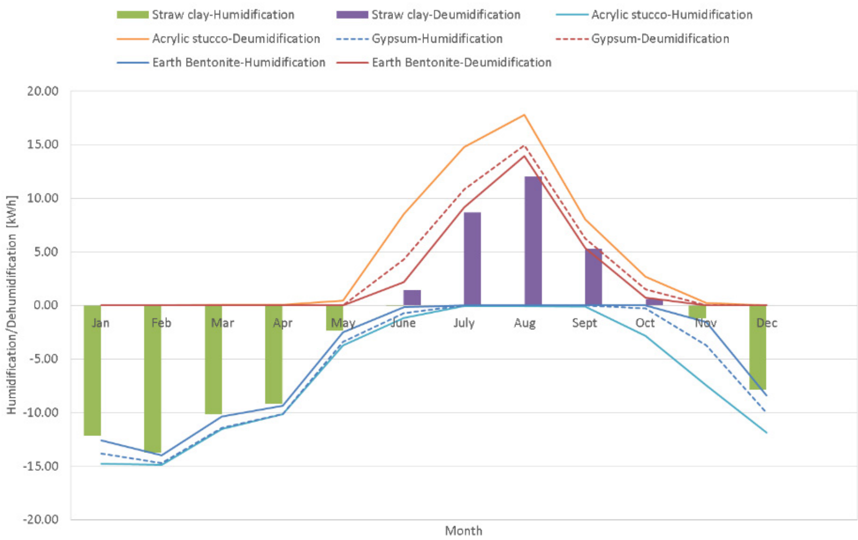

Fig. 7. Montly energy demand for humidification/dehumidification [kWh].

boundary conditions (0,7%). Comparing the water vapour diffusion resistance coefficients, Minke[14] has found that earthen building materials show high capillarity; thus, they are able to avoid fungus growth and formation of internal condensation in walls. When changing the basic mixture composition (percentage of clay/silt, sand, gravel) a significant difference can occur in terms of the water vapour resistance coefficient (μ). Furthermore, the addition of fibers (like straw) allows achieving the lowest resistance μ. Thermal insulation strictly depends on the technique and the raw materials used. As a general interpretation the lighter the material (low density) the higher its thermal insulation and the greater the water content that can be absorbed. The porosity of the material, influencing the volume of air entrapped in the pores, determines the water absorption rate, on one hand, and the thermal conductivity, on the other hand. Therefore, when considering earth blocks, got by compaction, high density value is achieved and the thermal conductivity is very high.

Commonly, lightweight earthen materials can achieve the lowest thermal conductivity value. However, also the addition of lime can cause a significant improvement of thermal insulation, generated by the interaction of clay-lime.

In order to consider the potential of earthen materials to improve indoor comfort the software WUFI+ was used to simulate the hygrothermal behavior of a TESTROOM, placed in a Mediterranean climate (Bari) (*fig. 6*).

The TESTROOM was supposed to be a double bedroom. It was occupied 7 days a week by two occupants at rest, during the night, between 11.00 p.m. to 9.00 a.m., and one occupant at rest, in the afternoon, between 3.00 p.m. and 5.00 p.m. For each user the convection heat transfer was supposed to be 65 W, radiation heat transfer was set as 36 W and the water vapor rate produced in the room was supposed of 43 g/h. Furthermore, the air change rate was set as 0.3 Vol/h. The analysis was carried out considering four different cases. It was supposed that the internal surface of the walls of the building was covered by an earth plaster, an earth bentonite panel, a gypsum plaster and an acrylic stucco plaster. Results, shown in (*tab. 3*) and (*fig. 7*), demonstrated that the earthen materials lead up to a greater improvement of the hygric performances, unlike traditional plasters as stucco and gypsum. The earthen materials allow to achieve a significant energy saving up to 27% reduction for yearly humidification and 52% reduction for yearly dehumidification comparing to Acrylic Stucco.

▪ *Conclusions*

The overall goal of the paper was to show that unfired earthen materials have excellent hygrothermal performances in comparison with traditional ones. The sustainability of earthen materials is demonstrated by their use since over 9000 years.

The experimental analysis at Polytechnic University of Bari, carried out on different basic mixtures, aimed to increase the current knowledge on earthen materials used on sustainable buildings.

The indoor climate of a TESTROOM in a Mediterranean climate context was modeled using a simulation software. The hygrothermal parameters of the earthen building materials were taken from the laboratory measurements results. The experimental tests and the numerical simulations show that the earthen plasters can significantly damp the amplitude of relative humidity fluctuations in comparison with the traditional materials with increased surface diffusion resistance.

Moreover, the results of the model demonstrated that the earthen coatings can greatly absorb the moisture in the room when a moisture generation occurs (e.g presence of people) and, conversely, release it when the room is unoccupied.

Further investigations are ongoing about the optimization of the performances of the earthen materials for outdoor application and load-bearing structures with the use of different additives and natural adhesive.

▪ Notes

[1] Pumpelly 1908.

[2] Minke 2006.

[3] Bertagnin 1999.

[4] «Le diverse ricerche ... hanno evidenziato per alcune aree geografiche l'assenza o una limitata presenza di testimonianze relative all'uso della terra cruda. ... Appare possibile ipotizzare l'assenza di una tradizione costruttiva del crudo in alcuni ambiti regionali, come conseguenza di un'indubbia diversa e diffusa disponibilità materica ma anche di una mancata o perduta influenza culturale del crudo».

[5] Grim 1962, Guggenheim, Martin 1996, Moore 1996.

[6] Shaw, Weaver 1965.

[7] Minke 2006.

[8] Minke 2006.

[9] Liuzzi, Rubino, Stefanizzi, Petrella, Boghetich, Casavola, Pappalettera 2018.

[10] Padfield 1999, Allison, Hall 2010.

[11] Padfield 1999.

[12] Allinson and Hall 2010.

[13] Minke 2006.

[14] Minke 2006.

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