RILEM contribution to earthen building

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Abstract. Earth as building materials and earthen building products are important for the conservation and rehabilitation of historic and vernacular construction, but also to build new eco-efficient buildings. Earth is not standardized as for other more common construction materials. For earthen products to be applied, depending on the building technologies used and the architectural and engineering design, their performance must be known. Therefore, there is a need to define standardized test procedures, so that performance results can be validated and compared. Within the International Union of Laboratories and Experts in Construction Materials, Systems and Structures (RILEM) an effort has been made, so that earthen materials and products can be addressed, and test methods can be discussed, optimised and defined. This article presents the evolution within RILEM of earth as building material, earthen building products and elements, details difficulties, but also the achievements reached so far. It intends to spread the work now being done, namely within RILEM Technical Committees BEC, MAE and PEM, so that a larger number of professionals can contribute and profit from results achieved.

Keywords: Processing, bio-stabilisation, durability.

1 Introduction

Earth has been used as a building material since mankind needed to build shelters. The first use of earth as building material was most probably mixing local earth with water to produce an earth mortar, applied to fill the spaces between branches put together to build shelter (Bruno et al. 2008). From then on, several other building technologies developed using earth as building materials. "Earth materials" therefore encompasses a wide range of techniques and resulting material types and behaviours, all of which must be understood and accommodated if working towards the idea of promoting them as a construction option.

1.1 Variations in earthen materials

Each earth, excavated from the local soil, has its own mineralogical types and fractions of clay, silt, sand and coarser particles. Therefore, those technologies were adapted to suit the local resources, namely type and state of the earth, availability of water, etc. For instance, from some soils it was possible to cut earth blocks that could be directly used to build masonry walls. Other very common buildings products for technologies using earth are earth mortars, adobe, and, from the 20th century, compressed earth blocks (CEB) and extruded earth blocks to build masonry walls, and rammed earth and cob to build monolithic walls. Except for the case of rammed earth, where the earth can include coarse particles (gravel), for all the other technologies the earth used is sieved and coarser particles are removed.

To build earth blocks masonry, an earth-based bedding mortar is commonly used to layer the pre-fabricated (or pre-extracted) earth blocks. But earth mortars were also currently used to layer stone masonry. No bedding mortar is needed for the monolithic walls, except if pre-fabricated wall sections are produced and assembled on site. Earth mortars are also used to fill wattle and daub walls and for plastering and, in the 21st century, are being used as the basis for 3D printing (Perrot et al. 2018; Asaf et al. 2023) and earth concrete (Pinel et al. 2017).

Adobe, extruded earth blocks and cob walls are produced using a fine earth paste (a mortar, considering it has clay as binder, silt and sand as aggregate) in plastic state, therefore needing a high content of added water. Depending on the earth used, adobe can be produced just with the earth, or additional sand or plant fibres can be added if the clay content is too high, or additional clay or air lime if the clay content is too low. Adobe can be produced using manually handled simple moulds or industrialized ones. The paste fills the mould without compaction or any other mechanical stabilization, and is removed shortly after, as soon as the drying shrinkage and hardening starts. Adobe masonries are frequently rendered and plastered. Extruded earth blocks are produced exactly as solid fired bricks; the difference is that they are not fired, they just dry.

For cob, the most common is that plant fibres are added to the earth paste, and portions of the earthen composite are pilled to build the wall. Each portion can be compacted by hitting with a stick or similar. No formwork is needed to produce cob and it is easy to produce cob involving a wooden-based structure. However, some examples of "shuttered cob" exist in northern Europe, where cob was built within formwork to provide additional support and achieve a higher density. The exterior and interior surfaces of the walls can be left rough to be rendered and plastered, or trimmed flat.

Rammed earth and compressed earth blocks are produced using a lower water content as the earth is only moistened. For rammed earth, the earth is just disaggregated before being moistened while a formwork (traditional or similar to the ones of concrete) is assembled. Layers of the earth are placed inside, and each one compacted (manually or mechanically) until filling all the formwork. With traditional ramming, big stones were placed in the central part of the wall section and not left close to the surfaces. With traditional formworks, they were disassembled when filled and assembled again to produce the adjacent rammed earth section and, when completing all the sections of the same height, assembled to produce the next upper sections, and successively until the top of the wall is complete. With concrete-based formworks, the complete heigh of the wall can be produced with the same formwork.

Rammed earth has a good durability even when not rendered and plastered. Traditionally it was only rendered when some degradation occurred in the surface so that a good adhesion was promoted between the rendering mortar and the rammed earth surface. Alternatively, the surface could be just limewashed. When building very fast was needed, for instance defensive structures, air lime was added to the earth, namely calcium oxide that would hydrate together with the moistened earth (Parracha et al. 2020; Infante Gomes et al. 2022). In those cases, frequently the render was applied to give the impression of large stone masonry blocks (Rocha et al., 2024). Nowadays research and construction adding cement to the earth are frequent. Considering the large thickness of the rammed earth walls, the technology becomes quite unsustainable even if low contents are added, making the justification quite questionable.

To produce compressed earth blocks, a disaggregated moistened earth is placed inside metallic moulds of a manual or industrial press and demoulded just after. Frequently low contents of binders, namely cement, are added to the earth when moistened. As for binder added rammed earth, if a comparison is made with hollow concrete blocks, the binder content per block may not be very positive and sustainable. When inorganic binders, such as cement, are added to moistened earth to produce rammed earth and CEB, as the water added is very low, the curing conditions should be humid; otherwise the binder will not hydrate and the addition is not even effective.

1.2 The history of earthen material research with RILEM

The International Union of Laboratories and Experts in Construction Materials, Systems and Structures (RILEM) was founded almost eight decades ago after the devastation of the Second World War: the directors of the main laboratories in construction materials around the world joined forces to advance free-access scientific knowledge related to construction materials and to facilitate the reconstruction of what the war had destroyed (RILEM, 2024). RILEM endeavours to advance scientific knowledge related to the use of many construction materials and products, such as wood, bamboo, historic lime mortars, concrete, masonry, asphalt, and other construction materials, and to disseminate this knowledge. The main work of RILEM is done in Technical Committees (TC's), where corporate and individual members bring forwards proposals for action.

RILEM members are mainly researchers from academia (about two third) and industry (one third), emphasizing the complementarity and the applicative scope of the works done; recently, many young generations members have been contributing. The proposals are evaluated by a Technical Advisory Committee, which also provides monitoring of the TC´s progress (Vyncke et al. 2018).

Within RILEM an effort has been made to address earthen materials and products, and test methods discussed, optimized, and defined. A first TC on these issues was the TC 96-EB - Earth construction, followed by the TC 153-CEB - Building with earth – Compressed earth block technology, starting in 1992, and the TC 164-EBM - Mechanics of earth as a building material, starting in 1994, all with few members and integrated in the cluster "Others". The TC 164-EBM intended to define test methods to assess the compression and tensile strengths of compressed earth samples. Also, tests to characterize the durability of cement-stabilized compressed earth blocks subjected to wetting/drying artificial aging tests were performed (Vyncke et al. 2018). The achievements resulting from these TCs had no larger dissemination as online dissemination and meetings did not exist in that period.

For two decades, earth construction was rarely addressed by RILEM TCs. The first RILEM recommendation on masonry dates back to 1988, while on rammed earth it dates only to 1997 and on historic mortars to 2000 (Menon, 2024). That changed from 2016 with the formation of TC 274-TCE - Testing and characterization of earth-based building materials and elements, with 32 members and in Cluster E – Masonry, timber and cultural heritage. Based on the remaining challenges of this TC (Fabbri et al. 2022), in 2022 three other TC started: TC MAE – Mechanical performance and durability assessment of earthen elements and structures also with circa 100 members; TC BEC – Bio-stabilised earth-based construction with circa 100 members; TC PEM – Processing earth-based materials with more than 100 members. The objective is to ensure that the community stays together with a common focus on earth-based materials characterisation at different domains for new construction and building rehabilitation. Therefore, a transversal work package (WP) was proposed to ensure, throughout the duration of the three TCs, the dissemination of scientific results, scientific animation, but also for transfer of knowledge to industrialists. This paper presents a record of these committees, their research questions, and their major activities and findings to date. The paper acts as a milestone in the lifespan of these committees, to reflect current achievements and to establish a benchmark for future endeavours.

2 Recent and ongoing RILEM TC´s on earth building

2.1 RILEM TC 274-TCE

The goal of the RILEM TC 274-TCE (Testing and characterisation of earth-based building materials and elements), which was launched in 2016 and finished in 2022, chaired by Jean-Claude Morel and Antonin Fabbri, was to define dedicated testing procedure for stabilized and unstabilised earth as a building construction material (crude earth). The TC comprised seven working groups, working in respectively earth characterisation, hygrothermal, mechanical behaviour, seismic behaviour, durability, standards, and life cycle analysis. This activity led to the publication of a RILEM State of the Art Report (STAR), presenting the existing testing protocols for earthen materials and construction and that analyse them with criticism (Fabbri et al. 2022). Based on the results of this bibliographic work, two round robin campaigns were realized: one on the measurement of the vapor diffusion coefficient; and another on the evaluation of mechanical strength through three-point bending tests. The publications of the results of these experimental campaigns are in progress and the main findings of each WG are summarised below.

Characterisation. The characterisation WG sought to determine appropriate methods to assess materials for earth construction with respect to a required technique. The challenge facing the WG was to develop a fair framework to compare previous literature and tests on earth materials, considering changes in material, manufacturing techniques, water content, density, stabilisation, and soil suction. Part of this work was to develop definitions for each of the techniques with respect to a quantifiable property of that material, for example its particle size distribution. Contrasting literature definitions of materials (for example, if researchers referred to an earth masonry unit as “adobe” or “mudbrick”) and their physical descriptors demonstrated that a wide range of materials may be encountered for the lower technology techniques, for example adobe, whilst those more industrialised techniques (rammed earth and CEB) required a stricter control on the raw material particle grading.

Hygrothermal. Apart from ecological advantages, one of the technological advantages of many earth building elements is the moisture buffering capacity (Lima et al. 2020; Ben-Alon and Rempel 2023) and, therefore, the passive contribution they can have to equilibrate indoor relative humidity, in turn improving occupant thermal comfort and reducing energy consumption. Another, recently being studied, is the contribution earth building elements can have to capture pollutants such as ozone (Darling et al. 2017) and CO_2 (Aris-Roucan et al. 2023; Santos et al. 2023) and their ability to insulate acoustically.

The hygrothermal WG explored the range of previous methods used to define the hygrothermal but also the acoustic performance of earthen materials and structures and their subsequent success. The group identified a distinct lack of consensus regarding methods to measure the dry mass of the earthen material: a property that is fundamental to determining of material characteristics such as sorption–desorption capacity, dry density, thermal conductivity, heat capacity, strength, and stiffness. Rather than being a property which is so mundane as not to be worth exploring, instead an inability to define the dry mass in a consistent way prevented studies from being compared. In a similar way, different protocols exist for determining moisture conductivity, moisture buffering potential and water durability (which affects hygroscopicity due to damage to the pore network). Issues were also discovered in laboratory testing procedures, whose specimen manufacturing protocols produced material that does not represent that in situ. However, it was clear that, as interest in hygroscopic behavior increases and certain groups come to the fore, some consistency in approach is evolving. The WG was therefore able to forecast this consistency to recommend a set portfolio of practices to characterise hygrothermal behavior for earthen building products.

Mechanical behaviour. The key challenge facing the mechanical behaviour WG was to define suitable representative volume elements (RVEs) to characterise the behaviour of structural elements and material elements for the different forms of earth construction. The WG considered three different classes of material (as defined by the characterisation WG): rammed earth (monolithic material compacted in a damp state); earth blocks (discrete earthen elements bonded by mortar, including adobe, compressed earth blocks (CEBs) and binder-stabilised CEBs; and cob (monolithic clayey material comprising fibres, compacted in a moist state).

A review of the literature demonstrated a wide range of reported mechanical properties for different earthen mixes and techniques, which arose predominantly from a lack of consistency between testing methods and a lack of understanding of the hydro-mechanical behaviour of the materials. Critically, few studies were able to explore the properties of the interfaces between compacted layers (appearing in rammed earth but, to a lesser degree, in cob and in the mortar lines for masonry structures). The suitability of different tests was explored and a new test (the shear wedge test) suggested to characterise layer interfaces without the need to adapt existing testing machines. For rammed earth and cob, methods to produce cylindrical RVEs were presented, based on existing standards. For earth blocks, a new RVE comprising four courses of blocks bonded by mortars was presented as being able to capture the compressive behaviour of a full-scale wall. For all the tests, the WG emphasised the importance of moisture content equilibrium with the atmosphere to be able to compare results between tests.

Seismic behaviour. The WG documented the static and dynamic properties of earthen materials, divided into two categories of construction techniques: monolithic (rammed earth, cob); and discrete (adobe, CEB, etc.). The dynamic characteristics also require an understanding of the design of the structure, in particular its height and mass distribution, as well as its material properties. Accepting that many bespoke earthen structures exist, the main type of earth building for considering seismic behaviour were:

- one-story buildings with earth walls;
- two-story buildings with earth walls on both floors;
- two-story buildings with earth walls only for the ground floor and the first floor comprising timber.

In the latter case, earthen walls surmounted by timber was a typical construction adaptation to the climate.

Given the need to consider design as well as materials, the WG explored analytical and numerical methods to model earth structures. For the case of earthen structures, the simplified behaviour of adobe/CEB masonry could be captured using limit analysis methods, while the in-plane and out-of-plane behaviour of adobe walls required macro-block modelling with limit analysis. Monolithic earthen structures could adopt the same simplified modelling approaches used for masonry; however the field of application needs further validation.

The WG noted that finite element methods (FEM) for modelling earthen structures require parameter values that are difficult to obtain experimentally, particularly for describing the behaviour of layer interfaces. FEM was restricted largely to monolithic earthen materials. Discrete element methods (DEM) are also emerging to analyse masonry structures. However, numerical techniques on the whole are in an immature state.

Experimental methods to test seismic performance were restricted to large-scale shaking table testing. The tests, although expensive, provide excellent insight into structural behaviour and how structures react to reinforcement. Unreinforced adobe structures were particularly susceptible to seismic failure due to the weak mortar; such structures benefitted the most from reinforcement of various types (external wraps, internal frames, embedded bars, etc.). Tests on monolithic structures and composite structures (e.g. timber frame structures with earthen infills) were more limited and are a fruitful area for additional research.

Durability. Durability is another issue important to address as many studies demonstrate that durability, and not mechanical performance, is the dominant barrier to the use of earth as building material. However, it is one that can be easily overcome with improved guidance and understanding.

The durability WG reviewed the potential impact of six environmental agents (water, ice, wind, fire, solar radiation, and chemical attack) on the long-term stability of earth buildings, together with some of the most common techniques for measuring and improving material durability. Of the environmental agents investigated, water attack was the most detrimental due to its coupled effect on the material static and dynamic properties. Ice and fire were also noted to be potent aggressors but with considerably less supporting research. the most common deterioration mechanism arising from environmental attack was progressive cracking, which leads to spalling and erosion (exposing new material to attack). Understanding the coupled material hydromechanical and mineralogical properties is therefore key, as these dictate the subsequent shrinkage and swelling response, either to changes in water content or temperature (high or low), or both. The presence of salts (either from the natural material or introduced via stabilisers) must also be understood, as salt precipitation affects the pore size distribution and internal stresses. As for the characterisation WG, a lack of consistency exists for durability testing, making comparisons between materials difficult. However, separating durability from weathering protocols may provide some simplification, as the task of assessing durability becomes separated from the environment.

Standards. Any engineered construction needs guidelines on the production of materials, construction of the structural elements, quality control methods and design guidance. It is an absolute necessity to develop new codes and standards in order to encourage the designers to build with earth and to convince the regulatory bodies, which are sometimes reluctant to the use of non-conventional materials, that earth is relevant for construction. Approximately 70 standards were identified but there is lack of coherence among them or, even, a globally accepted terminology. Of the documents reviewed, there are a greater number developed for stabilised earth (focusing on stabilised CEBs and rammed earth) than for unstabilised products.

As identified by the other WGs, apart from design of buildings, there is a need for international laboratory standards in testing the earthen materials and building products. Such documents must coherently address: earth selection, composition/grading; moulds and machinery; production or manufacturing techniques; testing and quality control; structural design guidance including earthquake resistance design; construction methodology and construction procedure; thermal performance, hygroscopicity and moisture buffering; durability, maintenance and limitations; and comprise a common glossary on earthen products.

Life cycle assessment. The WG explored how earthen materials have been appraised using life cycle analysis (LCA) and which factors dominate the resulting embodied energy and carbon. This WG drew upon the results of the other WGs, combining the new frameworks understanding material techniques, characterisation, performance, durability, and resistance to environmental hazards, with an appraisal of the energy required to achieve those properties.

Transport as well as the type and quantity of stabilisers (in particular, cement) dominated the results, which were in turn a result of the local climate type, the nature of the local soil, and geographical context. Critically, although all references which compared earthen wall to conventional material walls at the building scale found better environmental performances for the former, the WG showed that, according to design choices and local context, earthen construction is not always better than the equivalent concrete construction. However, a distinct difference between the operational energy of earthen and non-earthen structures was found, i.e. combining LCA models with thermal and durability models is a key research issue. Construction methods must, therefore, be linked to the local context of the structure and this mentality must be reflected in any standards or guidelines dictating the use of earthen materials.

Overall. The work of TCE-274 demonstrated the fractured state-of-the-art of earthen building material knowledge in the areas of characterisation, appraisal, and design. It highlighted the need to understand the underlying mechanisms present and prevalent when building with earth in their particular context, which is a considerable departure from the more common methods or criteria specification approaches used for modern building. In particular, the work of TCE-274 demonstrated deficiencies in critical areas for supporting standardisation, for example surrounding stabilisation, reinforcement, durability, and modern production methods. Those deficiencies prompted the formation of three new technical committees based on the work of TCE-274: MAE, BEC, and PEM.

2.2 RILEM TC MAE

The aim of TC MAE (Mechanical performance and durability assessment of earthen elements and structures), chaired by Antonin Fabbri and Christopher Beckett, is to study ways of characterizing raw earth elements and structures. This technical committee is divided into three major WG. The first aims to provide clear recommendation for the mechanical testing of earth-based building materials. In particular, important assets that are being studied are (i) the scale effect for rammed earth and cob and provide some guidelines to realize lab and on-site tests and (ii) to determine bond strength factors for reinforcement in earth walls, to be compatible with existing Eurocode approaches. The second WG focuses on durability issues, and more precisely on abrasion and erosions tests, which are known to be quite scattered and not necessarily representative on in situ resistance. Part of this work is to identify robust testing methods and to demonstrate consistency between results for different laboratories. A round-robin testing campaign has commenced which will examine the water and abrasion resistance of a standardised earth block, accounting for issues for example block size and test repeatability. The third WG deals with in situ testing. Indeed, earth is a complex material whose implementation requires skills not always known and/or mastered by masons, and which does not have normative dimensioning methods or ‘rules of thumb’ describing the conditions and processes of implementation of the works. Furthermore, it is necessary to make informed decisions about structure conservation without requiring samples to be taken from those monuments. The challenge of this WG will be to contribute to filling this gap by developing methods to monitor the quality of the earth elements of a structure during their implementation, following rehabilitation operations or whilst in service.

2.3 RILEM TC BEC

The TC BEC (Bio-stabilised earth-based construction), chaired by Ana Brás and Celine Perlot, is focused on bio-stabilisers and bio-stabilisation methods to improve earthen materials' properties to replace hydraulic stabilisers. The most frequently hydraulic binders (lime or cement) are used as chemical stabilisers, but they have the disadvantage of increasing the carbon footprint of the earthen materials due to the emission of greenhouse gases during admixtures manufacturing and to change the earth permanently, which limits drastically its reusability and recyclability. In place of hydraulic binder’s stabilisation, alternative bio-sourced methods with low environmental impact are increasingly used. These, inspired by centuries-old practices or biomimetics, are highly variable and act differently. At present, there is no fully established classification of bio-additives and bio-stabilisation methods, but they can be grouped according to their nature or effects. Bio-stabilisers are additives originated from plants, animals, and minerals (e.g. oils, fats, tannins, from vegetal or animals, fibres, bio-ashes, urine, casein) that promote precipitations of supplementary mineralogical phases or their transformation, improving materials properties such as strength and water resistance through enzymatic induced calcite mineral precipitation, bio-polymerisation and mineral transformation. Other bio-additives do not modify the mineralogical phases of the materials but can improve water sensibility by occluding the external open porosity. Similarly, bio-stabilisation techniques include, for example, the addition of hemp fibres, straw fibres or mycelium, which can strengthen the materials.

Therefore, the objectives of this TC are to: (1) suggest a definition and classification for different types of earthen building bio-additives and bio-stabilisation; (2) understand how bio-additives and bio-stabilisation methods can modify the mineralogy, microstructure and textural properties of different construction earth-based materials; (3) understand how bio-additives and bio-stabilisation methods can modify the performance of different earth-based materials (focusing on physicomechanical and hygrothermal properties); (4) understand how bio-additives and bio-stabilisation methods can improve the durability performance of different earth-based materials (5) assess the contribution to climate change adaptation of new and existing earth-based buildings.

To achieve these objectives, different WG have been set up for each subject: WG1 – Literature review, to investigate current efficiency and evaluate bio-additives and bio-stabilisation methods for earth stabilisation in new construction and existing buildings;

WG2 – Effects of bio-additives and bio-stabilisation on earth based materials properties - microstructure and mineralogical characterization; WG3 – Impact of bio-additives and bio-stabilisation methods on short and long-term performances related to hygro-thermal and mechanical behaviours; WG4 – Durability characterisation and performance-based assessment of bio-stabilised earth-based materials; WG5 – Bio-additives and bio-stabilisation methods contribution to climate change adaptation of new and existing earth-based construction.

As a first step, each WG studies the literature to summarize the various results and write a chapter in a state-of-the-art book (currently being finalized). Then, the blocking subjects for these bio-stabilisation methods will be identified before defining some round-robin tests which will aim to help in the definition of a performantial approach (publication of recommendation). At the same time, data are being collected to provide input for the climate change assessment.

2.4 RILEM TC PEM

The TC PEM (Processing of earth-based materials), chaired by Emmanuel Keita and Arnaud Perrot, aims to focus on earthen material at its fresh state, from fundamental considerations to practical solutions. It is structured in four WG: Rheophysics, Rheological and characterization methods, Drying and shrinkage and New processes.

The first WG will target the precise understanding of the microstructure and physico-chemical properties of cementitious materials in their fresh state. Such knowledge development has led to significant advancements in the concrete industry, including the design of self-compacting mixes, ultra-high-performance concrete, and the development of 3D concrete printing. This understanding, termed rheophysics, links micro-structural properties to flow behaviour, enabling the design of efficient additives, prediction equations and rheological models. However, this knowledge is lacking for earthen materials, and there is a temptation to emulate concrete industry expertise. Only a few studies attempt to relate the fresh-state microstructure of earthen construction to behaviour due to the variability of materials, admixtures, and processing methods. Earthen materials exhibit wide consistency variations, from liquid to granular, based on initial water content, necessitating a common terminology for rheological behaviour. The TC aims to provide this framework by defining earth-based material behaviours, classification categories, and suitable rheological models. A comprehensive literature review will form the basis for understanding rheophysics in earthen materials, including microstructure descriptions, mechanical models, and the effects of admixtures.

Rheological characterization tools for earthen materials vary widely, from fluid to granular-like materials, with no common and shared practices or standards due to the diversities in materials and processing methods. Empirical on-site techniques exist but lack quantifiable parameters for mechanical or rheological behaviour. In its second WG, the TC plans to evaluate existing methods for quality control and provides them a scientific framework to derive rheological or mechanical parameters. An inter-laboratory study to define common procedures is planned at the end of the TC life.

The third WG is expected to carry out investigations into the drying stage of earthen materials processing that aim to understand microstructure consolidation and mechanical property development, addressing challenges like shrinkage, cracks, and heterogeneity. Experimental methods will be refined to evaluate drying kinetics and mechanical property development, informing mix-design solutions to mitigate defects induced by drying. Techniques from related fields, such as concrete and soil studies, will be considered, emphasizing dimensional stability and strength enhancement.

New processing methods for earthen materials, including digital fabrication and self-flowable earth, offer sustainability prospects but lack comprehensive reviews and standardized practices. These methods require adaptation of traditional techniques, documentation of material specifics, and process characteristics, considering material-process interactions. In the 4^{th} WG, the TC will assess environmental impacts, balance benefits and drawbacks of admixtures, and explore the integration of traditional techniques with digital manufacturing technologies.

In summary, the TC PEM aims to advance understanding, standardize practices, and develop terminology for processing earthen materials. Through comprehensive literature reviews, evaluation of existing methods, and investigations into new processing methods, it seeks to facilitate advancements in earthen construction while promoting sustainability and preserving traditional techniques.

3 Final remarks

Earthen building products are important for the conservation and rehabilitation of historic and vernacular construction, but also to build new eco-efficient buildings. Earths are not standardized as for other more common construction materials. For earthen products to be applied, depending on the building technologies used and the architectural and engineering design, their performance must be known. Therefore, there is a need to define standardized test procedures, so that performance results can be validated and compared. That is the main aim of RILEM TC on earth building.

References

Asaf, O., Bentur, A., Larianovsky, P., Sprecher, A.: From soil to printed structures: A systematic approach to designing clay-based materials for 3D printing in construction and architecture. Construction and Building Materials 408, 133783 (2023).

Arris-Roucan, S., McGregor, F., Fabbri, A., Perlot, C.: Towards the determination of carbon dioxide retention in earthen materials. Building and Environment 239, 110415 (2023).

Ben-Alon, L., Rempel, A.R.: Thermal comfort and passive survivability in earthen buildings. Building and Environment 238, 110339 (2023).

Bruno, P., Faria, P.: Earth mortars use on neolithic domestic structures. Somecase studies in Alentejo, Portugal. Conservar Património 8, 5-12 (2008).

Darling, E., Corsi, R.L.: Field-to-laboratory analysis of clay wall coatings as passive removal materials for ozone in buildings. Indoor Air 27(3), 658-669 (2017).

Fabbri, A., Morel, J.-C., Aubert, J.-E., Bui, Q.-B., Gallipoli, D., Reddy, B. V. (Eds.): Testing and characterisation of earth-based building materials and elements: State-of-the-art report of the RILEM TC 274-TCE, Springer, Cham (2022).

Fabbri, A., Morel, J.-C., Aubert, J.-E., Bui, Q.-B., Gallipoli, D., Ventura, A., Reddy, V. B. V., Hamard, E., Pelé-Peltier, A., Abhilash, H. N.: An overview of the remaining challenges of the RILEM TC 274-TCE, Testing and Characterisation of Earth-Based Building Materials and Elements. RILEM Tech Lett 2022, 6, 150-157.

Infante Gomes, R., Santos Silva, A., Gomes, L., Faria, P.: Fernandina Wall of Lisbon: mineralogical and chemical characterization of rammed earth and masonry mortars. Minerals 12, 241 (2022).

Lima, J., Faria, P., Santos Silva, A.: Earth plasters: the influence of clay mineralogy in the plasters' properties. Int. J. of Architectural Heritage 14 (7), 948-963 (2020).

Menon, A.: Cluster E – Masonry, timber and cultural heritage. RILEM Technical Report 2022-2023, 46 (2024).

Parracha, J.L., Santos Silva, A., Cotrim, M., Faria, P.: Mineralogical and microstructural characterisation of rammed earth and earthen mortars from 12th century Paderne Castle. J. of Cultural Heritage 42, 226-239 (2020).

Perrot, A., Rangeard, D., Courteille, E.: 3D printing of earth-based materials: Processing aspects. Construction and Building Materials 172, 670-676 (2018).

Pinel, A., Jorand, Y., Olagnon, C., Charlot, A., Fleury, E.: Towards poured earth construction mimicking cement solidification: demonstration of feasibility via a biosourced polymer. Materials & Structures 50, 224 (2017).

RILEM Homepage: https://www.rilem.net/module_asso/newsletter/template/html_newsletter.php?id=631&_view=8811137aa54244c635644ee03858ad1316411e0ae843d07f04245782b7df94bb&langue_selected=fr, last accessed 2024//1/31.

Rocha, M., Faria, P., Gago, A.S.: Conservation of defensive military structures built with rammed earth. Buildings, 14(1), 238 (2024).

Santos, T., Santos Silva, A., Gomes, M.I., Faria, P.: Evaluation of the hygroscopic and CO_2 capture capacities of earth and gypsum-based plasters. In: Bokan Bosiljkov, V., Padovnik, A., Turk, T. (eds) Conservation and Restoration of Historic Mortars and Masonry Structures. HMC 2022. RILEM Bookseries 42, 207-215. Springer, Cham (2023).

Vyncke, J., Kupers, L., Denies, N.: Earth as Building Material – an overview of RILEM activities and recent Innovations in Geotechnics. MATEC Web of Conferences 149, 02001 (2018).