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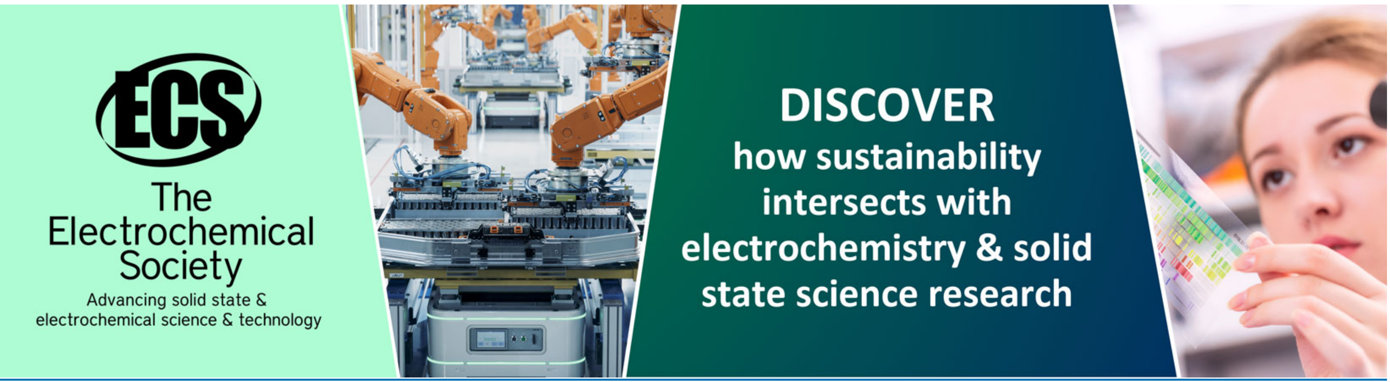

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Earth buildings in Romania. Tradition and perspectives

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Abstract. Earth is one of the most commonly used traditional building materials. Recently its usage was reassessed, considering its qualities, with earth being viewed as environmentally friendly and sustainable. Extended research has been done to analyse material qualities and construction techniques. New buildings were developed, some of them with modern architecture and high aesthetic qualities. In this context, the paper proposes an interdisciplinary approach aiming to analyse earth buildings in Romania from an architectural and structural point of view. Furthermore, their potential use in contemporary architecture is evaluated. Currently, local regulations for the usage of earth as construction material are absent and there are only few examples of earth architecture in recent Romanian practice. We propose a necessary analysis for the process of retrieving a traditional building material, which has a high potential for contemporary architecture in our country. The study examines the historical usage of earth as a building material in Romania. The types of buildings and the construction techniques across various regions are identified. An analysis of the specific structural issues of earth buildings in Romania follows. Conclusions are drawn regarding the potential use of earth as a construction material in contemporary Romanian architecture.

1. Traditional earthen construction techniques

Earth as a building material in Romania has a long tradition. It was used for both rural and urban constructions, mainly for houses and auxiliary buildings, but sometimes also for churches and schools. From a geographical point of view, earth was commonly used across Romania, but building techniques vary from one region to another.

Earth was used for both structural and non-structural elements. Structural walls were made of rammed earth, adobe, or in combination with other materials (wood frames with earth infills - *paiantă*). Non-structural elements include interior walls, flooring and roofs (for earth lodges).

The methods of building with earth in different forms, in Romania, are very old. They were based on using local materials and craftsmen from the building site or neighbouring villages [1]. The raw material used is either clay in natural form (often moistened before being used), or in mixture with organic matter (chaff, straw, sawdust, etc.). The latter improve the mechanical properties by increasing the tensile strength of the mixture and reducing the deformations and cracks after drying [2].

Traditional methods include semi-buried lodges and surface dwellings. Earth lodges are nowadays only found in ethnographic museums. Surface dwellings have exterior walls made either out of earth (rammed earth, cob, adobe) or with timber framing and various earthen infills (clay mixed with straw or chuff, wattle-and-daub, sun-dried blocks).

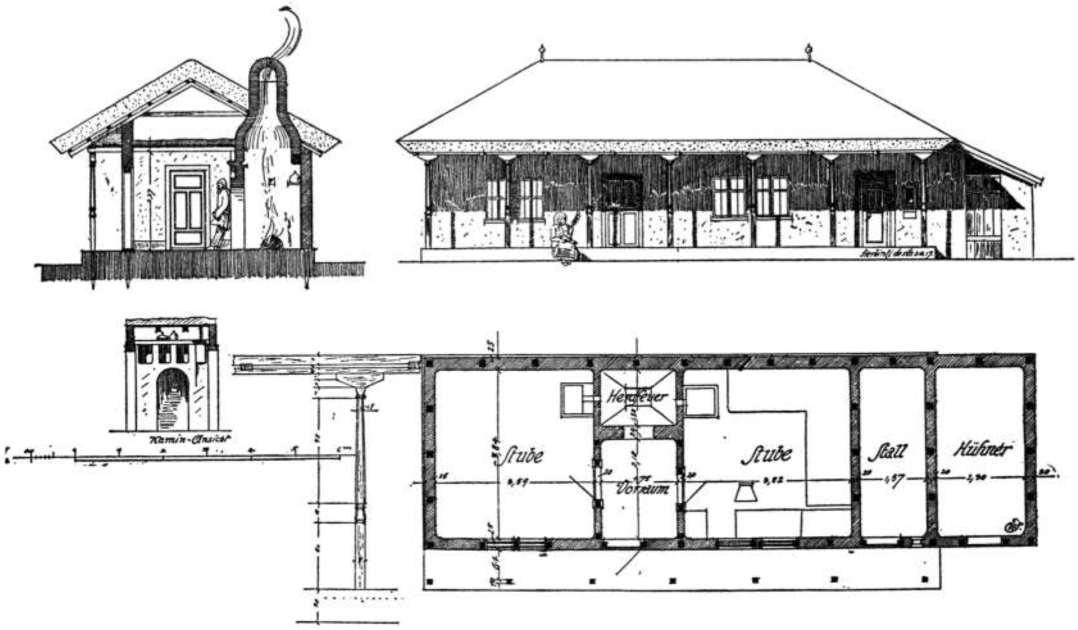

Figure 1. Traditional Romanian house made of timber framing with earth infills (*paiantă*) [3].

Old buildings did not generally have foundations (figure 1). The walls rested on massive horizontal round or cut wooden beams, directly on the ground or on large stones buried beneath the corners. More recent constructions had brick or even concrete foundations. The floor of the rooms was made of compacted earth, glued with clay smoothed by hand [1]. The hipped roof was made of round or carved wood, and the covering of wood shingle, reed or clay tiles. Walls were typically coated with loam plaster. The wall of the main façade was often decorated with specific elements embossed in the plaster [1].

1.1. Semi-buried buildings: earth lodges

Before mid 19th century, earth lodges, called *bordei,* were prevalent for housing in the plains of southern Romania [4, 5]. This construction type is present in Romania since the Neolithic period, when most of the buildings were oval or round-shaped [6, 7]. Archaeological research revealed 7-9th century and early medieval dugout shelters [6]. Around 1850, an important number of houses were semi-subterranean buildings, both in rural and urban areas [8]. In 1950, such buildings were still present only in some villages in the Oltenia region [6].

The construction of earth lodges in the southern regions of Romania has a long tradition, and their presence can be related not necessarily to the scarcity of other construction materials, but rather to a local archaic constructive tradition [4, 6]. Besides houses, semi-subterranean buildings sometimes had other destinations such as churches, grain/ice storage buildings, animal shelters, etc. [4, 6]. Earth lodges could have two or more rooms, and some configurations allowed for the construction of windows (figures 4 and 5) [4, 5, 9]. The tradition of semi-subterranean buildings is also found in northern Bulgaria [4] and other places in Europe [4, 6].

Earth lodges were constructed partially below and partially above ground level (figures 4 and 5). The building was covered with a thick layer of earth (figure 5) [4]. The interior floor level was generally at 0.6 – 1.2 m below ground [5].

Figure 2. Semi-buried house (*bordei*) from Muntenia (1860), engraving by Auguste Lancelot [10].

In the rudimentary buildings, the walls were covered only with a layer of clay, to create a flat surface. Predominantly, the walls were doubled by other materials, such as wood, wattle-and-daub, sometimes brick, and could be covered with lime plaster. Both the plan layout and the interior comfort of such constructions could be similar to the one of surface dwellings (figures 3 and 4). The amount of wood that could be used in semi-buried buildings was quite significant. Mainly oak was used, and the costs of such a building were significant [4, 5].

The pits where earth lodges were built were dug during summer, about 2 m deep. These pits were filled with wood, straw, corn cobs and then burned. Under the effect of the heat released by the fire in the pit, the clay in the earth solidifies and obtains properties similar to ceramics: low permeability and high strength [4].

The constructions had no attic. The ceiling was formed by tree trunks split in half, with the flat surface towards the interior, placed similarly to gable roofs. Split oak trunks with the flat side inwards were also placed on the outer walls. The wood was carefully sculpted on the visible side. The interior walls of the building were made of adobe or wattle-and-daub (figure 3) [6].

The plan was developed by adding side rooms, similar to the above-ground dwellings, and adding deep rooms (figure 4). The central room, where the earth was located, had a pyramid-shaped chimney made of wattle-and-daub or adobe, extending over the sloped roof (figures 2 and 5) [4, 6].

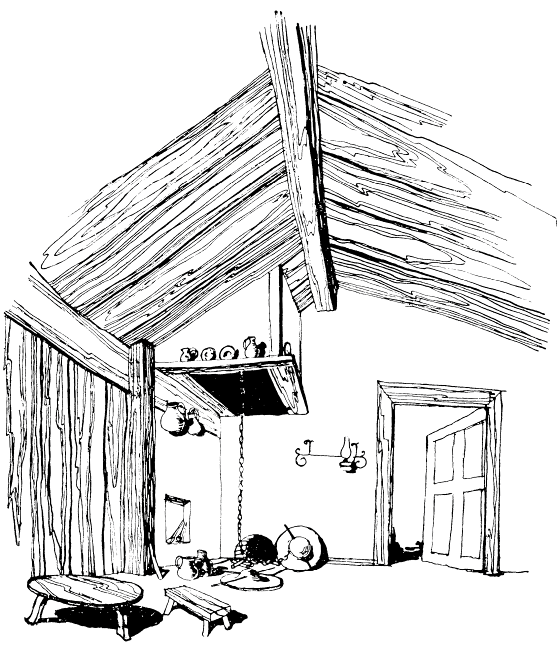

Figure 3. Interior image of a semi-buried house (*bordei*) [9].

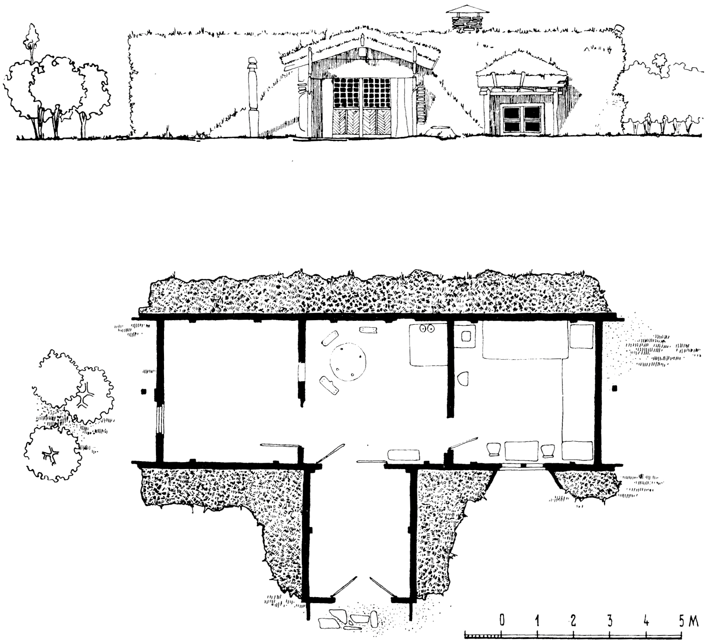

Figure 4. Semi-buried house (*bordei*) from Oltenia. Plan and South elevation [9].

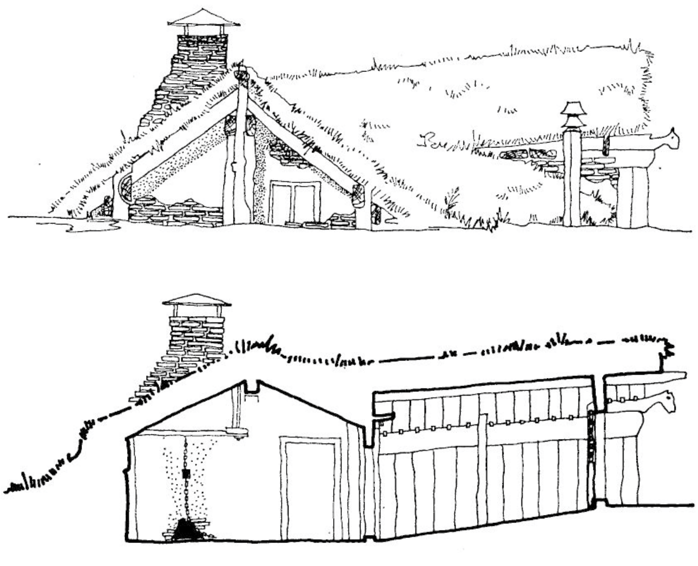

Figure 5. Semi-buried house (*bordei*) from Oltenia. Section and West elevation [4].

1.2. Buildings with earth walls

As in the case of earth lodges, the buildings with earth walls are concentrated especially in the plains of southern Romania [8]. In the 19th century, in the southern Romanian historical regions Muntenia and Oltenia, most of the surface constructions were made of wood (about 80% in the hill areas and about 53% in the plains). Buildings made of earth accounted for 20%, while brick and stone for 5%. Earth walls were also used, to a lesser extent, in Banat [11, 12, 13], northern Transylvania [13, 14] and in the central part of Moldova region [11]. Three building methods were used: rammed earth, cob and adobe.

1.2.1. Rammed earth ("pământ bătut cu maiul"). The mostly used method was similar to the technique of casting concrete into formwork. Earth without other mixture at its natural humidity [1] or moistened with water is placed in successive layers in a timber formwork. Each layer is then compacted to the maximum with wooden rams (figure 6). As the height of the wall increases, the wood planks are slid vertically and then the following layers are executed [5, 6]. The layers were at most 20 cm thick to allow a good compression of the earth. The final layer of compacted earth was 6-10 cm thick. In order to obtain homogeneous walls, the execution was to be carried out continuously, without interrupting the process until the completion of the construction [1]. In order to increase the resistance of the wall, vine chords were sometimes used [5]: every 3-4 layers, strings were placed horizontally, along the walls, primarily at the corners. Wood boards were placed on the top of the walls (sometimes the same planks used for formwork), so that the weight of the beams, the roof framing and the roof sheltering were evenly distributed on the walls [1]. The thickness of the walls varied between 50 and 80 cm, and in their thickness furniture elements (niches or cupboards) were sometimes integrated [1, 5]. The door and window openings were cut into the already built walls after these were finished [1]. Foundation thickness was between 70 and 100 cm. The foundation of the walls was made of compacted earth, burnt brick or, more recently, concrete. The foundations exceeded the thaw depth in the ground (80-100 cm) [1]. The rammed earth constructions could also have cellars [5]. Using the rammed earth techniques, solid constructions could be obtained. Their durability could reach up to 100-200 years under constant maintenance [1]. This construction technique was used in Romania until 1930s [4].

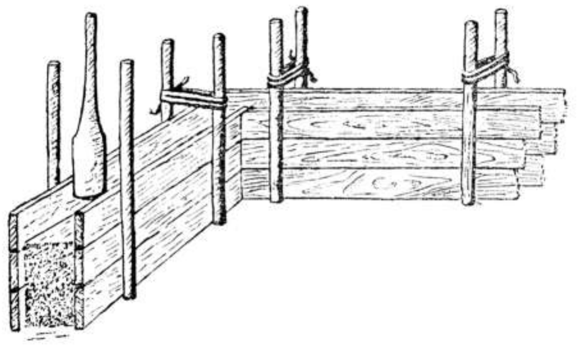

Figure 6. Rammed earth construction method (*pământ bătut cu maiul*) [13].

1.2.2. Cob. Another method of erecting earth walls was "fork building" - *pereți din pământ clădit cu furca* (figure 7), used in north Transylvania historical region [13, 14] and in the central part of Moldova region [11]. The clay, mixed with bigger chopped straw, was raised with forks by two men at the height of the wall, where a third one built it and stamped it with his feet. The walls were placed on a stone foundation or directly on the ground. The successive layers were flattened with a shovel and allowed to dry for a few days until a new layer was made [15].

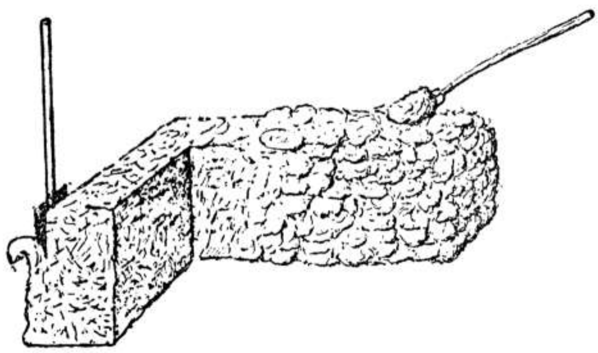

Figure 7. "Fork building" (*pereți din pământ clădit cu furca*) construction method [13].

1.2.3. Adobe. Adobe bricks (*chirpici*) is a construction material used for walls, made of unfired clay, formed in wooden moulds. The composition of the *chirpici* consists of a mixture of clay, with the addition of chopped straw, chaff, sawdust, etc. (*ceamur).* Pieces of dimensions ranging from 12x16x33 cm to 20x20x40 cm are not burnt, but sun-dried. The advantages of this construction material are the low price and good thermal insulation [2, 5]. The walls are made similar to masonry walls, using the adobe bricks and clay mortar [15].

1.3. Buildings with wood frame - earth infill walls ("paiantă")

The *paiantă* buildings date in Romania back from the end of the early Neolithic [16]. The walls of these constructions were made of wood beams, poles, braided rods / woven wickers, and roughcast from clay mixed usually with straw, and seldom with sand or leaves or of cane and thin rods, glued with adobe, supported on a wooden beam structure [17, 18]. Archaeological excavations have revealed the same constructive system dating from the Bronze Age until the Middle Ages, with stone foundations [6]. This constructive system was often used in the hill and mountain areas [18, 19]. In the rural areas, sometimes even schools [20] or churches [6] had the walls built with this technique.

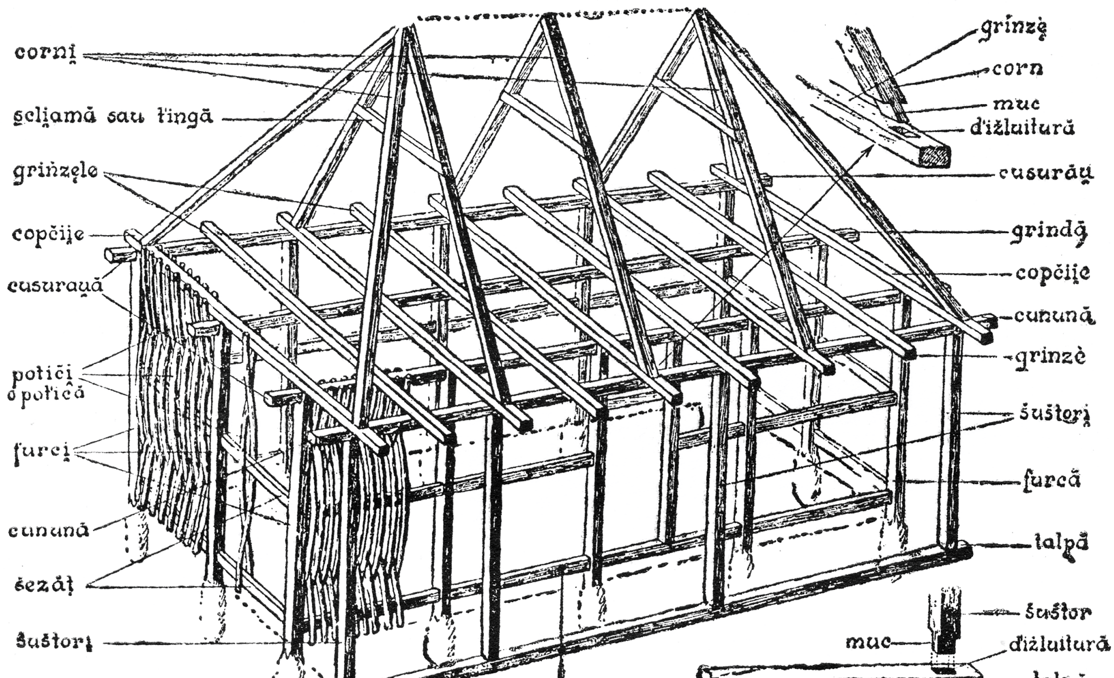

Figure 8. Wood structure of a building with wood frame and earth infill walls (*paiantă*) [13].

The wooded framing of *paiantă* walls had two structural typologies: vertical wood poles thrust in the ground ("fork system" / *în furci*, figures 8 and 10) or framing built on a base wooden beam (*pe tălpi*, figure 11) [15]. On the main frames, a wattle and daub wall was made (figures 8 and 11). Usually, rod wicker was made from the bottom to the top, then was covered on both sides with earth mixed with organic materials (straw or chuff) (figure 11) [5, 6, 15]. A variation of that system was to complete a vertical netting made of thin rods / wickerwork between the horizontal elements of the structure, or long pieces of broken trunks. Another alternative was interlacing of the vertically arranged beads with adobe "wefts" *(vălătuci)* arranged horizontally (about 7 cm thick). These were made of a layer of clay covering a layer of straws – rolled-up together [6, 15].

For wattle and daub walls, the first layer of daub was done on the inner side, and then, after it dried, the outside layer was made. In some cases, as to obtain a thicker wall, several successive layers of earth composed the wall. In the Danube river meadow and in the Delta, the rods were replaced with reeds, and for the filling was used the *ceamur* - a mixture of clay with straw, fibrous herbs, tow or chaff, squeezed using horses [15]. After the walls had dried out, they were covered on both sides with earth plaster. The surface of the walls was smoothed with a layer of clay and often whitewashed [20].

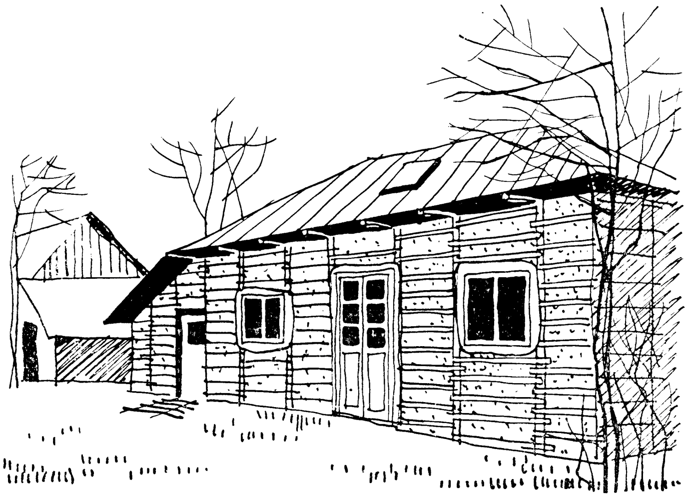

Figure 9. Buildings with wood frame and earth infill walls (*paiantă*). The drawing shows the building before the last layer of earth was added to cover the walls [9].

1.3.1. Wood poles structure ("în furci"). The system involved creating a vertical wood structure for the outer walls by thrusting into the ground 15-20 cm wide poles, spaced at around 1.20-1.50 m. The number of the vertical elements varied according to the dimension of the rooms and the desired structural strength (figure 10). The top of the vertical pillars was carved, for a better connection with the top girders, on which the beams of the ceiling were supported [1, 15, 20]. The depth at which the oak poles were buried was about 1 m, and their top reached 2 – 2.20 m above the ground [6, 15].

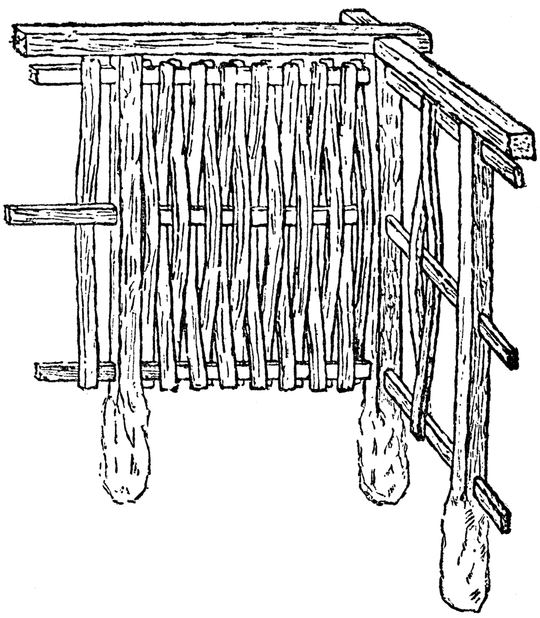

Figure 10. Construction system of a buildings with wood frame and earth infill walls (*paiantă*), with wood poles structure (*în furci*) [13].

The structure was strengthened by horizontal wood beams ("belts"). These were made by fixing, between the poles, oak or hornbeam horizontal wood joists, at about 70 cm from the ground and from the top (figure 8) [6, 13, 15]. The "forks" system was used in Transylvania, but also in Moldova, especially in the central and eastern part of Moldova [6, 15]. The disadvantage of this construction system is the contact of the wood elements with the soil moisture. To prevent decay, the tips of the poles were charred and soaked in oil. Another problem of the system is that, in time, under the weight of the construction, the poles were sinking in the ground, and it was necessary for the abode to be deepened [15].

1.3.2. Structures on wooden beams ("pe tălpi"). The most used solution was building the timber framing on a bottom wooden beam (figure 11). This beam was generally placed on a stone foundation, as to avoid moisture. The vertical columns (similar in size and distance to the forks) were fixed to the base beam and to the sill beam [15]. Sometimes, wooden diagonal braces were also used. In the western part of Moldova, the framing was reinforced by placing, on both sides, horizontal wood lath or beech rods. The space between these was filled with damp earth, mixed with chaff (figure 9). The walls were covered with a layer of earth mixed with chaff, then a thinner layer of earth mixed with cattle dung, then were lime-washed [1, 6].

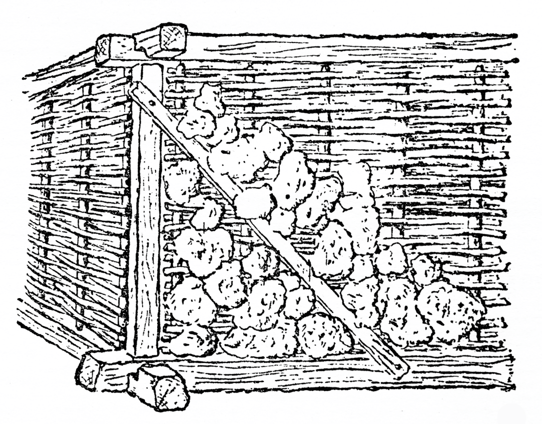

Figure 11. Construction system of a buildings with wood frame and earth infill walls (*paiantă*) on wooden beams (*pe tălpi*) [13].

Buildings where earth is used as a construction material, in particular houses and auxiliary buildings made of wood and earth (*paiantă*), are still present in all the regions of Romania. Some existing buildings with high architectural value were moved from the place of origin to ethnographic museums, while other are listed as historic monuments. The need of preserving the existing buildings demands a modern approach towards the use of earth. Also, there is a rising interest for new green buildings made with traditional materials and construction methods.

2. Current issues related to the use of earth for buildings

In Romania, only standardized materials can be used in buildings. When national or European standards are not available (as it is the case for earthen materials), a technical agreement for the material must be issued prior to its use. This procedure involves costs that sometimes surpass the financial possibilities of potential clients. An alternative solution is to use already approved products. But this could lead to the impossibility of using local-available materials, while transport of materials to the site diminishes the eco-friendliness of the solution.

Regarding the structural solution, large areas of Romania are prone to high seismic hazard. Structural engineers, who are legally responsible for the entire lifespan of the buildings, are often reluctant to adopt solutions when lacking clear national or European code provisions. This is, to some extent, also the case for architects or engineers in charge of designing buildings for other essential criteria, such as thermal insulation, soundproofing, fire resistance, etc.

Romanian climatic conditions, notably rainfall and temperature, vary from one region to another in significant extent. For this reason, difficulties arise in implementing solutions that were validated in other countries, or even in other regions, without prior detailed studies.

Another difficulty arises from the loss of traditional building knowledge in the last 50 years. The introduction of national standards and regulations for construction was done, as in many other countries, in order to improve the quality of living and to minimize the risk of injury for people under extreme loads on buildings. While these regulations have their benefits, they also sometimes lead to the loss of traditional architecture. Some locally available natural materials and traditional construction techniques could no longer be used and had to be replaced with engineered materials that not only changed the architecture of the buildings, but sometimes even proved inadequate for some of the local conditions. Similar situations can be found in the literature for other countries. For instance, in [21] the case of Japanese Amami Island is discussed, where traditional hand-hewn timber buildings using local grown trees, clay and bamboo walls and thatch roofs were replaced with wooden stud walls with insulating core, steel fasteners and galvanized roof sheeting. This led to the loss of a sustainable and self-contained building system, of centuries-long carpentry traditions.

2.1. Experience of other countries

There are countries, some with high seismic demand (such as New Zealand, USA, India), where regulations have been developed and are currently in-force regarding the use of earth for buildings, either standards [22-24] or guidelines [25]. Standards allow for a rigorous design of engineered solutions. Guidelines are less detailed and strict, but address the general issues that can improve the structural behaviour of the buildings. The [22] and [23] standards do not only address the seismic design, but also the problems related to rain and wind-driven rain, water being, probably, the main cause of structural failure for earth buildings [26].

In other situations, research was conducted with the aim of evaluating the earthquake strength of existing vernacular buildings. These buildings do not comply with modern design principles and fall beyond the scope of in force technical regulations. Simplified evaluation procedures may highly underestimate the structural strength of the buildings. As an example, adobe buildings are generally assimilated to unreinforced masonry buildings and evaluated as such. Yet, a recent study [27] involving full scale laboratory testing on adobe walls had interesting results. Even if the typical failure modes are similar to those of masonry walls, the tested specimens exhibited a much larger ductility than expected, which leads to the conclusion that adobe buildings should not be simply designed or evaluated based on the methods developed for masonry.

A good practice example is shown in [28], where an extensive study was conducted for an area where earth buildings were traditionally built. The study led to the development of improved configurations for rammed earth buildings with modern living conditions. Over 400000 m^2 of buildings were constructed based on the research program.

Another example is shown in [29]. A prototype building with gypsum-adobe walls and wooden roofs was developed for usage in a highly seismic area (intensity 8). After detailed design and testing (including shaking table tests) over 1000 houses were built based on the prototype.

2.2. Recent developments in Romania

Recent projects and studies show that there is a rising interest in Romania related to earthen housing as a solution for green architecture and for the preservation of historical heritage.

2.2.1. Individual initiatives. There are rare examples of newly built engineered buildings using earth in Romania. One of these, a rammed earth structure was built in Lelese, Hunedoara county. Prior to construction, in 2014, extensive laboratory testing had to be undertaken in order to establish local soil composition, its mechanical properties and solutions for improving the reliability of the material [30].

2.2.2. Architectural monographies. Recently, architectural design guides were issued for some regions [31]. Over 140 guides are planned for release in order to cover all the Romanian historical regions. These guides recommend specific materials and construction techniques to be used in order to preserve the traditional housing styles, including earthen buildings. As only architects contribute to these guides, the conceptual structural solutions are not backed by engineering design and can not be directly put into use.

2.2.3. Engineering assessment. Structural engineering assessment of vernacular buildings is required by building owners or local authorities, in particular after extreme events (e.g. floods or landslides). The authors performed multiple evaluations of this type. As the buildings do not comply with current building codes, there is no clear assessment method. Evaluations based on engineering judgement can lead to different results, depending on the person conducting the analysis.

2.2.4. Engineering laboratory testing. Research based on laboratory testing is aimed at correctly assessing the structural vulnerabilities of non-engineered buildings and developing improved solutions. As an example, in [32], traditional buildings with timber frames and mud masonry infills are evaluated by in-plane static cyclic tests. Results are consistent with observations after major earthquakes, that traditional houses with infilled timber frames structure are often resilient enough so they protect the lives of their inhabitants.

2.2.5. Engineering technical methods proposals. Some engineering research goes beyond the structural problems of houses built with locally available natural materials and also addresses other problems such as thermal insulation and waterproofing. In [33], a modular construction method is proposed, based on wooden boxes with two compartments, filled with rammed earth and straw. According to the authors, this modular wall can provide structural strength and thermal insulation as required by current regulations, while offering an ecological and economical alternative to building with industrial prefabricated modules.

3. A vision towards the future

Existing earth buildings in Romania represent a part of our architectural heritage. Many of them might not comply with 21st century criteria regarding structural safety or quality of living. Yet, the solution of imposing only the use of engineered materials for their refurbishment will ultimately lead to their disappearance, along with centuries-old traditional craftsmanship. In light of the current trends towards sustainable buildings using local natural materials, there is a certain need of change in vision regarding earthen buildings.

Individual initiatives aimed at building a modern eco-friendly earthen house that complies with structural safety criteria, while also ensuring up-to-date conditions of living, must deal with high initial costs. These costs are related mainly to structural design that goes beyond the design codes and to material testing prior to obtaining a technical agreement for the product. People that lack the funds for preliminary studies are left with two solutions. The first one is to build a code-compliant masonry or concrete building (more costly and less ecological), which will further deteriorate the local existing architectural stock. The second one is building an earth building which, by lack of standards and detailed studies, might ultimately be improper or even unsafe.

Only initiatives by public authorities can overcome this problem. A feasible solution is to conduct integrated studies (architectural and structural) at regional level, funded either by local on national entities. These studies can analyse the technical local conditions (earthquake hazard, climate, soil types, etc.) in light of the cultural tradition and existing buildings. Based on these integrated studies, solutions can be developed, either as guidelines for the design of new buildings or the refurbishment of existing ones, or even as a catalogue of buildings that are adapted to the local conditions while ensuring modern living conditions.

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