

EARTH AS A MATERIAL FOR CONSTRUCTION OF MODERN HOUSES

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Abstract. *Earth was used for construction of residential buildings in the past. Due to the more widespread tendency toward the use of sustainable local materials, earth is present as one of the dominant materials for building of modern houses. The implemented techniques for construction of earth houses differ depending on the characteristics of a region and architectural tradition. This paper presents the characteristics of earth as a building material, traditional techniques for construction of residential buildings using earth, regulations which permit the construction in many countries of the world, as well as traditional residential building constructing techniques which use earth. Likewise, through the emblematic realizations of contemporary architecture it was shown that earth houses have the potential to provide the modern standard of living and to satisfy the aesthetic requirements.*

Key words: *habitation, house, earth as building material, construction techniques, building standards*

1. INTRODUCTION

Terms “to live” and “to reside” are logically inseparable from the term “house”. According to Cvijić, a house is “a cultural subject exposed to evolution” (Cvijić, 1991). The change in residing can be traced through the history of architecture, from the moment when man felt the need to find shelter from natural disasters to the present days. He has always made his house in accordance with available materials trying to reduce unfavorable geographical and climate factors as much as possible.

Earth was one of the earliest used materials for construction of residential buildings at different times in the past on the territory of Europe, but also in Asia, South America,

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Africa due to its characteristics and distribution. The first architectural creations of the primitive man concerned modification of the habitat in caves and rock shelters, improvement of hydro and thermal insulation comfort by making floors of rammed earth and pebbles, as well as construction of dikes as protection from wind (Anderson et al, 2012). Natural materials that were abundantly used in construction such as wood, earth and stone are still used today. From the standpoint of the environmental protection, the traditional materials, which are present in the surrounding and easily accessible, are renewed during the proper usage (Zekić et al, 2010). Traditional natural materials are modified following the development of technology and adjusted to the new market demands.

The change in the way of construction has been conditioned by the increase in financial resources of the population, availability of standardized building materials, technological development, together with the increased speed of realization of modern constructions (Jovanović 2014, pp. 502). Introduction of laws and regulations in the current construction industry resulted in complete suppression of the use of earth as a building material. The Law of the Republic of Serbia in 1950 prohibited the use of earth as a building material for construction of all types of structures, and it is still in force today. The adopted regulations started the application of certified construction materials.

In spite of that, there is a greater tendency in the world towards construction of earth houses in the spirit of sustainable development, because earth is one of the environmentally-friendly materials. More than 30 percent of the world's landfills is construction waste, because in construction there is a mass use of non-renewable materials that cannot be recycled. (Vrančić, 2011) The price of such construction varies depending on the region. The total cost of construction of earthen houses in Australia exceeds the cost of construction with modern materials (Chilkoti, 2012), while in Africa such constructions are affordable and belong to the category of "low cost housing".

The following chapters present characteristics of earth as a building material, traditional constructing techniques for construction of residential buildings from earth, as well as regulations which permit the construction in many countries of the world. Through the series of emblematic realizations of contemporary architecture it was shown that earth houses have the potential to provide a modern standard of living and to satisfy aesthetic requirements.

2. PROPERTIES AND MECHANISMS FOR IMPROVEMENT OF CHARACTERISTICS OF EARTH AS A BUILDING MATERIAL

The basic material for construction of earth buildings is loam, which can be found in the deeper soil layers, below the layer of humus (Krnjetin, Mrkajić, 2008). Before the building begins, it is necessary to remove the topsoil in order to use loam. That is the mixture of clay, sand and mud, and sometimes it contains bigger aggregates of gravel and sand, identical to the rock from which it originated. The most important characteristic of loam is the plasticity and the ability to design the material in moist condition (Marjanović, 2010). By drying the loam in the air a desired shape is retained until induration.

Stabilization is the term referring to the improvement of characteristics of earth in order to prevent possible fissures formed after drying and to improve the strength under

pressure. "To stabilize earth means to change the ratio in the earth-water-air system, which can greatly improve its characteristics" (Marjanović, 2010).

Due to the local specificities of earth of different locations, the same stabilizers are not always suitable. Before the beginning of building it is necessary to carry out testing of the earth. Samples of material with different supplements are observed after the induration. Every sample behaves differently, possibly deforming, according to the amount and type of the stabilizer. (Minke, 2006). According to the German standards, additive supplements are required, regardless the origin of earth. The regulation prescribes the ratio and type of stabilizers and they depend on the fat of earth and construction techniques. (Vollhard et al, 2007) Inorganic stabilizers such as sand, gravel and flying ash (Kabir, 2005) increase the strength of earth, while adding 5% of hydraulic lime causes the sample to absorb less water (Bui et al. 2009).

Organic stabilizers which increase the fat and decrease erosion of a dried earth wall can be urine, muck, blood, as well as fat and oils which contribute to waterproof earth structures (Minke, 2006).

Cement is also used as an artificial stabilizer. During the construction, especially if the method of construction is rammed earth, strength of the wall under pressure is increased by adding cement. In the construction sense, a wall is a carrying element and it is necessary to provide higher security. In the opinion of an Austrian expert on earthen architecture Martin Rauch adding of cement to soil in the process of building is not necessary, and it is even harmful, because that kind of material cannot be recycled. In that way, earth as a building material cannot be returned 100% to the earth from which it originated, and according to his opinion "it is impossible to build the house which will last forever" (Chilkoti, 2012).

3. STANDARDS FOR CONSTRUCTION OF EARTH BUILDINGS

Earth was used as main building material for the construction of houses in many parts of America, Asia, Africa, Europe, many years before standards and regulations stating that installation of certified building products is mandatory were introduced. At the moment almost 50% of world population lives in the structures made of earth (Guillaud et al, 2008). Most of those structures are in underdeveloped countries.

In France, in 1979, the school and laboratory CRATerre under the name of School of Architecture in Grenoble started to work. It was founded with the aim of preserving and promoting the earthen architectural heritage in France, educating students on earth construction techniques, laboratory research, publishing activity. It was only in 1986 that the French government supported the CRATerre School and officially helped further work. Germany has a long tradition of building structures from earth. In Germany there are three schools where methods and construction with earth are studied. The construction was officially regulated in 1944 when the first law for earth building was adopted (Earth Building Code), and it was changed in 2008 under the new name of „Lehmbau Regeln“. In Spain, in 1992 an official document was issued as the support for building with rammed earth and adobe under the name of "Bases for design and construction with rammed earth". New Mexico has a state regulation concerning building with rammed earth and adobe from 1991. In Australia the first regulation for earth

building was adopted in 1952 in the edition of “Bulletin 5“, which was being modified over the years, until in 2002 it was replaced by the new regulation “Australian Earth Building Handbook“. New Zealand has the best organized regulation for building in this field, which considers many factors, area, height, basic material, pressure testing, as well as thermal properties. The only African country that made a regulation for earth building is Zimbabwe, where “Code of Practice for Rammed Earth Structures“ was adopted in 2001 (Houben et al, 2008).

4. METHODS OF EARTH BUILDING ILLUSTRATED BY MODERN ARCHITECTURAL ACHIEVEMENTS

4.1. Methods of building in the bondruk [post-and-pan] system

Structural elements of buildings built in bondruk system (eng. post-and-pan) are the skeletal wooden structure and the filling of earth. Traditional bondruk system consists of vertical wooden columns and horizontal beams. Struts of a smaller dimensional cross-section than vertical poles are placed in order to strengthen the overall system. A wooden frame in the shape of a frame is the basis for the substructure, which can be made of wooden planks and wicker. An earth wall is obtained by coating the entire system with a mixture of earth and straw or filling cavities with earth blocks. The advantage is fast and cheap construction. Bondruk system has been accepted in seismic zones due to the flexibility of wood as a support structure with a smaller deformation during the earthquake.

According to Luis Miles, bondruk system precedes a steel construction (Luis, 2008). The example from Chile shows a combination of modern steel construction and traditional application of earth as filling. The project from 2010 is a residential house built in Batuco, Santiago, Chile, by architects Patricia Arias and Pablo Alvear. The house is designed on two levels, the total area of 275 m², with a separate ground level for guests (Fig. 1).



Fig. 1 The appearance of the house from the yard, north-western facade, Chile, Santiago, Batuco, architects Patricia Arias, Pablo Alvear¹

The house was built outside the town, surrounded by a rich greenery. It was set free on the plot. The construction terrain was flat, without limiting natural and created conditions.

¹ <http://www.archdaily.com/379734/casa-munita-gonzalez-arias-arquitectos-surtierra-arquitectura>

The house was designed to have minimal negative impact on the nature and maximum passive use of solar energy. The wall oriented to the east which is discreetly inclined towards the ground and which on the ground floor and first floor has rows of windows, prevents the direct penetration of sunlight and overheating of the rooms during summer months. Connection with the exterior is achieved through large windows between the living room and the garden, while long windows were placed in the kitchen directly beneath the floor joists. (Alvear, 2013)

The basis of the structure consists of steel profiles, which were used instead of wooden horizontal beams and vertical columns. The walls consist of doubly welded wire cloth between the steel columns, plastered with loam and straw. On the ground floor the central element is the rammed earth wall in which the furnace for heating is located. In this way heat accumulation of earth wall is provided during the heating season, and at the same time the space between the kitchen and the living room is separated. The visual connection is not interrupted because the wall is one meter high.

The floor joist between the ground and first floor is a wooden coffered ceiling that was filled with earth and straw. All elements of the windows and doors are made by recycling old wooden structure. Foundations are strip-concrete with elements for embedding steel columns. (Alvear, 2013)



Fig. 2 The appearance of the house during construction, Santiago, Chile, the base of the ground floor and first floor, source 6

In the first part of the ground floor there is a living room, a kitchen, a dining room on a higher floor level, while in the second part there is a bedroom with a bathroom for parents (Fig. 2). On the second level there is space for children, space for rest and rooms with private bathrooms. Internal staircase leads from the living room to the first floor, the access part of the rest area and down the hallway that leads to other rooms. The roof plane follows the longitudinal line of the house and break in the middle with a different inclination (Alvear, 2013).



Fig. 3 The appearance of the basic structure and filling, the house during construction and after construction, Darmstadt, Germany, the project of the company "Schauer + Volhard"²

This is the house project from 2012 of the company "Schauer + Volhard", of total area of 125 m², in Darmstadt, Germany, with the basic structure of wood, filling of earth and straw of the exterior walls. It was built in the urban part of the city, on a flat terrain, surrounded by greenery and a garden. Thermal insulation was installed on the inner side of the walls. The filling of interior walls consists of earth blocks, because (Fig. 3) earth blocks have greater density and weight, so in winter they provide greater thermal effect throughout the house. In the central interior wall there are chimney openings. (Plic, 2014)

The house is proposed for Terra Award prize awarded by an international organization under the auspices of the French school CRAterre-ENSAG Lab, supported by UNESCO "Earthen architecture" of a special section for the protection and promotion of earth architecture.³

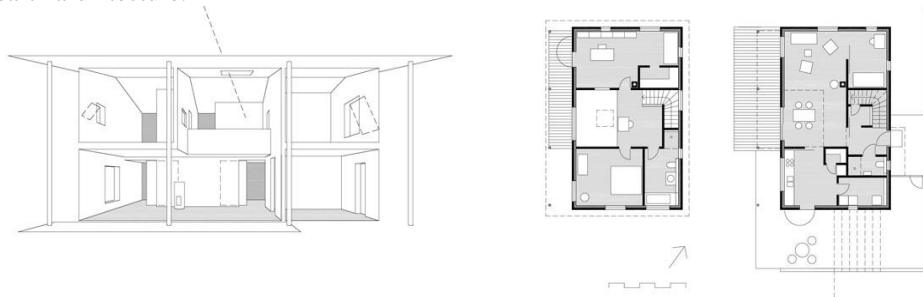


Fig. 4 Plan and cross-section of the house, Darmstadt, Germany, the project the company "Schauer + Volhard"

The plan of the ground floor of the house is simple rectangle base in which are placed features of a living room, dining and food preparation. Upstairs there are bedroom and study room.

² More in: http://www.schauer-volhard.de/Seiten/2Bauten_und_Projekte/1Wohnhaeuser/1400_Haus_J/1400_Titel.html

³ More in: <http://terra-award.org/project/house-j/?lang=en>

4.2. The method of construction by rammed earth

The traditional way of building a monolithic wall of rammed earth is done by filling and compacting of earth between the mold (formwork for filling of concrete is used nowadays) at a distance of 45-50 cm, up to 90 cm. Both sides of the formwork are placed between the vertical beams on prepared foundations. The formwork is interconnected with dowels, which are removed and re-installed after the completion of the lower layers (Hellwing, 1946). Earth compacting is nowadays done mechanically, by tires, which significantly increases the compressive strength. After drying of the entire building, which can last up to two years, the strength of the wall can be compared to the strength of stone. (Jernberg et al, 2015)

In Germany, Austria, New Zealand and Mexico there are numerous examples of construction of residential and public buildings built by the rammed earth method, where the centuries-old traditional method was applied. It was previously used in Tibet, Morocco, China but also in France, Spain etc. (Minke, 2006). The modern construction is based on adding new stabilizers in order to reduce erosion and increase the resistance to pressure because, in a constructive sense, a monolithic earthen wall is the carrying element and the ceiling and attic beams are supported by it.



Fig. 5 The entrance to the house in Victoria, Australia, architect: Jolson Architecture Interiors⁴

The example of a house in Victoria, Australia, measuring 465 m², is a blend of the modern design and traditional construction methods of supporting walls of rammed earth. The design was developed in cooperation with the design bureau Jolson Architecture Interiors and landscape architect. In terms of design, this house is like an earth sculpture in the desert environment in a balance with the environment that surrounds it.

The massive walls in the facade without windows are directly exposed to the wind and partly protect the inner courtyard. At the same time they are used for accumulation of heat from the sun. The house is with its front facade oriented to the west, while with its width towards the east. It was designed to be transparent, which made a connection between the interior and exterior.

⁴ <https://designrevolutionaustralia.wordpress.com/2011/04/10/earth-house-victoria-by-jolson-architecture-interiors/>

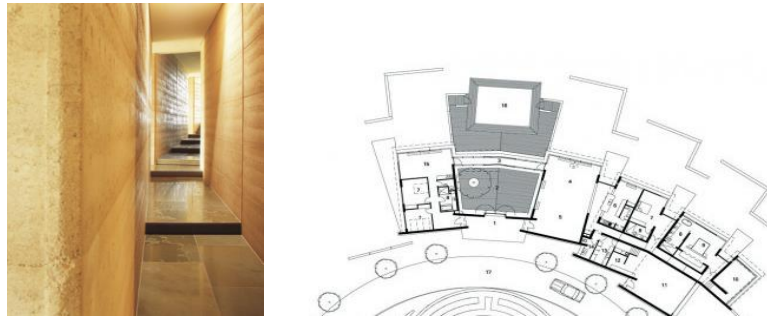


Fig. 6 Details of the interior of the hallways and a plan, source 6

The house consists of two separate parts, connected by an internal courtyard. On one side is the sleeping area for guests, and on the other is a large living room with a fireplace. The living room is followed by kitchen and a long corridor (Fig. 6) which leads to the rooms facing east. (Jolson Architecture Interiors, 2010).

The Austrian artist Martin Rauch, who discovered the architecture through sculpture, made many public and private buildings of terracotta in his home country. This house was built in Austria in 2007, using rammed earth technique with the addition of brick in each layer. Large window openings created a visual link with the outside environment. The roof is flat and covered with stone slabs (Fig 7).

A non-standard construction technique of rammed earth was used for construction of the Martin Rauch house. The technique consisted of inserting parts of the brick in each subsequent layer during the building process to serve as a protection of the earthen wall from moisture. In the rain, raindrops bounce off the projecting parts and protect the layer below. Standard roof overhangs that protect the earthen walls of the classical construction were replaced by baked bricks. Stone parts were also built in the wall with earth and bricks, so that the face of the wall can resist the erosive action of water. (Frey, 2013)



Fig. 7 The layout of the house in Austria, architects Roger Boltshauser, Martin Rauch⁵

⁵ <http://eartharchitecture.org/index.php?/categories/67-Compressed-Earth-Block>

4.3. The method of construction with bags filled with earth

A California architect Nader Khalili, born in Iran, has made his long career of an architect humanist, lecturer and innovator in America. He devised a system of construction suitable for vulnerable people, called "ceramic houses." (Houben et al, 2008). Owing to the rapid building method, they are suitable for temporary accommodation of people affected by natural and humanitarian disasters.

The system consists of a vertical stacking of bags or strips filled with earth. The method was derived from the army as a technique by which earthen trenches were secured and shelters were made. In English speaking countries the term is known as the "earth bag", earth in sacks, which also became familiar among us. Filled strips are up to 25 cm high, arranged in a row, closing residential area by shearing to the top which forms a dome (Sruthi et al, 2013).

Bags can be made of a polypropylene polymer or of natural materials such as jute or hemp. Filling material is a mixture of soil, that is clay and sand, the composition is similar to that used in the construction of buildings with rammed earth.



Fig. 8 Construction of ceramic houses in America, architect Nader Khalili⁶

The houses made of earth bags are built over low foundations, they are waterproofed from the ground and for the installation additional profiles are pulled through, built from the outside. A building made in this way is then plastered by mud or cement mortar, outside and inside (Kristol, 2009).

Ceramic houses are, according to researches, non-flammable, they can be built quickly, with small areas in of the base, about 40 m² with a central room and additional rooms on the side, with a circular base (Fig. 8). According to Nader Khalili designs an experimental village was made in Hisperia, in the state of California in order to promote the earthen architecture as an alternative housing. At the same time, the non-profit organization "Cal-Earth Institute" (The California Institute of Earth Art and Architecture), Institute for the country, art and architecture with center in Hisperia were established as a support of the idea of human dwellings (Kristol, 2009).

After the devastating earthquake that struck Haiti in 2010, it was necessary to quickly rebuild the destroyed homes. The community of the affected city, together with a small Konbit Shelter Association, chose fast and safe building of houses using the technique "superadobe". Long strips were mechanically filled with earth with the help of the local

⁶ <http://calearth.org/galleries/eco-dome.html>

workforce. (Fig. 9) These houses with thick walls can keep a low temperature in the interior. The mixture which was used to fill the bags was made of 90% of earth and 10% of cement thereby achieving higher compressive strength. (Anderson, 2012)



Fig. 9 The interior of the living room, and the draft of the base, source 1

4.4. The method of construction with compressed blocks

Compressed CEB, in English "Compressed Earth Block", is the invention of the French architect Francois Cointeraux, who in the 19th century created a mechanical device which compressed earth block under pressure. In this manner the preparation of blocks for building was accelerated and it allowed an immediate use, similarly to the process of the cartridge (Kabir et al., 2005). To create the earth blocks it is necessary for the production material to be dry, sieved to particles of the maximum size of 6 mm.



Fig. 10 The layout of the house in Japan, Studio YAMASHITA, Yasuhiro / Atelier TEKUT⁷

Water or a certain stabilizer is added in thus prepared mixture. For the construction of low-cost houses - "low cost housing" in Zimbabwe, blocks that were kept in humid conditions for 7 days after being made were used, and then gradually dried for 21 days. (Zami, 2008). A block with such improved properties is still used in countries of Africa and Australia.

An example of a house in Chiba, Japan, built in 2008, is the result of the scientific research of a specialists in the field of earthen architecture. The house is a contribution to the informing of a wider public about housing in the earth houses (Fig. 10). The project was done by the architecture studio Yamasita, Yasuhiro / Atelier TEKUT with the total area of

⁷ <http://www.treehugger.com/sustainable-product-design/japanese-flair-for-detail-elevates-earth-bricks-house-by-atelier-tekuto.html>

54 m². The initial idea was to experimentally demonstrate that it is possible to increase the resistance of an earth block by adding stabilizers, in this case magnesium oxide. The block with magnesium oxide is more resistant to the pressure than the block with organic stabilizers and oils. In nature magnesium oxide can be found in oceans and in soil, and throughout the history of architecture it was used for the construction of the Great Wall of China and the pyramids in Egypt. The experimental house has one room with natural light coming from the roof and from glass prisms arranged under the roof cladding. The use of compressed blocks can be seen both in the exterior and in the interior (Mok, 2011).

An example of earthen architecture is the house in Napa, Australia. It was built with compressed earth blocks away from the town, on the land that is inclined. The material for the construction was of local origin. The walls were not further finished by mud mortar but the blocks rather remained visible in the interior and exterior.



Fig. 11 House in Napa, California, architect Juliet Hsu⁸

It was designed in three parts of rectangular form, with the ground floor and the first floor. In the front part that represents the front of the house, the living room and the bedroom are located. The central part which is an entrance hall connects the massive earthen walls using the transparent glass. The configuration of the terrain influenced the rhythmic movement of rectangular masses as well as roof planes with small inclination. The roof overhangs over the rectangular shape are accentuated, below which the windows are placed (Sardar, 2014).

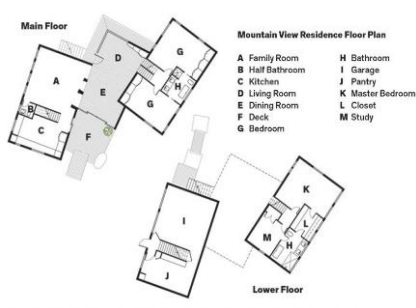


Fig. 12 The layout of the dining room, base of the ground floor, architect Juliet Hsu⁹

⁸ <http://www.rammedearthworks.com/modern-napa-rammed-earth-block-residence/>

5. CONCLUSION

The traditionally inherited earthen architecture is the base that can be upgraded by using the technologically advanced principles of modern architecture. By using earth as a natural building material, we are able to create residential architecture with sustainable materials from the immediate vicinity of the building site. Modern residential architecture includes the use of inorganic additives, such as cement, which improves basic characteristics of earth, regardless of the composition of local soil, thus achieving greater safety of the building.

In accordance with the needs of the population and in order to achieve certain standards, many developed countries such as Australia, Germany and France have adopted laws which closely determine the method, control and application of earth as a building material. In that way countries actively engage in the control of construction and put the investors' needs in the legal framework, providing undisturbed use of adobe as a building material.

The old methods of building houses of adobe are not forgotten, but pushed out of use under the influence of new construction techniques. Based on the given examples, earthen residential architecture returns using the old construction techniques in modern architectural form and functional organization. The houses here presented are built outside of settlements, in accordance with users' needs and financial possibilities of the owner. The earth as a wall filling in its original color in the post-and-pan system is equally valued both for the interior and exterior. In addition to the fact that the method is economically acceptable, the natural color of the earth also fulfilled the aesthetic function.

The climate in which they were built did not closely determine the use of certain methods of construction. But regardless of the region in which it is created, earthen architecture is one of the ways to achieve environmentally sound construction standards and it contributes to environmental protection.

Earthen architecture is probably the only solution for financially vulnerable part of the world's population, providing them a suitable home at a very low price, especially if the population lives in the regions with temperate and warm climate. The technique of earth bags turned out to be the fast and efficient way of construction for all affected people after an accident or earthquake. The subsequently build houses are not only temporary accommodation but permanent solution for all people affected by a natural disaster.

On the other hand, in developed countries living in an earth house, with all the benefits that such construction provides, is a privilege. Mass use of the construction of earth houses allows the reduction of construction costs in developed countries so that it could be accessible to everybody with developed awareness of the ecological construction of earth houses.

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⁹ <http://www.dwell.com/green/article/ingenious-new-building-method-replaces-concrete-block-rammed-earth>

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ZEMLJA KAO MATERIJAL ZA KONSTRUKCIJU MODERNIH KUĆA

Tokom prošlosti je zemlja korišćena za izgradnju stambenih objekata. Danas je prisutna kao materijal za građenje savremenih kuća. Jedan od razloga je sve aktuelnija težnja upotrebe održivih lokalnih materijala. Primenjene tehnike građenja zemljanih kuća razlikuju se u zavisnosti od karakteristika podneblja i graditeljske tradicije. U radu su prikazane osobine zemlje kao građevinskog materijala, pravilnici kojima se dozvoljava gradnja u mnogim zemljama sveta, kao i tradicionalne konstruktorske tehnike građenja stambenih objekata od zemlje. Takođe, kroz niz amblematičnih ostvarenja savremene stambene arhitekture pokazano je da je u kućama od zemlje moguće postići moderni standard stanovanja i zadovoljiti estetske zahteve.

Ključne reči: *stanovanje, kuća, zemlja kao građevinski materijal, konstruktivne*