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OPPORTUNITIES REGARDING THE INNOVATIVE CONSERVATION OF THE ROMANIAN VERNACULAR URBANISTIC HERITAGE

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Abstract

The main objective of the proposed research is to preserve the vernacular urban heritage of Romania by identifying realistic and innovative solutions for the conceptual and applied capitalization of the traditional technologies used in creating living spaces. This can be achieved by using modern methods, techniques, and tools (such as specific design methods and detailing, material mix design, specific material parameters, etc.) to redesign traditional Romanian housing entities, utilising existing construction materials and techniques predominantly of rural origin, empirically validated over the centuries, and reformatting them with modern scientific knowledge to generate a new model that is valid and compatible with current safety, aesthetic, and quality requirements. Earthen buildings, whether vernacular or constructed with qualified personnel such as craftsmen and traditional masons, use different techniques and construction technologies (rammed and poured, load-bearing walls, adobe bricks, mixed wood-earth structures, etc.) and were developed differently across the Romanian territory, depending on the climatic and relief zoning. By optimising these techniques and technologies, identifying their vulnerabilities and corresponding engineering solutions to counter them, and establishing pertinent fields of applicability in direct relation to their physical, mechanical, and durability characteristics and their evaluated bearing capacity, the conservation of the Romanian traditional housing legacy can be achieved. The opportunity of the proposed research is clearly connected to the current context of almost half of the Romanian population leaving for rural areas, including residential buildings made of earth. Supplementary, traditional building materials, like earth, clay, wood, etc., are based on primary natural resources, and they will generate ecologic housing concepts with a high degree of eco-efficiency in terms of use/re-use and recyclability, energy saving, and the health of the living space, in accordance with the general drive for resource savings and Circular Economy implementation in all fields, including the construction industry.

***Keywords**: Earthen building materials; Traditional housing heritage; Conservation; Structural performance; Green buildings*

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Introduction

Innovative materials and techniques for the construction industry can be derived from primary natural resources and vernacular methodologies and applied to green housing concepts, promoting energy efficiency and the well-being of occupants. These materials and techniques can be developed by enhancing local traditional technologies and concepts and utilising raw materials such as clay, sand, wood, straw, wool, and more. The main objective for re-considering these solutions is to create sustainable and environmentally friendly living spaces. Various construction products, including adobe bricks, structural and non-structural elements like walls and floors, as well as complete structures with corresponding finishing elements, can be designed, produced, and used. This approach not only preserves the cultural heritage of Romanian architecture but also aligns with European and national strategies that promote the use of natural, ecological, and non-polluting materials. These materials are obtained from easily accessible sources, display minimal levels of toxicity and carbon dioxide emissions, possess excellent recyclability, and can be repurposed for subsequent applications.

The term "vernacular" commonly refers to the specific characteristics and peculiarities of a particular country or region, encompassing language, dialects, culture, and even the architectural styles of local houses. In the context of building materials, vernacular materials are primarily distinguished by their local availability [1]. Among these materials, earth stands out as the most widely used worldwide. According to various census studies, even in today's era, over one-third of the global population resides in housing facilities made from earth, with developing countries exceeding a 50% proportion [2]. Given this reality, it becomes highly unlikely in the near future or even in a longer perspective to meet the infrastructure demands for housing facilities solely through the use of new, modern, and industrialised materials such as concrete, steel, glass, bricks, and others. Furthermore, the environmental consequences associated with the production of these materials cannot be ignored. A potential solution lies in harnessing the value of earth as the most abundant natural material, which offers a diverse range of compositions such as loam, clay, sand, silt, and more. Various building techniques can be employed, including mud bricks, adobe bricks, soil blocks, rammed earth, poured earth, and others, to improve their structural capabilities through innovative techniques, additional materials, and ongoing research.

The consistent return to appreciation and utilisation of vernacular urban heritage has been recorded worldwide in the last decades, leading to global attention in various fields, including science, economics, and entrepreneurship. This growing interest encompasses regions at different stages of development, ranging from highly developed to moderately developed areas. The increasing focus on vernacular architecture stems from several factors: firstly, it involves the preservation of traditional construction knowledge specific to different building materials such as earth, wood, and stone; additionally, it takes into account the unique characteristics of the landscape and the area where it is implemented.

Vernacular architecture offers significant potential for sustainable development, particularly in terms of civil infrastructure. It aligns with ecological principles by promoting energy efficiency and providing a high quality of life at an affordable cost. This is achieved through the effective utilisation of local resources, resulting in a reduced reliance on energy-intensive materials like cement. By capitalising on locally available resources, the foundation is laid for sustainable urban development, both in rural and urban metropolitan areas. This approach contributes to lower carbon dioxide emissions, aligning with European strategies aimed at addressing climate change, resource conservation, and environmental protection.

The use of <earth> as a raw material in construction, whether for structural purposes, filling, finishing, or repair and consolidation, either on its own or in combination with compatible materials in terms of composition and structure, entails a multifaceted and modern scientific exploration. This exploration encompasses various aspects, including manufacturing techniques and technologies, physical and mechanical properties, durability performance, structural integrity, architectural and aesthetic considerations, economic factors, and the establishment of appropriate regulations within a comprehensive legislative framework. All of these elements are essential for maximising the material's potential and ensuring its optimal utilisation in construction projects.

The global interest in preserving and harnessing earth-based architecture's diverse and widespread heritage remains strong. UNESCO, the United Nations Educational, Scientific, and Cultural Organisation, provides continuous support for the investigation, conservation, and innovative promotion of the universal heritage of traditional earth architecture [3]. Additionally, renowned scientific institutions and organisations such as CRAterre in France [4] and "Dachverband Lehm eV" [5] in Germany actively engage in experimental and applied research on earth structures. Their work has a significant influence on the development and implementation of regulations and legislative frameworks related to earth construction, both at the national and European levels.

Representing one of the two fundamental research axes of the NIRD URBAN-INCERC research project PN 23 35 04 01, financed by the Romanian Government starting in 2023, *the current study is focused on identifying innovative solutions and directions related to valorizing the traditional technologies of earth-inhabited spaces, with multiple applicability, both on existing buildings as well as for new housing entities*.

General Context of the Research and Project Structure: Major Scientific Axes and the Corresponding Objectives

The current global, geo-political, industrial and economic, urban and demographic, scientific, cultural, and environmental context, etc., is dominated by intense concern over environmental degradation, climate change, and future access to natural resources for the next generation in the short, medium, and long term. Therefore, the NIRD URBAN-INCERC research project PN 23 35 04 01 seeks to offer scientific, technical, and applied solutions in the field of national construction infrastructure as part of the European Union (EU), based on the following considerations:

- It is anchored in the field of construction as an essential contributor to the national GDP (the construction industry alone represents 9% of the Romanian GDP without the supporting industries, according to the National Strategy on the Circular Economy (SNEC 2022), considering the 2020 available data);
- It is focused on the irreversible repercussions produced on the environment by the present society and the acute need for a fast change in the development and consumption approaches by the applicative implementation of the Circular Economy (EC) principles at the national level, in accordance with the objectives assumed in SNEC 2022, the National Strategy for Research, Innovation, and Smart Specialization (SNCISI 2022-2027), the Recovery and Resilience Plan for Romania (PNRR), etc.

The general goal of PN 23 35 04 01 is the design and the applicative validation of technological algorithms specific to construction and supporting industries in direct partnership with the entrepreneurial environment, and it is pursued by means of two distinct but complementary research axes, Ax I (i) and Ax II (ii):

(i). *Development of innovative engineering solutions for eco-intelligent construction products by an efficient capitalization of additions generated by local industries;*

(ii). *Innovative assembly of solutions for the conceptual and applied valorization of traditional technology for earthen inhabited space.*

The structure of the project includes 16 distinct phases, assigned alternately to the two directions, considering the conceptual symmetry that generates a synergistic convergence in the final stage. The estimated results are connected to four general objectives (GO) (Fig. 1), associated with the general goal of the project, and established in accordance with the general and specific objectives of SNCISI 2022-2027 and SNEC 2022:

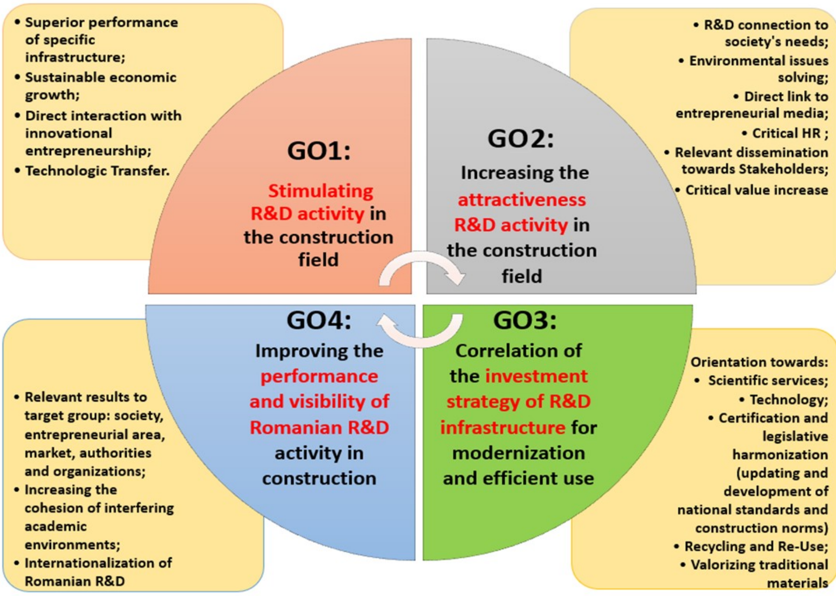

Fig. 1. The 4 general objectives (GOs) of NIRD URBAN-INCERC research project PN 23 35 04 01

a. **GO1 - Stimulating Romanian R&D activity in the construction field by:**
- ✓ Superior performance of specific infrastructure;
- ✓ Sustainable economic growth;
- ✓ Direct interaction with innovational entrepreneurship;
- ✓ Technologic Transfer.

b. **GO2 - Increasing the attractiveness of Romanian R&D activity in the construction field by:**
- ✓ R&D connection to society's needs;
- ✓ Environmental issues solving;
- ✓ Direct link to entrepreneurial media;
- ✓ Critical human resources;
- ✓ Relevant dissemination towards stakeholders;
- ✓ Critical value increase.

c. **GO3 - Correlation between the investment strategy of R&D infrastructure for modernization and its efficient use, considering the orientation towards:**
- ✓ Scientific services;
- ✓ Technology;
- ✓ Certification and legislative harmonisation (updating and development of national standards and construction norms);
- ✓ Recycling and Re-Use;
- ✓ Valuing traditional materials.

d. **GO4 - Improving the performance and visibility of Romanian R&D activity in construction by:**
- ✓ Relevant results for the target group: society, entrepreneurial area, market, authorities, and organisations;
- ✓ Increasing the cohesion of interfering academic environments;
- ✓ Internationalisation of Romanian R&D.

The estimated results aim to offer concrete solutions to the current problems in the construction sector by developing products and services (materials, elements and structures, processes and technologies, etc.) with superior overall performance and increased energy efficiency. The intelligent and sustainable transition of the Romanian construction infrastructure is also considered, as is implicitly the increase, in the short and medium term, of the degree of implementation of the principles of the Circular Economy (EC) in Romania. A key partner in the scientific approach is represented by the local entrepreneurial media, in order to determine the mobilisation of organisations towards open innovation through concrete and efficient technological transfer of research results, simultaneously with the cohesion of the academic environment in complementary directions of scientific interest.

Research Ax II: New Solutions for Innovative Conceptual-Applicative Valorisation of the Traditional Earth Technologies of Romanian Inhabited Spaces

The second axis of the project is focused on the conceptual and applied valorization of the traditional technologies of earth-inhabited spaces by using modern methods, techniques, and tools with multiple applicability, both on existing buildings as well as for new housing entities [6]. The proposed research is considered in direct relation to all stakeholders, namely the parties interested in the direct or indirect outcomes of the study. Belonging to the internal and external environment with respect to the research core, they include the academic and research media, the entrepreneurs, the users (clients), suppliers, and also the social, economic, and political compounds, local and central authorities, etc. The research intends to cover the whole range of construction products, namely materials, elements, and structures, as well as technologies for production and implementation. Natural clay-based materials are currently experiencing a return to the spotlight due to their very low impact on the environment, considering their complete life cycle, namely the production, application, exploitation/disposal processes, compared to modern materials [7].

The global assessment of the current state regarding the potential of the proposed theme, i.e., the valorization of the traditional technology of creating inhabited space from the earth, involves the analysis of the interior and exterior environment, namely the evaluation of the strengths and weaknesses, the opportunities, and the threats. The scientific research report on the current state of national and international research in the concerned field (internal environment, IE) and also the consulting of the local and regional entrepreneurial environment (designers, executors, experts in the field), the authorities, market analysis, etc. (external environment, EE) will substantiate a SWOT analysis, favouring the synthesis of investigative strategies and a further selection of lines of investigation with high-performance potential in accordance with established objectives of the Ax II.

Internal Environment (IE) Evaluation – Current Relevant Issues

Considering the established objectives of the project and the estimated results, the documentation study focuses on a pertinent national and international consultation of the norms, regulations, designing standards, raw materials or composite materials, the cast-in-place technologies, etc., in the earthen housing entities field, the component materials, the execution technologies, together with the profile studies carried out by the academic or related research environment worldwide.

a. Integrating the general principle of vernacular constructions into the concept of Sustainable Development

The proposed research approach is designed by integrating the general principle of vernacular construction into the concept of Sustainable Development. Sustainable architecture has often been associated with technology and energy performance as important factors in achieving comfortable living standards. However, nowadays, design approaches focus mainly on the objective of energy efficiency, which limits the definition of sustainability and does not consider the specifics of the place or relevant cultural and regional aspects. There is a powerful need to pay more attention to the social and cultural components of local specificity in order to develop solutions that increase the sense of belonging and encourage the formation of communities with common interests [8–10]. This can be achieved by exploiting the specific knowledge of the local community in the development of sustainable architecture solutions, with the aim of achieving a balance between energy efficiency and cultural and regional appropriateness.

Vernacular construction techniques, influenced by local traditions, serve as adaptable responses to the unique environmental conditions of a particular area. Traditional buildings are designed to fulfil a wide range of physical and spiritual needs while harmoniously blending with the surrounding communities [11, 12]. The notion of being indigenous to a specific place encompasses a complex relationship with the environment and a diverse range of customs. These elements collectively establish a shared foundation of values that shape the cultural practices of a community. When approaching architecture from a sustainability standpoint, it becomes evident that a comprehensive understanding of the local context is crucial, spanning from the national level down to the local level [13–15]. This entails recognising, considering, and preserving all relevant aspects specific to the area. In this context, the current theoretical study delves into scientific documentation regarding innovative *Eco-Clay materials* used in construction products and earthen structures, both at the regional, national, and international levels. *To effectively integrate these constructions within the framework of sustainability, it is imperative to account for cultural aspects and local heritage.* This necessitates a deep understanding of the unique conditions of the location, including its historical, political, and social context, as well as the construction techniques employed and contemporary advancements in the utilisation of traditional materials.

b. The balance challenge: Meeting design requirements vs Meeting economic efficiency criteria for Romanian earthen housing entities

In traditional constructions, including those made of earth, there is often a conflict between two seemingly contradictory criteria:

I. Meeting design requirements: This involves ensuring the safety and functionality of the structure. It encompasses aspects such as strength and stability under normal and extreme loading conditions, as well as meeting architectural, thermal, acoustic, and waterproofing requirements.

II. Meeting economic efficiency criteria: This pertains to creating a housing entity with minimal financial resources. Economic considerations can influence the choice of structural systems, non-structural components, and materials used throughout the construction process.

Balancing these two criteria is a challenge for the current study. While it is essential to meet design requirements for a safe and functional structure, there is also a need to minimise costs and optimise resource utilization. This may lead to strategic decisions regarding the choice of construction systems, materials, and components, aiming to achieve an economical outcome without compromising the overall integrity and performance of the structure. Finding the right balance between meeting design requirements and achieving economic efficiency often requires careful evaluation, planning, and consideration of various factors, such as local availability of materials, construction techniques, local building regulations, and the specific needs and resources of the project.

c. The lack of regulations for the design and execution of earthen constructions on a national, European, and even global level with respect to structurally relevant criteria

On a national, European, and even global scale, the lack of a unified guiding and regulatory system for earthen constructions has been identified. This system should encompass design, execution, and quality control criteria to ensure the safe utilisation of such constructions, taking into account the specificities and applicability of the region in which they are situated, like seismic action or durability issues, etc.

Upon reviewing the norms and regulations pertaining to the construction of houses using compacted, rammed, or poured earth, particularly in seismically active areas, it is evident that most of these documents serve as instructional publications, providing construction specifications to be followed. Two notable papers [16, 17], together with the NZS 4297:2020 standard (engineering design of earth buildings), were identified as sources that include formulas for seismic design. Other publications refer to additional papers to obtain more detailed information on seismic design, such as the NZS 4203:1992 (Engineering Design of Earth Buildings) referenced in NZS 4297:2020.

Moreover, the design guidance provided in NZS 4297:2020 is considered useful by Australian standards. Regarding the IS 13827:1993 standard (Engineering design of earth buildings), it references the IS 1893 Part 1:2002 standard (Engineering design of earth buildings) for seismic design, while the ASTM E2392-M10 standard (Standard Guide for Design of Earthen Wall Building Systems) specifies the need to perform seismic design according to ASCE 7.

Although seismic design is not explicitly mentioned in NBC 204:2015 (Guidelines for earthquake-resistant building construction: earthen buildings), it is covered by the Nepali NBC 105:1994 (2007) code (Seismic design of buildings in Nepal), which, in turn, recommends its application along with the Indian Standard IS 4326:1976 (Code of Practice for Design and Construction of Earthquake-Resistant Buildings).

As observed, the design of structures constructed with compacted or poured earth requires consulting various documents from different countries to address seismic considerations. In Europe, a potential solution to this issue would involve the development of a unified code similar to Eurocode 8, Part 1 (General Rules), seismic actions, and rules for buildings. This standard provides specific design criteria for different building materials such as steel, concrete, and masonry, offering detailed guidance on design calculations to ensure structures can withstand seismic forces.

The lack of comprehensive understanding of the structural behaviour of earthen constructions is the primary reason why existing regulations (standards, codes, and instructions) are often adapted from masonry regulations, leading to compatibility and adequacy challenges. It can be concluded that the design methods for earth construction have not been extensively researched, correlated, and unified in the form of clear regulations that are widely accepted, implemented, and legislated at the national or European level, specifically considering their relevance to the case of Romania. Addressing this gap would require dedicated research efforts and the formulation of specific regulations tailored to the unique characteristics of earth construction, ensuring the safety and reliability of such structures, especially in seismic regions.

d. ***Brief review of the vernacular urban heritage of the Romanian space***

Traditional houses were built to last for generations, often using locally sourced materials that are sustainable and adaptable to the local climate and environment. These materials are generally durable, energy-efficient, and have a low environmental impact. As a result, traditional houses tend to blend into the surrounding landscape, reflecting local culture and architectural styles [18–20].

In Romania, there exists a construction system that has been documented on our territory since the Neolithic period. This system involved constructing house walls using a wooden frame and closing elements made of reeds and yellow clay [21]. Initially, the pillars of the building's skeleton were embedded in the ground. However, as time progressed, they were secured to wooden slats supported by a foundation of river boulders. This foundation was elevated above the level of the surrounding land, indicating that the lifespan of the construction extended beyond that of the embedded part in the earth, which naturally degraded over time. This technological advancement was made possible by the implementation of a new beam joining system, which enhanced the overall strength and durability of the building. A short overview of the typology of traditional Romanian houses and their evolution is presented in figure 2, according to the studies of traditional architecture towards conservation and valorization by the means of typification (*Locuinţa Sătească din România, ICCPDC, 1989)* [21].

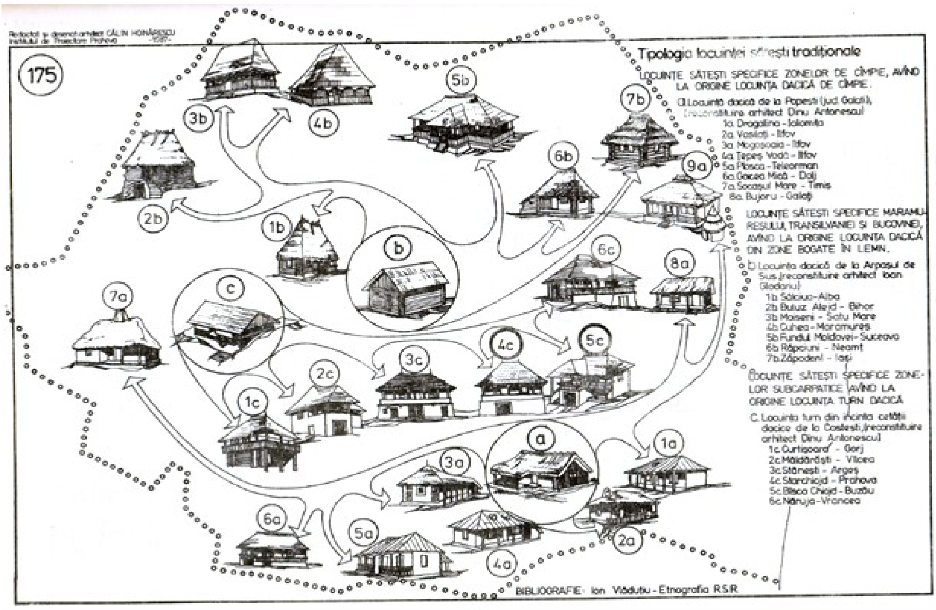

Fig. 2. Short overview of the typology of traditional Romanian houses and their evolution [21]

Fig. 3. Types of traditional Romanian houses: a) Romanian traditional household; b) Traditional Romanian household with vegetable materials for roofing; c) Traditional Romanian one-story house; d) Temporary housing (summer) in the Danube Delta (https://romaniadacia.wordpress.com/2015/08/07/the-romanian-peasant-and-agriculture/)

The construction system utilising wood, reed panels, and yellow clay adhesive was employed in our country from the Neolithic era until the mid-20th century. This system evolved over time, was influenced by regional factors and specificities, and adapted to the needs and resources available to the local population, as depicted in figures 3 and 4. Initially, wicker panels glued to clay were used. However, as the system progressed, a broader range of infill materials came into use, such as wooden boards sealed with clay, wood, unburnt clay bricks, and more recently, fired bricks.

Fig. 4. Types of traditional Romanian houses: a) Traditional household with clay walls and woven reeds fence; b) Current Romanian household, in Chilia Veche; c) Current Romanian household, in the Danube Delta; d) Traditional Romanian household (Baia Mare Ethnography and Folklore Museum) (https://www.facebook.com/MuzeulSatuluiBM/)

The evolution of the construction system, as depicted in figures 3 and 4, exemplifies the adaptability of traditional building techniques to changing cultural, environmental, and technological influences. Throughout the years, these techniques have responded to various factors, ensuring their continued relevance and usage in diverse regions. By embracing these adaptations, people have been provided with sustainable and cost-effective housing options that have stood the test of time. This evolution not only preserves the cultural heritage of the communities but also showcases the ingenuity and resourcefulness of traditional builders in creating practical and enduring dwellings.

e. ***New methods of non-destructive investigation and performance analysis (physical-mechanical properties estimating) with applicability on <earth> and earth-derived building materials***

The use of rammed or poured earth techniques offers significant advantages, particularly in terms of cost reduction and minimising environmental impact. One major benefit lies in the utilisation of local materials, which eliminates the need for long-distance transportation of building materials, thereby reducing costs and greenhouse gas emissions associated with transportation. Additionally, rammed or poured earth has low embodied energy since it requires minimal processing of materials and low energy consumption during construction. Consequently, it emerges as a more sustainable and durable alternative compared to traditional construction methods [22–26].

Given these advantages, there is a growing need to investigate and understand the properties, durability, and earthquake behaviour of such structures. Both destructive and non-destructive methods are employed for this purpose. Non-destructive testing (NDT) holds great value as it allows determining the mechanical or thermal properties of various materials and structural and non-structural elements without compromising their structural integrity [27–29].

Furthermore, the development of non-destructive testing (NDT) techniques specific to earth-based materials can significantly improve the conservation of earthen constructions. NDT methods are preferred as they can detect and characterise defects or damages without requiring sampling, preserving the original structure. In assessing the health and performance of existing earthen buildings, non-destructive testing should be the primary approach, with destructive testing used only to a limited extent. This approach ensures the conservation and long-term preservation of valuable earth-based structures while obtaining valuable information about their condition and properties.

One of the most commonly used non-destructive methods is the *Ultrasonic Pulse Method (UPV),* which is successfully used on materials such as concrete, wood, and metal with the aim of determining mechanical properties, the modulus of elasticity, and internal defects of the material. However, research focused on the application of the UPV method to compacted earth-type elements is still in its early stages [30–33].

One relevant example is provided by *E. Bernat-Maso et al.* [34], who managed to determine Young's modulus and evaluate the moisture content of raw soil materials with the ultrasonic method, also proposing an effective technique to control the drying process. During the research, it was concluded that the UPV method is effective in controlling the drying process of elements made of earth. In the area close to the hygrometric balance, a linear relationship was identified between the humidity of the soil material and the transmission speed of the ultrasonic waves. This connection becomes more apparent as the drying process progresses. In the research, it is mentioned that the hygrometric balance is established when the ultrasonic velocities exceed the value of 1100m/s (Fig. 5).

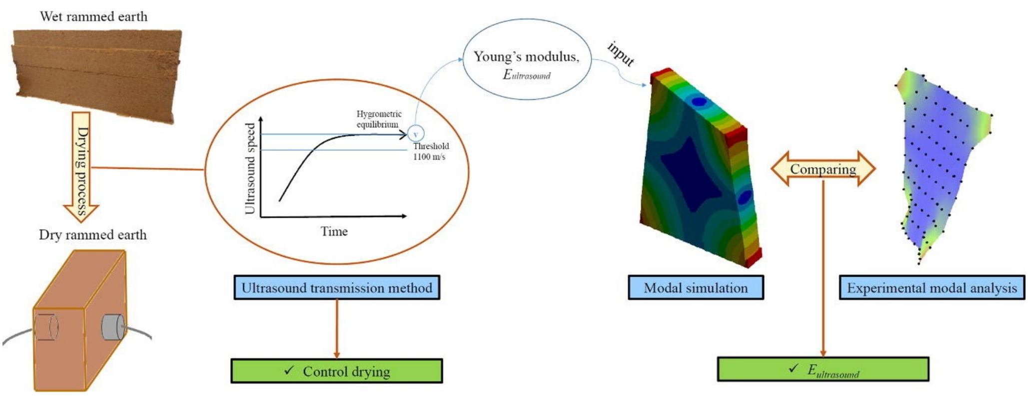

Fig. 5. Scheme of the procedure used to determine the drying process and Young's modulus by the ultrasound method [34]

Although earthen constructions have existed since ancient times, being among the first forms of human-made constructions, and non-destructive tests have been used for decades, a synergy between the two was only recently developed, mainly due to the interest in preserving and protecting the historical heritage of these types of constructions as well as the increased interest in the development of structural systems focused on the use of this type of material. The studies carried out have demonstrated that non-destructive methods can be used appropriately in this field and can provide important information regarding the mechanical properties of elements made of earth. Thus, an existing construction can be accurately evaluated, or quality control can be successfully implemented so that the impact on the elements is minimal.

External Environment (EE) Evaluation – Relevant Aspects

The External Environment (EE) for the research area is currently dominated by three major aspects creating the Romanian context:

- ✓ The population and housing census;
- ✓ The residential market dynamics;
- ✓ The overall sustainability drive, leading to European and National strategies for Circular Economy fast implementation.

a. The population and housing census

One of the initial steps regarding the EE analysis relies on the evaluation of the national housing fund made of materials such as adobe, plaster, etc. in relation to the overall existing one.

The used data are provided by the Romanian National Institute of Statistics (INS) regarding the 2011 population and housing census, also used in the project "Assessment of national disaster risks (RO-RISK)", code SIPOCA 30, co-financed by the European Social Fund, based on financing contract no. 3/17.03.2016 concluded with the Ministry of Regional Development and Public Administration, where NIRD URBN-INCERC was a partner of the research consortium. According to data from the Romanian National Institute of Statistics based on the 2011 population and housing census, nearly half of the Romanian population resides in rural areas. Furthermore, approximately 2 million residential buildings in Romania are constructed using earth as a building material, with about 75% of these earthen buildings located in rural areas, according to the National Institute of Statistics (https://www.recensamantromania.ro/rpl-2011/rezultate-2011/).

Based on the available data, the share of earthen constructions utilising adobe and plaster (wattle and cob systems), with or without a wooden structure, stands at 32.9% at the national level. These structures are typically single-level (ground-floor) buildings, with the possibility of an attic on a wooden structure. Most of these constructions were executed before 1992. The distribution of these earthen constructions based on adobe and plaster across different counties is presented in figure 6.

Fig. 6. National distribution of percent share of adobe and cob buildings

This distribution highlights the regional variations in the prevalence of such buildings, showcasing the importance of local building traditions and materials in shaping the architectural landscape of Romania [35].

A high rate of residential buildings made of wattle and cob systems and adobe systems as local typical earthen structures can be observed in lowland counties, where the availability of wood material is less compared to hilly and mountainous areas (Fig. 7).

Fig. 7. Examples of Romanian rural heritage, wood houses in the mountain region – Izvoarele village, Harghita County

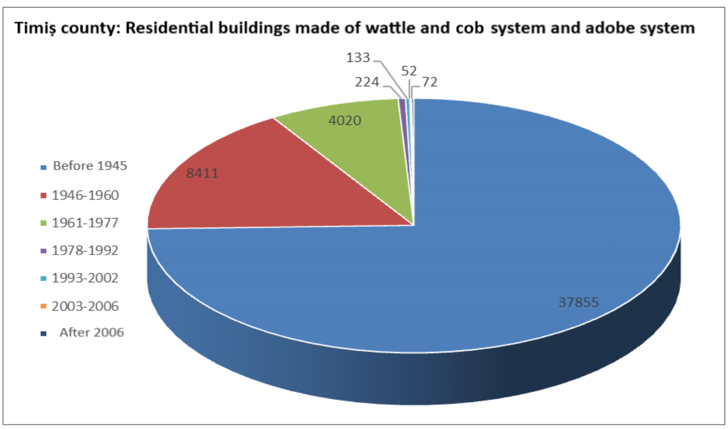

Fig. 8. Timiș county: Residential buildings made of wattle and cob system and adobe system

Timiş County, with its predominantly plain relief, contains 33.5% of earthen buildings as residential housing systems. Regarding their age, at the level of Timiş County, the large number of buildings built in these systems were built before 1945 (Fig. 8).

b. The residential market dynamics

The residential market dynamics show a significant increase starting with 2014 as a comeback after the 2008–2012 crisis, and the 2015–2023 period follows the trend and shows increases of 25–30% every year. Also, according to the Romanian National Institute of Statistics INS cited by Mediafax, it seems that approx. 100,000 Romanians move annually from cities to villages (https://www.mediafax.ro/social/satului-romanesc-i-se-mai-da-o-sansa-peste-100-000-de-romani-se-muta-anual-de-la-orase-la-sate-19853639). 2020–2023 was in line with trends, with increased focus on houses located in rural areas and the COVID-19 pandemic having a strong influence on this drive. The COVID-19 pandemic, which started in 2020, has accelerated this migration, driven by the necessity to maintain physical distance while also seeking the freedom to move outdoors without the risk of infection. With the rise of remote work and online schooling, an ideal environment has emerged to make the most of rural spaces that were previously neglected and experiencing continuous depopulation. We are therefore facing an important rural heritage for consolidation, repair, and maintenance (Figs. 7 and 9).

Fig. 9. Examples of Romanian rural heritage - Mailat village, Vinga commune, Arad County:
a) Traditional house in an advanced state of decay, suitable for consolidation and repair works using traditional materials and techniques; b) Traditional house (in use);
c) and d) Traditional house renovated with appropriate materials to preserve the architectural specificity

The consultation process, which involves assessing the local or regional entrepreneurial environment, including designers, executors, and field experts, along with authorities and market analysis, is also considered a mandatory step in EE evaluation [36, 37]. This assessment aims to effectively address relevant elements from the external environment that could impact the successful implementation of the targeted research results. During the consultation, entrepreneurs in the entrepreneurial environment, such as construction product manufacturers, architects, and designers, are questioned about their interest in integrating these products into their regular offerings. Local authorities, particularly in rural areas with potential for clay-based technology utilization, are also engaged in discussions, expressing a growing interest in this subject. This interest is driven by considerations for existing housing stock and available funding opportunities. Moreover, the target segment, represented by the generic customer, is identified. They have a direct interest in utilizing these construction solutions for both consolidation and repair and new construction purposes.

c. The overall sustainability drive, leading to European and National strategies for Circular Economy fast implementation

The European Commission has approved a series of proposals aimed at aligning the EU's climate, energy, transport, and taxation policies with the goal of reducing net greenhouse gas emissions by at least 55% by 2030 in comparison to 1990 levels. The major key points considered by the Green Deal are (https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en):

- ✓ Transforming the EU economy and societies
- ✓ Making EU transport sustainable for all
- ✓ Leading the third industrial revolution
- ✓ Cleaning the EU energy system
- ✓ Renovating EU buildings for greener lifestyles
- ✓ Working with nature to protect our planet and health
- ✓ Boosting global climate action

At the EU level, the European Commission, together with the EU Parliament, presented the circular economy action plan and the packages of measures to implement the CE implementation in strong correlation with the European Green Deal, supporting the CE national strategies as well. In Romania, the National Strategy on the Circular Economy (SNEC 2022), the National Strategy for Research, Innovation, and Smart Specialisation (SNCISI 2022-2027), and the Recovery and Resilience Plan for Romania (PNRR) represent the main supporting strategies for the national green deal transition and are key points for the current research.

The SWOT Analysis for Research Ax II: New Solutions for Innovative Conceptual-Applicative Valorisation of the Traditional Earth Technologies of Romanian Inhabited Spaces

The results of the investigation of both the internal and external environment, as mentioned earlier, are compiled and centralised, delivering the SWOT analysis, aimed at synthetically evaluating the opportunities and directions for the current research in the field of vernacular earth-based material valorisation. The SWOT analysis clearly highlights the significant potential of the proposed research theme, leading to the identification of strategic directions for an integrated approach in this area, considering the specific implementation environment. The analysis involves assessing:

i. The *internal factors* (IF), including: a) *strengths* (S) and b) *weaknesses* (W);
ii. The *external factors* (EF), including: c) *opportunities* (O) and d) *threats* (T).

The SWOT analysis is widely used and easily accessible, providing an overview of the target subject (be it a business, organisation, individual, funding proposal, scientific project, etc.) [38]. It offers insights into the internal environment, including resource processing capabilities within the production process transformation matrix. Additionally, it evaluates the external environment concerning organisational development.

It is an important correlation tool that helps develop four types of strategies [39]:

i. Max-max strategies (SO): advantages-opportunities;
ii. Min-max strategies (WO): disadvantages-opportunities;
iii. Max-min strategies (ST): advantages-threats;
iv. Min-min strategies (WT): disadvantages-threats.

Internal Factors (IF) comprise Strengths (S) and Weaknesses (W), as follows:

a. Strengths (S):

S1. Millenary tradition and experience consolidated over time: Earth-based construction techniques and technologies of living space have a long history (since antiquity), a global spread, and varied possibilities. Cob, adobe, rammed earth, poured earth, repair materials, plastering, and finishing.

S2. Supported ecological character through: reduction of incorporated energy; sustainable, locally available natural raw materials; and high recycling capacity, allowing for full reuse of resulting materials and quick reintegration into the natural cycle or a new life cycle (Circular Economy).

S3. Encouraging results in the field of earth-based vernacular materials research at an international level by identifying natural or industrial by-product additives compatible with raw materials (clay) and offering avenues for improving their performance in dry state, drying times, stability, reduced shrinkage, and improved bearing capacity at young ages.

S4. Multiple directions of scientific investigation, worldwide (Europe, Australia, New Zealand, Asia), exploring earthen constructions or the consolidation of existing ones, covering areas such as compositional and material development, structural solutions, production technologies or structural execution, strengthening and repair materials and solutions, etc.

S5. Reduced costs of the raw material (sand, clay, etc.), and when enriched with compatible additives, they become comparable to substitute materials in terms of cost.

S6. Non-destructive testing (NDT) studies are gaining momentum for the non-invasive evaluation of earth-based materials and structures, facilitating their analysis and assessment.

b. Weaknesses (W):

W1. The production process in earthen constructions is time-consuming due to the extended drying times of the raw materials involved in various technological applications, such as load-bearing or filling walls, adobe or brick masonry, plastering, repairs, and finishes.

W2. Vulnerabilities in the specific performance area that impose limitations on their intended field of use:

- Limited bearing capacity, which restricts the number of levels or specific uses.
- Durability issues, such as high sensitivity to water and rain (especially at plinths), low resistance to freeze-thaw cycles, and significant contractions.
- Seismic load performance has insufficient data available for an accurate assessment.
- Quality control presents challenges, as actual performance often depends on the specific construction methods employed.

W3. High costs associated with the use of polymer additives have been recently identified as a potential solution to enhance the material performance of earthen constructions, both in their fresh and cured states.

The external factors (EF) comprise: *Opportunities* (O) and *Threats* (T), as follows:

c. Opportunities (O):

O1. Technological development, which facilitates the development of new and innovative construction products

O2. The construction market, encompassing both new projects and renovations and repairs of existing construction, has been continuously expanding at the national level in recent years, alongside complementary industries (Eurostat data).

O3. Sustainable development and environmental protection are integral concepts in European and national policies, significantly influencing the construction industry's trajectory

O4. Romania possesses a substantial housing stock made of vernacular materials: approximately 2 million residential buildings are constructed with earth, with around 75% located in rural areas, according to data from the National Institute of Statistics based on the 2011 population and housing census.

O5. The attractiveness of the field is increasing: Growing market demand for earth construction and traditional materials; The COVID-19 pandemic, starting in 2020, has accelerated this migration from urban to rural areas. The entrepreneurial environment is increasingly interested in vernacular and earthen constructions, with architects, designers, material and technology producers, and research and private funding entities getting involved in the field; The target market includes young individuals aged 25 to 45, as well as middle-aged individuals and couples between 45 and 65, from both urban and rural areas, with average incomes of approximately 1000–1500 euros per month per household. They are interested in housing solutions valued at up to 80,000–100,000 euros. Local authorities, especially town halls in rural areas, are increasingly interested in utilising residential space made from traditional materials, particularly earth. The ample availability of development space for housing structures made of vernacular materials (including earth) in rural and metropolitan areas associated with large urban centres

O6. Intensification of specific studies in the field of traditional earth-based materials at national and international levels, yielding encouraging results in various areas (compositional stability, structural performance, durability, and technology). These studies aim to improve their performance and create a legislative framework for effective implementation.

O7. The National Recovery and Resilience Plan (PNRR) or other related funding sources provide opportunities for funding associated with research, legislation, and implementation in the field.

O8. Earth construction technologies offer the possibility of stimulating and qualifying the local workforce, particularly in rural areas, where unemployment rates are extremely high due to their location and unique characteristics.

d. Threats (T):

T1. The absence of a comprehensive legislative framework that facilitates the implementation of earthen constructions, along with the lack of support from relevant authorities at the national level, regarding the adoption of specific technical or normative guidelines related to this field.

T2. The lack of unity within the academic and research environments hinders the establishment of consistent rules and normative conditions for regulating earthen constructions at a national level.

T3. Consumer and designer scepticism concerning the feasibility and viability of the concept.

T4. Competition from substitution products, materials, elements, and technologies that appear more attractive due to factors such as cost, labor requirements, productivity, and compliance with existing legislative frameworks (e.g., structures made from prefabricated sandwich panels with a polyurethane foam core).

T5. A decline in the number of qualified craftsmen with experience in earthen constructions resulted in a scarcity of workers capable of executing specialised projects and providing training opportunities for interested individuals, mainly from rural areas.

T6. A shortage of labour in the construction industry, including foremen and workers, due to emigration trends.

Research Strategies for Valorisation of Vernacular Products from the Earth for Construction: Materials, Elements, and Structures, Eco-Clay Technologies

The strategies of type SO (min-min), WO (min-max), ST (max-min), and WT (max-max) were identified on the basis of the SWOT analysis and are presented in Table 1.

Table 1. SO (min-min), WO (min-max), ST (max-min), WT (max-max) for valorisation of vernacular products from the earth for constructions

	Strengths	Weaknesses)
Opportunities	<u>SO (max-max) Strategies</u> 1. Accessing Funding Sources: To support the interested environment, including entrepreneurs, academia/research authorities, and users (beneficiaries), there are various funding programs available at both European and national levels, able to provide financial support for projects related to environmental initiatives, sustainability, and research (S2, S3, O4, O5, O8); 2. Consolidated research to verify, optimize and validate the overall Eco-Clay concept (S2, S3, O1, O2, O3, O4, O5).	<u>WO (min-max) Strategies</u> 1. Scientific approach for compositional development-optimization – Eco-Clay material (W1, W2, O5, O7, O8); 2. Scientific approach for development-optimization of structural regulation (Elements and Eco-Clay Structures) (W1, W2, O5, O7, O8); 3. Scientific approaches for production technology development, optimization, and technological transfer (Eco-Clay Technology) (W1, W2, O5, O7, O8); 4. Seismic Performance Evaluation of Eco-Clay Structural Solutions: Test Methodology and Data Interpretation (Direction of Investigation) (W2, O5, O8).
Threats	<u>ST (max-min) Strategies</u> 1. Scientific approach for developing regulation of the legal framework for the realization of earth constructions, e.g., establishing guidelines, standards, and laws that govern the design, construction, and maintenance of buildings using earth-based materials. (S2, S3, S4, T1, T2). 2. Training competent workforce in disadvantaged rural areas (investigation direction) (S8, S9, T6).	<u>WT (min-min) Strategies</u>

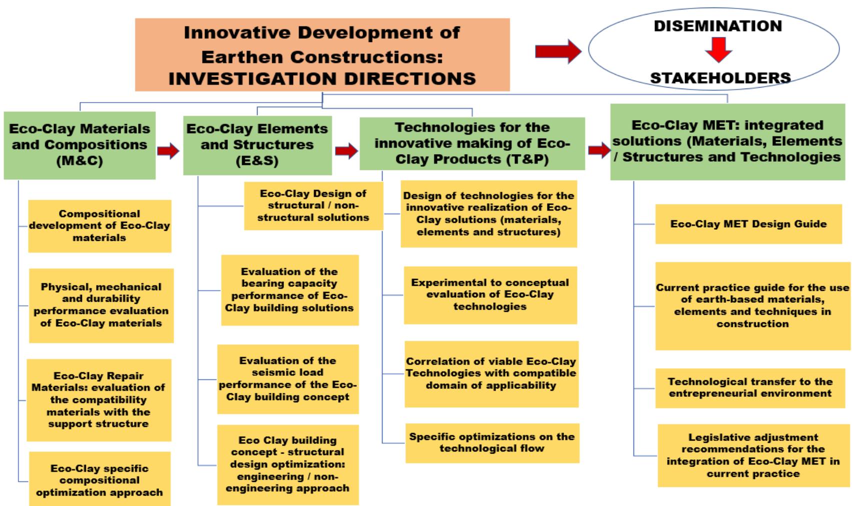

Fig. 10. Scientific directions for the valorisation of vernacular products from the earth for construction: materials, elements and structures, Eco-Clay technologies

The strategies of type SO (min-min), WO (min-max), ST (max-min), and WT (max-max), identified on the basis of the SWOT analysis and presented in Table 1, lead to the encouragement of scientific directions for the valorisation of vernacular products from the earth for construction: materials, elements, and structures; Eco-Clay technologies; and to identify those with high-performance potential in accordance with the established objectives (Fig. 10).

Basis of experimental investigation for *Ax II of research project PN 23 35 04 01: New Solutions for Innovative Conceptual-Applicative Valorisation of the Traditional Earth Technologies of Romanian Inhabited Spaces*

In recent years, there has been a significant focus on research programmes dedicated to developing building materials with low embodied energy [40, 41]. These materials aim to achieve more efficient thermal insulation properties, resulting in reduced energy consumption for heating and cooling during the hot seasons. Additionally, the use of such materials helps minimise demolition waste at the end of a building's useful life, contributing to lower environmental and economic costs over the entire lifespan of buildings. In this sense, raw earth is an attractive material because it is natural and widely available. In its simplest form, this material consists of a compacted mixture of soil and water that is put into place with the least possible transformation. Raw earth construction was practiced in ancient times but has only recently been rediscovered thanks to modern technology, which has improved manufacturing efficiency [42].

In this regard, *D. Gallipoli et al.* [43] provide a concise overview of earthen building structures, their historical development, and the different types prevalent throughout history. It highlights the advantages of using raw earthen construction in terms of its positive environmental impact, low energy consumption, and favourable indoor air quality. However, the paper also acknowledges the limitations that hinder its widespread adoption. Furthermore, the study delves into the hydro-thermo-mechanical behaviour of raw soil based on recent findings in geotechnical literature. It explores how key parameters, such as strength, stiffness, and moisture retention, are influenced by various factors.

1. a) Material Variables: The paper investigates the impact of material properties such as particle size and mineralogy on the behaviour of raw soil in construction.
2. b) Manufacturing Variables: It examines how factors like density and stabilisation methods used during the manufacturing process affect the performance of earthen building structures.
3. c) Environmental Variables: The study also explores the role of environmental factors, such as pore suction, ambient humidity, and temperature, in influencing the behaviour of raw soil in earthen construction. By analysing and understanding these key parameters and their relationships, the paper [38] aims to contribute to the knowledge and development of more effective and reliable earthen-building techniques.

As of now, there is no universally accepted methodology for the use of clay soil based on its specific characteristics, according to *J. Hülsemann* [44]. Existing specialised literature offers various classifications for clayey soils based on chemical composition, clay content, and grain size. Among these classifications, the use of sandy clay soil is recommended in vernacular constructions [45–47]. However, the specialised literature does not comprehensively address the influence of inorganic and/or organic additives, traditionally employed, on the physical-mechanical characteristics of clay soil elements. These characteristics include mechanical strength, thermal resistance, behaviour concerning water and water vapour, etc. Therefore, it is essential to conduct further studies and research to understand the characterization of raw clay material, clay mixtures with various additives, and the resulting elements. Ultimately, the existing studies can help overcome the limitations and encourage wider acceptance and implementation of sustainable earthen construction practices that offer significant benefits in terms of environmental impact, energy efficiency, and indoor air quality. Also, it was concluded that studies should specify the geographical location of the clay extraction area and the method of clay processing to establish a solid foundation for future research [48].

Within NIRD URBAN-INCERC, multiple studies have been performed in the last few years, both regarding structural aspects [49] and finishing ones [48], offering clear perspectives for continuous and optimised research in the field of earthen buildings and structures. The starting point of further theoretical and experimental investigation is represented by a comprehensive study performed within Incerc Timișoara in 2016–2017, within the framework of National Project PN 16–10.04.06, "*Research on the use of reinforced and unreinforced earth in the realisation of a structural system for traditional civil earth constructions according to ecological and sustainable principles. Theoretical and experimental studies on clay mixtures with additions used to make mortar and load-bearing elements*". The experimental procedure consisted of the examination of earth wall elements created through rammed and poured techniques, aiming to conduct a preliminary comparative assessment of these two methods. The evaluation focuses on aspects such as composition improvement, the manufacturing procedure of wall elements, drying crack patterns, and mechanical performance. To explore potential enhancements for both techniques, organic and inorganic material additions and horizontal reinforcing of the elements were introduced (Fig. 11).

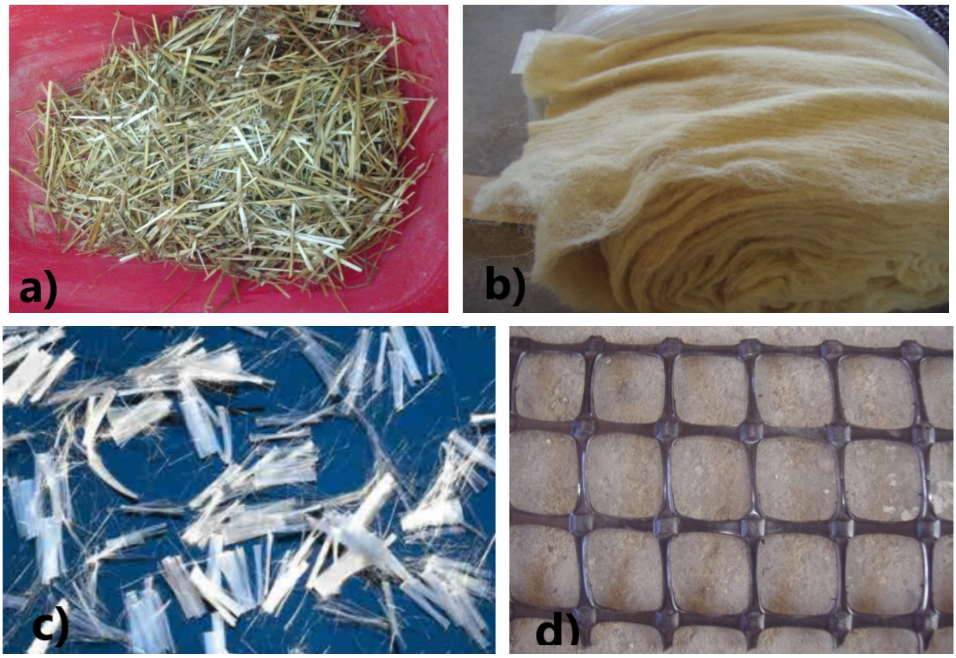

Fig. 11. The reinforcement type for the wall specimens: a) disperse reinforcement of wheat straws (WS R); b) horizontal reinforcement of thin wool layers (W R); c) disperse reinforcement of Polypropylene fibres (PP R); d) horizontal reinforcement of synthetic PP geogrid layer (PP-Gr R) [49]

Experimental tests were conducted on rammed earth (Fig. 12) and poured earth (Fig. 13) specimens to assess their compressive performance in relation to the corresponding displacement. The main objective was to conduct a comparative evaluation of the proposed reinforcing systems for both construction methods.

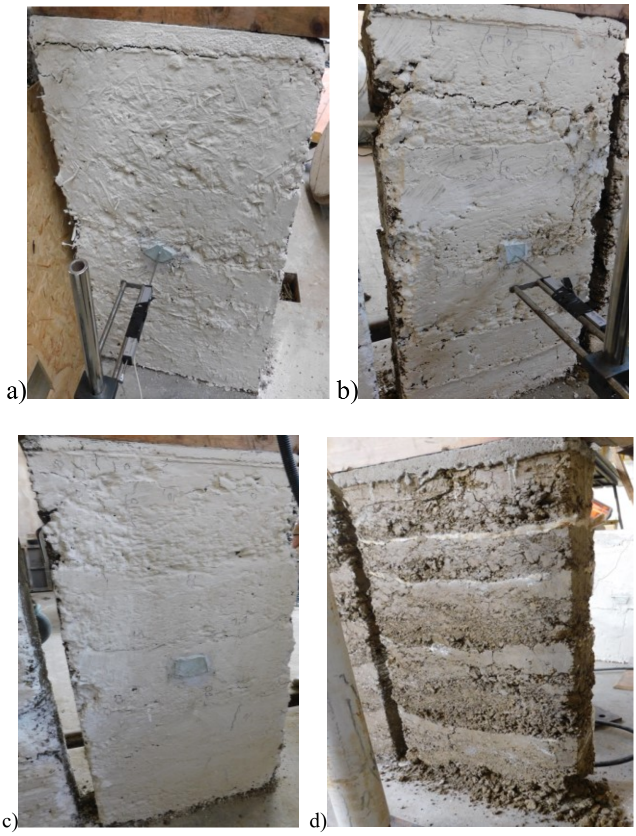

Fig. 12. The rammed earth, wall element specimens: a) wheat straws disperse reinforcement (WS R) wall element; b) horizontal reinforcement of synthetic PP geogrid layer (PP-Gr R) wall element; c) Polypropylene fibres disperse reinforcement (PP R) wall element; d) horizontal reinforcement of thin wool layers (W R) wall element [49]

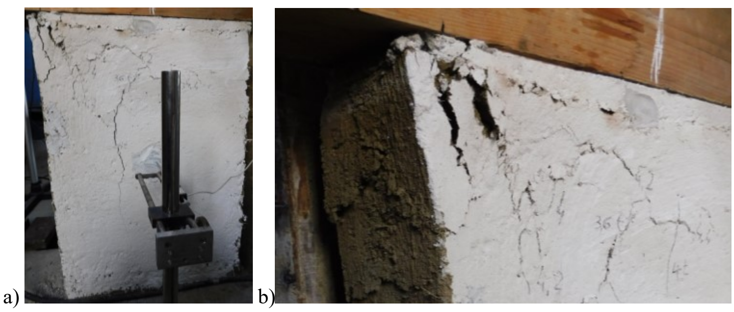

Fig. 13. The wheat straws disperse reinforcement (WS R) poured earth wall elements – failure under compressive loading: a) WS R wall element; b) WS R wall element - upper corner failure detail [44]

The initial experimental study demonstrates the potential of wheat straw (WS R) and Polypropene Fibre (PP R) in reducing loam contraction during drying and preventing brittle failure under loading. Additionally, the horizontal reinforcing layers exhibit promising results in preventing both vertical and horizontal displacement. Comparing the two techniques, poured earth shows better performance in terms of compressive load and displacement control. However, challenges remain, such as significant loam contractions during drying, leading to inconvenience and prolonged drying times. Both techniques are also sensitive to the manufacturing process, and the bonding of the mix to the horizontal reinforcing layer needs improvement. These areas warrant further research and consideration to enhance the overall performance and reliability of the considered topic [49].

Conclusions

The current paper offers a global view of present opportunities regarding the innovative conservation of the Romanian vernacular urbanistic heritage in terms of the consistent potential of the topic and opportunities for scientific research.

The compatibility of physical-mechanical and architectural-aesthetic aspects between the predominantly traditional rural housing stock and natural materials creates a significant potential for increased demand for these materials in the short, medium, and long term.

Traditional and vernacular constructions, such as burnt brick, clay, rammed earth, and wood, offer a sustainable approach to the development of rural and urban communities. These construction methods possess intrinsic ecological and aesthetic qualities as they easily adapt to the local climate and terrain, utilising readily available natural resources like earth and wood. Their minimal impact on the environment makes them socially desirable, fostering a sense of belonging among residents due to their reliance on local construction expertise and labor. Moreover, these structures are economically viable, making them financially accessible to a significant portion of the population while also stimulating local economies through the involvement of community members in the construction process. Additionally, these traditional buildings can promote tourism as they hold a unique and appealing charm.

The initial comparative evaluation performed on rammed earth vs. poured earth wall elements sought to identify overall improvements in each technique, offering directions for the next investigations considered in the topic [49].

The preliminary conclusions, both of a theoretical and experimental nature, indicate favourable results, which substantiate the continuation of the study in accordance with the scientific directions for the valorization of vernacular products from the earth for construction: materials, elements, and structures, Eco-Clay technologies (Figure 10), identified by considering a direct relation to all stakeholders with direct or indirect interest towards the outcomes of the study: the academic and research media; the entrepreneurs; the users (clients); the suppliers; the social, economic, and political compounds; local and central authorities.

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